Investigations into the nature and distribution of the sandveldt soils of the central province of Zambia with observations on their land use potential

Clayton, David Barry

INVESTIGATIONS INTO THE NATURE AND DISTRIBUTION OF THE SANDVELDT SOILS OF THE CENTRAL PROVINCE OF ZAMBIA WITH OBSERVATIONS ON THEIR LAND USE POTENTIAL

by

DAVID BARRY CLAYTON, B.Sc. (DUNELM), F.R.G.S.

being

a thesis

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"Soil Survey - the recognition of different soils and the determination of their important characteristics, the classification of defined soil units, the plotting of their boundaries on soil maps and, in co-operation with other specialists, the formulation of growth predictions - is purposeful research and its effects are far reaching. A major priority in any agricultural country must be a stocktaking of its soil resources, since these are basic to sustained production and its future expansion".

W.M. Hamilton

Secretary, New Zealand

Department of Scientific

and Industrial Research.

31st October 1962.

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DECLARATION

The content of this thesis is, apart from laboratory analyses, certain indicated profile descriptions and text references, entirely the product of my own research, and has not been submitted in candidature for any other degree or diploma.

1st August 1977.

D.B. Clayton

D.B. CLAYTON

FOREWORD

Zambia's national development policy is now centred on the development of agriculture and the proper utilization of renewable resources as it is now realised that the national economy cannot be sustained for ever by exploitation of non-renewable resources such as minerals. The success of our development strategy based on agriculture and the exploitation of renewable resources such as forests and grasslands depends, among other factors, upon the availability of data concerning the quality, quantity and distribution of soil types to provide a basis for land-use and resource planning.

That the Government of the Republic of Zambia had initiated and supported a soil survey programme, of which the subject of this thesis is a part, provides positive evidence of Zambia's determination to bring the rural community to play a major role in the development of the country's economy.

The Central Province, the subject area of the survey, is one of the two agriculturally advanced Provinces, Southern Province being the other, in Zambia, not only in terms of production at commercial farming level but also in terms of the number of farmers emerging from traditional and subsistence agriculture to middle level commercial production.

Soil survey in this area is, in my opinion, of high priority in order to ensure that land-use and resource planning maximises the use of the various soil types and avoids their wastage in the wake of rapid agricultural expansion.

The present work defines in detail the soil types found in the Central Province and indicates their land use potential. The academic value of the thesis cannot be doubted, but of great significance is its relevance to land-use and resources planning for the development of the rural sector of Central Province. The thesis will be of great value to planners, agricultural research and extension workers in the Ministry of Rural Development and other institutions in Zambia.

S.M. SILANGWA
SECRETARY GENERAL
NATIONAL COUNCIL FOR SCIENTIFIC RESEARCH
ZAMBIA

INVESTIGATIONS INTO THE NATURE AND DISTRIBUTION OF THE SANDVELDT SOILS OF THE CENTRAL PROVINCE OF ZAMBIA WITH OBSERVATIONS ON THEIR LAND USE POTENTIAL

ABSTRACT

This thesis describes the nature and distribution of the sandveldt soils of the Central Province of Zambia. It is based on the results of detailed, semi-detailed and reconnaissance soil surveys carried out in the Province between 1972 and 1974.

Sandveldt soils are light textured, developed over felsic and intermediate rocks and support *Brachystegia - Julbernardia - Isoberlinia* (Miombo) woodland. They are characteristically yellowish brown where well drained, structureless, and have low C.E.C. Base saturation is very variable and soil reaction is in the range strong to slightly acid. Regoliths are deeply weathered and relatively few weatherable minerals remain in most profiles. Sandveldt soils are Weathered Ferrallitic Soils of generally low agricultural potential. They are estimated to cover 505,000 ha, 41% of Central Province.

The thesis is divided into five parts:-

Part One explains the background leading to the requirement for soil survey work, describes the survey programme undertaken and methods employed, and reviews the previous work done in the area.

Part Two describes in detail the climate, geology, geomorphology and vegetation of the area and explains their pedological significance.

Part Three gives an account of the general features of sandveldt soils and their pattern of distribution. Six soil series comprised in a widespread catena are described in detail. A number of associated soils and landtypes are also described. The modal characteristics, genesis and classification of the various soils are discussed. The results of infiltration studies and physical investigations are described.

Part Four is an agricultural evaluation of sandveldt soils and includes assessments of land use capability, management and productivity, and crop suitability.

Part Five comprises conclusions and summary recommendations.

ACKNOWLEDGEMENTS

My thanks are due in the first instance to Mr. H. Brammer (F.A.O., formerly Senior Soil Surveyor, Zambia) for stimulating my interest in soil survey and an awareness of its fundamental importance, for guidance in survey techniques, for continual advice and much discussion, and for painstaking criticism of the original draft of this manuscript.

I am indebted to Mr. A. Njos (Agricultural University of Norway, formerly Norwegian Soil Survey Team leader, Zambia) for supervision of some of the fieldwork and for advice and discussion.

I am very grateful to Mr. O. Haugbotn for permission to reproduce certain profile descriptions and for helpful discussion, particularly on the range of characteristics of certain soil series.

Assistance given in fieldwork by Mr. S. Chilimina, Senior Agricultural Assistant, and Mr. G. Ngosa, Agricultural Assistant, both of Mount Matculu Research Station, is gratefully acknowledged.

I am grateful to the Tobacco Board of Zambia for facilities provided during fieldwork and for permission to reproduce airphoto No. 074 (Plate I).

Thanks are also due to Mr. A.N. Beaumont (Deputy Director of Agriculture, Land Use Branch, Zambia) for permission to reproduce airphoto No. 3017 (Plate 2) and Map 5.

I am greatly indebted to the Anglo American Corporation (Central Africa) for accommodation and facilities provided during fieldwork and for their generous financial assistance in the production of this thesis.

Finally my thanks are extended to Dr. D.J. Bellamy, my supervisor, for his guidance and support in the preparation of this manuscript.

GLOSSARY

BAROTSE	From Barotseland, the former name of Western Province.
CHITEMENE	The system of shifting cultivation practised in parts of Zambia, characterised by the burning of branches cut from the surrounding woodland on a circular cleared garden site.
DAMBO	A low lying, very gently sloping, treeless tract of country which is seasonally waterlogged by seepage from the surrounding high ground assisted by rainfall and which frequently contains the natural drainage channel for the removal of excess surface runoff.
MIOMBO	A type of woodland found extensively on the Zambian plateau and characterized by species *Brachystegia*, *Julbernardia* and *Isoberlinia*.
SANDVELDT	A general descriptive term for the land system which occupies large tracts of the plateau country of Zambia. It is mantled by light textured soils developed over acid and intermediate rocks and supports Miombo woodland.

SPECIES NOMENCLATURE

In the text, all Latin species names are underlined with a continuous line and are based on the following authorities.

1. Flowering Plants (except grasses)

   White, F. (1962). Forest Flora of Northern Rhodesia. O.U.P.

2. Grasses

   Hood, R.J. (1967) A Guide to the Grasses of Zambia. Govt. Printer. Lusaka.

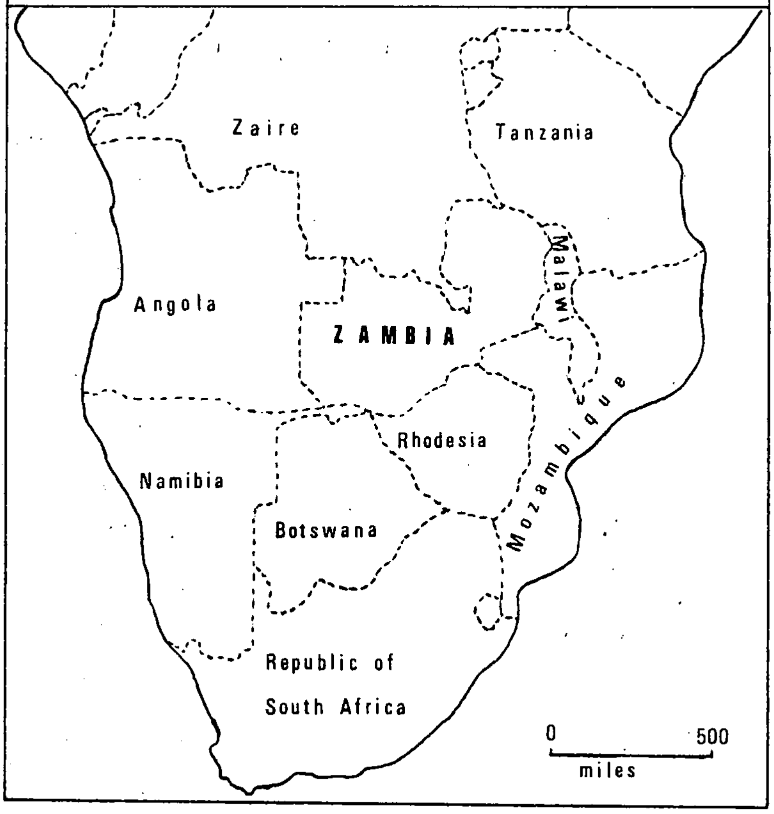
3. Crops

   Purseglove, J.W. (1968/72). Tropical Crops: Dicotyledons, Vols 1 & 2 (1968): Monocotyledons, Vols 1 & 2 (1972). Longman. London.

PART ONE : INTRODUCTION

MAP 1A Overleaf

MAP IA ZAMBIA LOCATION MAP



CHAPTER 1

BACKGROUND

Formerly known as Northern Rhodesia and located in Central Africa (Map 1A), Zambia gained its independence in 1964. In the years following independence, her copper exports maintained a healthy balance of payments. Foreign exchange has been in short supply more recently, however, due to low world copper prices and political manouevres in Central Africa. The other two primary sectors of the economy - manufacturing and agriculture - have exhibited a distinct difference in their rates of growth. Whilst manufacturing has made rapid and impressive steps forward, cash agriculture (as opposed to 'subsistence' agriculture) has failed to grow at a rate at all comparable to the rest of the economy and overall production has remained relatively stagnant.

Whilst there was a marked expansion in production in some sectors (e.g. poultry, fruit and vegetables, sugar, cotton and pigs) there was a considerable decline in others (e.g. tobacco and milk). Production of maize, groundnuts and beef fluctuated somewhat (Lombard and Tweedie, 1972).

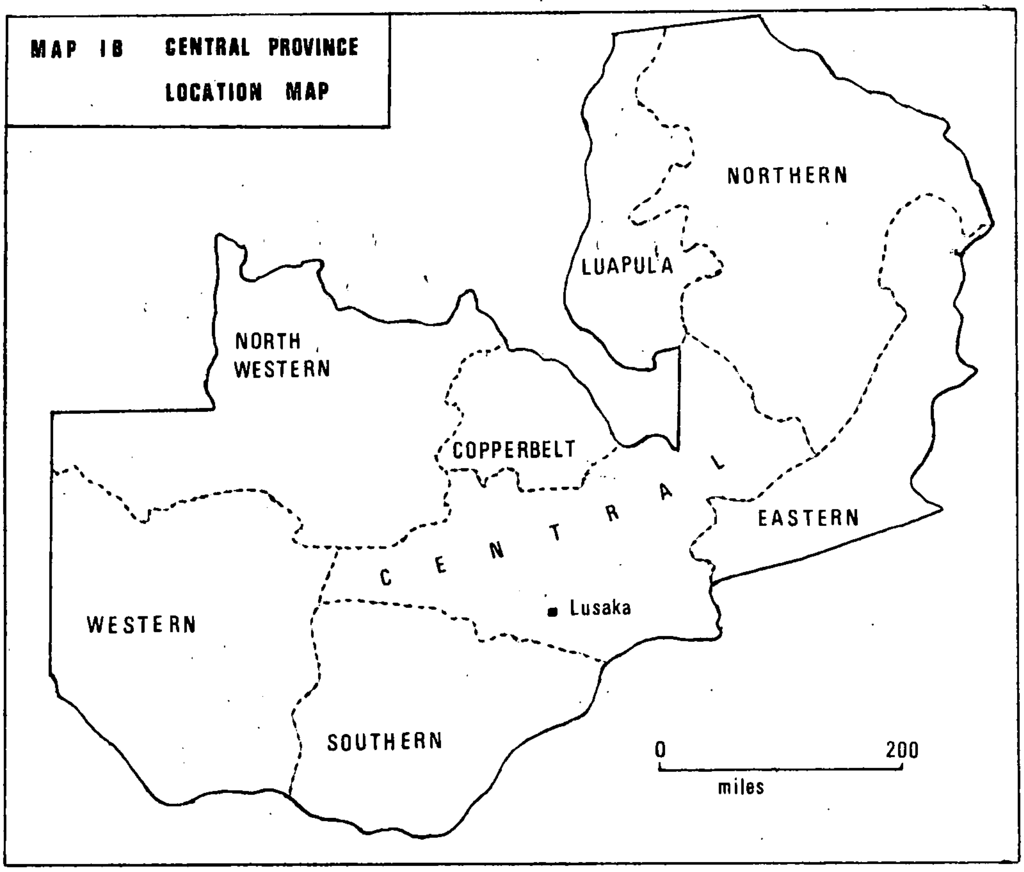
Prior to Independence, about three quarters of agricultural production for cash was by European farmers mainly in the Central and Southern Provinces. Since Independence there has been a gradual decline in the numbers of such farmers and the maintenance of agricultural production at a fairly constant level can be attributed to increased production by the remaining European farmers on the one hand, and to the rising contribution of small-scale Zambian farmers and direct production schemes on the other.

Zambia is a large country measuring 742,598 sq. km (290,587 sq. miles) in extent. The population in 1969 was 4,057,000 giving an average population density of 5.4 per sq. km. However, since Independence there has been a dramatic move from the rural areas to the towns, in search of more remunerative employment. In 1969 the population of the main towns stood at more than 1,118,000. In 1972 it was estimated that between 40 and 60% of Zambia's adult male population was, at least temporarily, resident in the urban sector (Lombard and Tweedie, 1972). In the Central Province itself the overall population grew by 40% between 1963 and 1969, and by an estimated further 24% between 1969 and 1972 (Lombard and Tweedie, op. cit.), largely as a result of urban drift from outlying Provinces. As a consequence, there has been a substantial increase in the demand for the agricultural produce of the commercial growers and an equally substantial decrease in the numbers of subsistence farmers. This in its turn has caused more demand in the markets.*

The Second National Development Plan (S.N.D.P.), (G.R.Z. 1971), identified as a top priority the need to expand agricultural production and substantially cut food imports. In an attempt to stimulate the transformation of traditional subsistence farming into market-orientated commercial farming a programme of intensive development in the rural areas - Intensive Development Zones (I.D.Z.'s) - was

*The problem was exacerbated in 1973 when Zambia suffered its worst drought for forty years, and in 1974 when late heavy rains caused disease (*Fusarium sp.*) which ruined much of the maize crop and compelled heavy inroads into stockpiles (Roberts, 1976, p232).

MAP 1B Overleaf


MAP 1B CENTRAL PROVINCE
LOCATION MAP
NORTHERN
LUAPULA
NORTH
WESTERN
COPPERBELT
CENTRAL
EASTERN
Lusaka
WESTERN
SOUTHERN
0
200
miles

implemented in the S.N.D.P. In addition a number of other developments were envisaged. These included large scale direct crop production schemes on the one hand and settlement/resettlement and training schemes involving family farms and assisted tenants on the other. The former, whilst substantially increasing overall production, particularly of maize (the staple food) and tobacco (the dominant cash crop), would supplement and gradually replace the decreasing number of expatriate commercial producers, whilst the latter, it was hoped, would encourage a 'return to the land' and thereby significantly increase the contribution of the small-scale Zambian farmer.

The Ministry of Rural Development was charged with determining the feasibility of such schemes and with undertaking their implementation.

As a first step a National Soil Survey Programme was instigated. A survey team was set up and staffed by specialists provided by the Norwegian Aid Agency (N.O.R.A.D.).

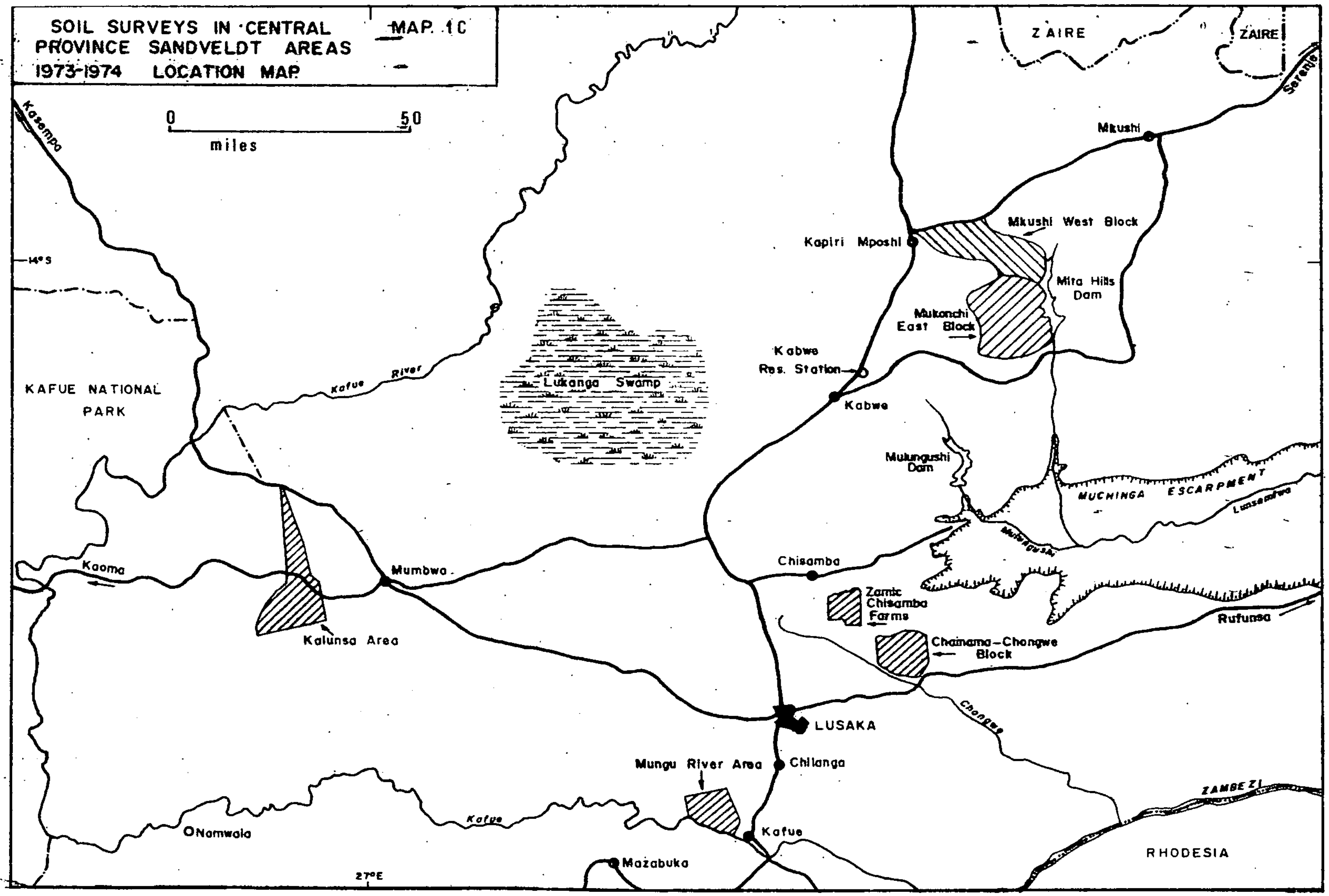
The broad task was to carry out reconnaissance soil surveys in order to delineate areas worthy of closer investigation and to undertake detailed and semi-detailed survey work for proposed schemes, as directed by the Ministry of Rural Development.

The author was seconded to the team from the Department of Agriculture and was based at Mount Makulu Research Station, near Lusaka, with special responsibility for parts of the Central Province (Map 1B).

Large areas of the Central Province were known to be mantled by sandveldt soils which for decades had been successfully exploited by European farmers for maize and tobacco production. It seemed reasonable to assume that these soils might be very suitable for the above mentioned developments.

Since very little was known about the sandveldt soils, except in very general terms, it was obvious that investigations should centre firstly upon determining their nature and secondly upon delineating their distribution.

MAP 1C Overleaf


SOIL SURVEYS IN CENTRAL PROVINCE SANDVELDT AREAS 1973-1974 LOCATION MAP
MAP. 1C
0
50
miles
14°S
27°E
KAFUE NATIONAL PARK
Kasempa
Kafue River
Kaoma
Lukanga Swamp
Kalunsa Area
Mumbwa
Kapiri Mposhi
Mkushi
Serenje
ZAIRE
ZAIRE
Mkushi West Block
Mita Hills Dam
Mukonchi East Block
Kabwe Res. Station
Kabwe
Mulungushi Dam
Mulungushi
MUCHINGA ESCARPMENT
Lunsemfwa
Chisamba
Zamic Chisamba Farms
Chainama-Chongwe Block
Rufunsa
Chongwe
LUSAKA
Chilanga
Mungu River Area
Kafue
Kafue
Mazabuka
Namwala
ZAMBEZI
RHODESIA

CHAPTER 2

THE PROGRAMME

Consultations with the Deputy Director of Agriculture (Land Use), the Heads of various Government Departments, and representatives of various International Aid Agencies in 1972, led to the identification of a number of areas in the Central Province with agricultural development potential. A number of possible schemes were envisaged but soil surveys were a primary requirement.

The following major surveys (located on Map IC) were therefore carried out during the 1973 and 1974 field seasons.

1. Chainama - Chongwe Block Reconnaissance Survey. (12,000 ha)

The Chainama - Chongwe Block lies to the east of the Lusaka - Chisamba district road and is bounded by the Chainama Hills to the north and by the Chongwe River to the south. The area was largely uninhabited and covered by woodland. It had been proposed for a large-scale irrigated wheat and maize production scheme by the ZamAnglo Industrial Corporation (ZAMIC), a subsidiary of the Anglo American Corporation (Central Africa) Ltd. Survey work was carried out during May and June 1973. (Report, Clayton 1974a.)

2. Mungu River Area Detailed Survey. (4,378 ha)

A block of vacant farms lying to the north west of Kafue town form the Mungu River Area. The area comprised Miombo woodland, open grassland and some cultivated fields. A steady influx of 'squatters' from the Southern Province prompted the Government to consider the purchase of the vacant holdings and the creation of a resettlement scheme on a family farm basis.

Technical assistance was to be provided by the Norwegian Aid Agency. Survey work was carried out during July and August 1973. (Report, Clayton 1974b.)

3. Chisamba Farms Detailed Survey. (5,870 ha)

Chisamba Farms represent the agricultural wing of ZAMIC and lie astride the Lusaka - Chisamba district road to the north of the Chongwe River, approximately 40 km. north east of Lusaka. The area consisted of large tracts of cleared Miombo woodland used for commercial maize and tobacco production.

A soil survey was requested to provide detailed soil and land capability maps of the farm complex and to determine the suitability of certain areas as possible alternative sites for the irrigated wheat production scheme originally proposed for the Chainama - Chongwe Block. Survey work was carried out during the period September-December 1973. (Report, Clayton 1974a.)

4. Mukonchi East Block Semi-Detailed Survey (19,031 ha)

The Mukonchi East Block lies between 45 and 60 km. north east of Kabwe. It is situated between the Mubofwe River and the Mita Hills Dam and is bounded by the Lunchu River to the north and the Luamabwe River to the south. Miombo woodland blanketed the entire area which was uninhabited. A survey was requested by the Tobacco Board of Zambia with a view to opening up the Block as an entension to the existing Mukonchi Assisted Tenant and Training Scheme on the left bank of the Mubofwe River. The East Block, if suitable, was to be opened up for commercial Virginia Tobacco and maize production, with technical and financial assistance provided by the Commonwealth Development Corporation. Survey work was carried out between April and September 1974. (Report, Clayton, 1974c.)

The results of these surveys constitute the subject matter of this thesis. The location of surveys carried out by O. Haugbotn (1974 a, b, c.), referred to in the text, are indicated on Map 1C.

CHAPTER 3

PREVIOUS WORK

Early but scant references to the soils of Central Province are contained in a report by Milligan (1931) on the position of the Northern Rhodesian agricultural industry, and in the report of an Agricultural Survey Commission (N.R.G., 1933) which inspected land along the railway line between Livingstone and Kabwe for potential 'European settlement'.

The first survey of soil and vegetation types of the country was supervised by C.G. Trapnell. Between the years 1932 and 1940 Trapnell and others toured the whole territory of Northern Rhodesia with general instructions to "make a general survey of soil and vegetation types, with a view to exploration of the natural resources of the country, and to make a study of native agricultural systems" (Trapnell 1937).

Although progress reports appeared in the Annual Reports of the Agriculture Department in 1933 and 1934 the publication in 1937 of Trapnell and Clothier's report on the survey of North Western Rhodesia marked an impressive achievement. This report was followed in 1943 with a companion publication by Trapnell, Martin and Allan covering North Eastern Rhodesia. These two reports were the forerunners to Trapnell's Vegetation-Soil Map of Northern Rhodesia with its accompanying memorandum first published in 1948 and subsequently re-issued in 1950.

The soil classification used by Trapnell in these accounts is on lines similar to those employed by Milne (1935) for the East African Soil Map. Although soil qualities are discussed very few analytical data are included. Representative profiles of Trapnell's principle soil types were subsequently collected by R.T. Odell in the course of the Central African Rail Link Development Survey and full analyses on a selection of these were carried out by E. Pawson. Odell's account, incorporating these analyses and including a vegetation - soil map was published in the Report of the Rail Link Development Survey (1952).

Despite recent more detailed investigations of soils and vegetation in specific areas of the country, Trapnell's accounts are widely consulted and remain important reference works for research workers, agronomists and planners.

Following the completion of Trapnell's surveys limited manpower resources and pre-occupation with specific Government projects precluded systematic mapping of soils, except on an exploratory or broad reconnaissance basis.

With the establishment of the Central African Federation in 1953 came a move to remedy the severe lack of detailed soil maps. The Department of Conservation and Extension (CONEX) devised a system of soil examination, classification and assessment for land use planning purposes.* The System required Field Officers to observe and record soil morphology, relief and vegetation in detail. Classification and mapping

*Summarised in "Land Use Planning Procedures 1953-1963", Land Use Services Division, Ministry of Rural Development, Lusaka. January 1973.

were necessarily based on morphological and topographical, not pedogenetic, characteristics. Of these, most emphasis was placed on those characteristics significantly related to hazard of use of the land. Units of classification were not, therefore, taxononic. Following collection and classification of soil data and delineation and definition of soil mapping units, the units were grouped into land capability classes.

The CONEX system was used to produce land-capability maps almost exclusively in 'European' farming areas along the 'line of rail' until the break up of the Federation in 1963. During the early years of the Federation a major reconnaissance survey of soils and land use was carried out in the Copperbelt Province (Wilson, 1956). Soils were classified by colour according to Munsell notation.

During the Federation period Webster (1959 and 1960) published papers on the genesis and classification of the soils of the Central African plateau. These represent the first pedological works specifically concerned with sandveldt and associated soils. Subsequently Watson (1962, 1964/5) published papers on closely related soils in Southern Rhodesia.

Following Zambian Independence in 1964 the CONEX system continued to be operated by the Soil Survey Unit within the Department of Agriculture. Survey work was minimal due to restricted manpower resources. Webster, however, was able to continue his investigations and identified (Webster 1965) a catena of sandy soils on the plateau at Masaiti (approximately 40 km S.W. of Ndola), the soils of which he ascribed to one association.

As a result of work carried out by Webster, Wilson, Ballantyne and others operating within the Soil Survey Unit, the Department of Agriculture produced a Soil Map of Zambia in 1965. The map is very general and of limited use. Ballantyne (1968 b) describes it as "useful in that it shows the occurence of soils of different pedological and agricultural significance; it does not claim, however, to define different types of soil with great accuracy nor does it show relationships between soils".

Yager (1968) was the first to identify soil series in Zambia. Many of these were quite broad and have subsequently been abolished with the establishment of soil series with more restricted property ranges.

Between 1968 and 1971 a multidisciplinary land resource study of the Northern and Luapula Provinces was undertaken by the Land Resources Division of the British Ministry of Overseas Development. The report (Land Resource Study 19, Mansfield et al., 1975 and 1976) provides useful comparative information on sandveldt soils soils in the higher rainfall areas.

In 1972 with the realization that systematic soil survey work would be a prerequisite to sound long-term agricultural development a re-fashioned Soil Survey Unit was established under H. Brammer with financial assistance from F.A.O. In the course of defining national soil survey requirements Brammer undertook detailed survey work in several areas and toured the country extensively. He was able to identify a wide range of soil types and published (Brammer 1973a) the first comprehensive account of the mode of occurence, genesis and agricultural value of Zambian soils together with an international classification.

Following up Brammer's work and under his guidance and later under that of A. Njos, a systematic soil survey programme was begun with staff provided by the Norwegian Aid Agency (NORAD). Soil surveyors were deployed on a Provincial basis and reconnaissance and detailed soil surveys initiated.

CHAPTER 4

METHODS

PREPARATORY

Each area was studied using aerial photographs. The scales used ranged between 1:15,000 and 1:30,000 according to availability. Landform, drainage and vegetation patterns were established in order to draw up a hypothetical soil map and to determine the siting of survey traverses. Old CONEX* land capability maps were available for some of the farmland and were an aid in this exercise.

The drainage pattern of sandveldt areas is dominated by a dendritic dambo (see glossary) network and it was, therefore, not possible to employ a traverse grid method to organise survey operations. Consequently, traverses were sited so as to cross the interfluves between the dambos. Each survey area was, therefore, blanketed by traverses in a manner which revealed maximum soil and land capability information with a realistic economy of effort. The frequency of traverses varied for the different survey scales. For reconnaissance surveys traverses were approximately 2-3 km apart, for semi-detailed surveys approximately 0.5-1.0 km apart, and for detailed surveys 100-150 m apart.

FIELD WORK

The major part of all fieldwork was carried out in the dry season in Miombo woodland where the major problem was one of location. Open farmland did not present the same difficulty. It was necessary to construct base-line tracks running north-south and east-west from which tree-blazed

*CONEX: Federal Department of Conservation and Extension.

traverses were cut along pre-determined compass bearings according to the traverse plan. Log-corduroys were constructed across streams and wet dambos for access purposes.

The soils were examined at 500 m intervals (1 km intervals in uniform areas) along each traverse for reconnaissance surveys, at 150 m intervals (250 m intervals in uniform areas) for semi-detailed surveys and at 100 m intervals (or closer) for detailed surveys. Additional examinations and 'off set' traverses were made wherever necessary, particularly on dambo-margin slopes and at 'dambo heads'.

Distances from numbered beacons at the start of the traverses were determined with a 50 m fixed chain. The soils were examined using a 120 x 5 cm (or 3 cm) corer operated by power auger and using a Perrin-type hand auger (120 x 8 cm) where the former proved impractical.

Each site examination involved a description of the soil profile in terms of colour using Munsell Colour Charts, texture, structure and other physical properties. General physiography, vegetation and land use were noted and slope measured with an Abney Level. The location of each examination site was pinpricked and numbered on the back of the relevant airphoto contact print. A discrepancy arises between the actual distance travelled over gently undulating terrain and the distance on the flat airphoto contact print. It was, therefore, necessary to make a calibrated adjustment when making such 'pinpricks'.

As surveys progressed a limited range of soil types was identified and the pattern of distribution mapped on airphoto mosaics (scale, 1:25,000 for semi-detailed surveys; as required for detailed surveys). Subsequently a number of 'tentative' and later 'provisional' soil series were established. For the detailed surveys these soil series and their phases became the predominant mapping units.

On completion of each survey representative soil profile pits were dug (2 m. x 1 m., x 2 m deep) and examined in detail in each mapping unit. These provided detailed profile descriptions and samples for particle size analysis, chemical analysis and for correlation purposes.

Following the end of the 1973-1974 rainy season when the range of established soil series had been set up, a number of physical investigations were carried out in the two soil series of greatest agricultural importance - Mushemi and Choma series.

These investigations included measurements of infiltration rates, bulk density, available moisture, porosity and particle density.

LABORATORY WORK

1. Particle-Size Analysis

Texture classes used throughout survey work were those of the United States Department of Agriculture (U.S.D.A.) system, not of the so-called 'International' system. The older 'International' system sets the limit between the silt and sand fractions at 0.02 mm , whilst the U.S.D.A. system sets the limit at 0.05 mm. Experience showed that the 0.05 mm limit correlated more closely with soil 'feel' and behaviour in Zambia.

After grinding and dispersion by Calgon (Sodium hexameta phosphate) and Sodium carbonate, clay and 'international' silt were determined by the hydrometer method (Bouyoucos G.T., 1927, Soil Sci., 23. page 319). U.S.D.A. and 'international' sand classes were determined by dry sieving. U.S.D.A. silt was calculated as 100 - (clay + U.S.D.A. sand).

2. Chemical Analyses

Organic Carbon percentage was determined by the Walkley - Black method (Walkley and Black, 1934. Soil Sci., 37. pp. 29-38).

Total Nitrogen percentage was determined by the Kjedahl method as modified by Bremner (Bremner, 1960. J. Agric. Sci., 55. pp 1-23).

Cation Exchange Capacity (C.E.C.) and Exchangeable Cations

The following method (Schollenberger and Simon, 1945, Soil Sci., 59, pp 13-24) was used to determine CEC. 25g of soil were leached with 250ml of 1.0 N ammonium acetate at pH 7.0. This was followed by washing with alcohol to remove excess ammonium acetate. Further leaching using acidified sodium chloride displaced the absorbed ammonium ions which were determined in the leachate by distillation (Peech et. al., 1947, U.S.D.A. Circ 757. pp 9-10).

Exchangeable calcium and magnesium were determined using a Perkin Elmer atomic absorption spectrophotometer. Potassium was determined by flame emission spectroscopy.

pH was determined by glass electrode in 0.01M calcium chloride, using a soil to calcium chloride solution ratio of 1:5.

Available Phosphorous was determined using Bray's No. 1 method (Bray and Kurtz, 1945, Soil Sci., 59, p 44).

REPORT AND MAP PREPARATION

This final phase was confined to the rainy season when field conditions were unfavourable and access to survey areas restricted.

Soil and land use capability maps were drawn up by the Cartography Section of the Land Use Services Division based on drafts prepared from airphoto mosaic soil distribution maps compiled during the course of field work.

PART TWO : ENVIRONMENTAL FACTORS

CHAPTER 5

CLIMATE

Zambia lies in tropical latitudes, between 8 and 18°S but its climate is tempered by its elevation. The majority of the country consists of a plateau between 900–1350m (3,000–4,500 ft.). Temperatures are remarkably moderate but considerable variations occur throughout the year. The most striking feature is the division into a long dry season (with cool and warm phases) and a shorter rainy season. Zambia is considered, therefore, to exhibit a three-season modified Sudan-type climate.

CONTINENTAL FACTORS

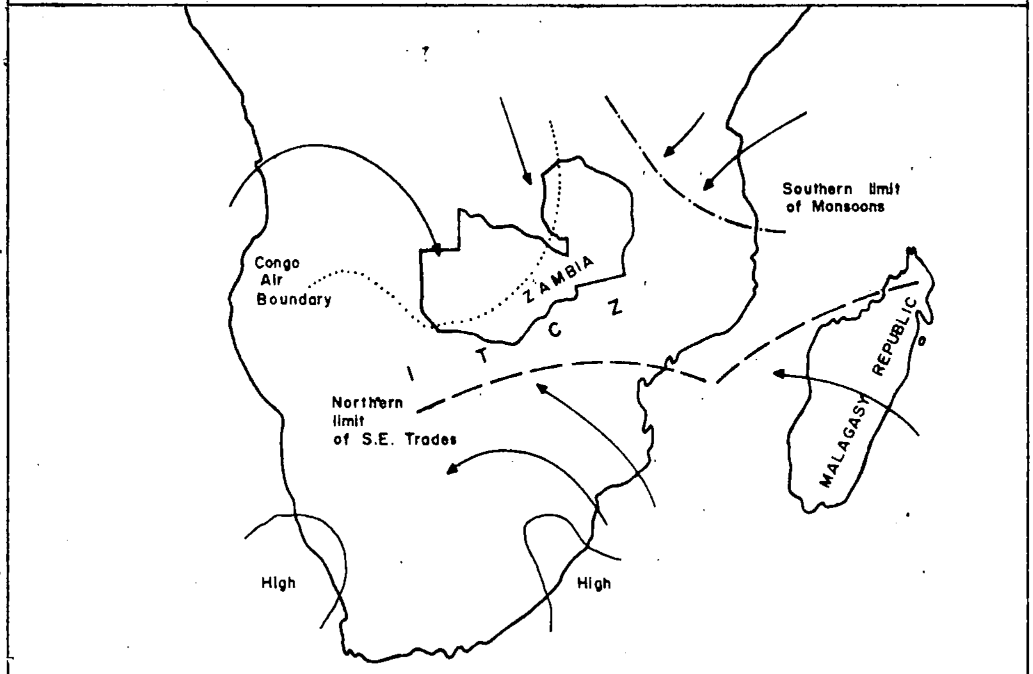
Zambia's climate is determined primarily by African geography and the nature of the surrounding oceans. Africa is unique among the continents. There are no great mountain chains to act as climatic divides. Plateau elevation modifies temperature and rainfall. There is no immediate source of cold continental air since Southern Africa is situated in low latitudes and is surrounded by water. Southern Africa receives few invasions of cold polar air since it lies 3200 km (2,000 miles) north of Antarctica. In Southern Africa air streams from over the cold Atlantic Ocean currents and from over the warm Indian Ocean currents sometimes penetrate to the interior and affect climate conditions.

RAINFALL (General)

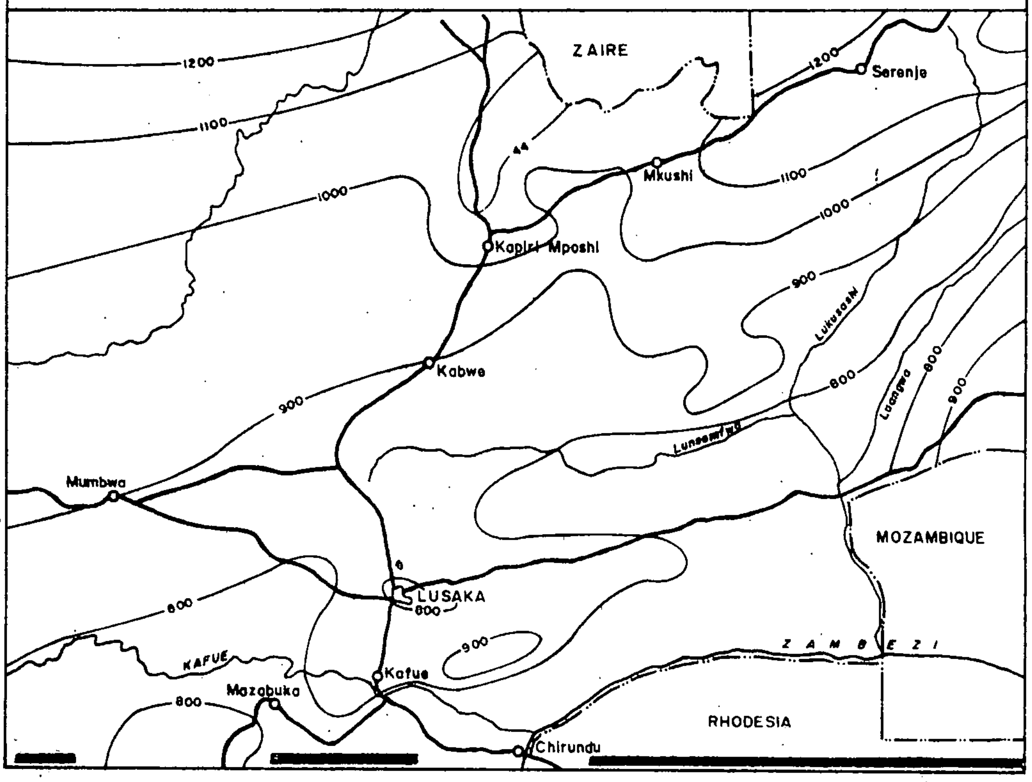
The main characteristics of the rainfall pattern are best explained in relation to the movement of large scale pressure and wind systems. The main rainy season coincides

MAPS 2 & 3 Overleaf

MAP. 2 GENERALISED AIR FLOW PATTERN IN JANUARY



MAP. 3 RAINFALL (mm) IN THE LUSAKA-MKUSHI AREA



with the southerly movement of the Inter-Tropical Convergence Zone (ITCZ) - a belt of comparatively low pressure with a mean position near the equator. The position of the ITCZ over Southern Africa during the Zambian summer (rainy season) is complicated by narrowing of the continent and the convergence of three airstreams as indicated on Map 2.

These are:-

i. Congo Air: Very humid from the South Atlantic Ocean curving inland over Zaire.

ii. S.E. Trades: Dominant Zambian dry season winds. In summer, with a more maritime track, they hold more moisture.

iii. N.E. Monsoon: Originates in Asia and crosses the Northern Indian Ocean.

Rainfall in Zambia has three main sources:-

i. Most rainfall occurs near the margins of the ITCZ along the Congo Air Boundary. Precipitation occurs to a lesser extent in the central area of the ITCZ.

ii. High pressure cells can sometimes detach from the semi-permanent Atlantic Ocean anticyclone and move eastward across the continent. Counter-clockwise circulation around such highs often brings an invasion of cool moist air from the south east. The associated weather may be cloudy to overcast with persistent rain or drizzle.

iii. Tropical cyclones originating in the Indian Ocean occasionally penetrate Zambia.

There is a general decrease in the rainfall amount from north to south, which may be attributable to the shorter time the south is influenced by the ITCZ. Northern Zambia averages 1015 mm (40-60 ins) while southern Zambia averages 635-1015 mm (25-40 ins).

The present rainfall regime of dry winter and wet summer apparently existed throughout the Pleistocene and recent periods. However, the mean annual precipitation has fluctuated widely. There have been, during these periods, three major pluvials of long duration, when mean annual rainfall was at least 500 mm (20 ins) more than the present mean. These pluvials were separated by short dry periods when the mean annual rainfall was 500 mm (20 ins) less than the present mean. Finally there were two wet phases of lesser intensity when rainfall was perhaps only 250 mm (10 ins) more than the present mean.

CLIMATIC RECORDS

Climatic records have been kept at Kabwe since 1910 and they may be taken as an average for the Lusaka - Mkushi area. All data quoted for the climatic elements described below are from Kabwe. Relevant data are presented in Tables 1-4.

1. Rainfall (Lusaka-Mkushi area). Rainfall varies between 1066 mm (42 ins) at Mkushi and 813 mm (32 ins) at Lusaka. At Kabwe, rainfall averages 925 mm (36.4 in) per annum, 96% of which falls in the period November-March. The 1000 mm (40 in) isohyet (see Map 3) lies just south of Kapiri Mposhi and Mkushi. Important distinctions are now made between

the strongly leached and more moderately leached soils which lie approximately to the north and south, respectively, of this isohyet.

2. Evaporation (Eo) averages 2156 mm (83.3 in) at Kabwe. Rates are high throughout the year, ranging between 193-287 mm (7.6-8.2 in) per month in the period September-November, and 130-150 mm (5.1-5.9 in) per month in the period December-March. Mean rainfall exceeds mean evaporation during the wettest period, December-February, by a total of 244mm (9.7 in).

3. Temperature. Mean monthly temperatures range between 16^{o}C (61^{o}F) in July and 24.6^{o}C(976^{o}F) in October. The mean minimum is 9.0^{o}C (48^{o}F) in July when rare light ground frosts may occur. The mean maximum is 31.9^{o}C (89.5^{o}F) in October falling to around 27^{o}C (80.5^{o}F) in September-November, reaching over 37^{o}C (98.6^{o}F) in October.

4. Relative Humidity is highest in the rainy season, 65-84%,and lowest at the end of the dry season, 40-42%. There is considerable daily variation between mean minima and maxima of 65 and 95% at the height of the rainy season and about 26 and 65% at the end of the dry season.

5. Sunshine ranges between 5.1-5.5 hours/day in December-February and 8.2-9.7 hours/day in April-September. The annual average is 7.9 hours/day.

6. Day Length at Kabwe ranges between 1 hr 19 mins in June and 12 hrs 57 mins in December (Figures calculated from tables in Climate Data Publication No. 3. Department of Meteology - Lusaka).

TABLE 1. Kabwe Climate Data

		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Annual
RAINFALL (mm)	Mean monthly/annual	1	2	2	18	96	231	226	207	121	20	1	-	925
	Monthly/annual av.no. rainy days	-	-	-	2	10	17	18	14	11	3	-	-	75
EVAPORATION (mm)	Mean monthly/annual	157	216	257	287	193	155	135	130	155	165	168	140	2156
	Absolute maximum	191	260	312	313	219	183	189	159	216	234	193	182	2429
	Absolute minimum	176	209	271	239	147	108	131	120	142	130	153	137	2196
	Deficit(-) Surplus(+) -mm.	-156	-214	-255	-269	-97	+76	+91	+77	-34	-145	-167	-140	-1231
TEMPERATURE (°C)	Absolute monthly/annual minimum	0	-0.6	5.6	9.4	12.8	13.3	11.7	12.2	11.1	8.33	2.2	1.7	-0.6
	Mean daily minimum	9.0	10.9	14.6	17.5	17.9	17.7	17.4	17.3	16.5	14.7	11.5	9.3	14.5
	Mean daily(24hr. mean)	16.0	18.3	21.9	24.6	23.0	21.6	21.1	21.0	21.8	21.2	18.1	16.0	20.2
	Mean daily maximum	23.3	25.8	29.6	31.9	20.5	27.6	26.9	26.7	26.7	27.2	25.8	23.6	27.1
	Absolute monthly/annual maximum	29.4	32.2	35.6	37.2	36.7	33.9	31.7	31.6	31.6	31.7	31.7	28.9	37.2
RELATIVE HUMIDITY (%)	Mean monthly/annual	58	48	42	40	65	78	82	84	79	71	62	60	64
	Mean daily max(6am)	83	75	67	63	83	94	95	96	96	94	90	87	85
	Mean daily min(2pm)	35	29	26	26	43	61	64	66	59	49	41	39	45
SUNSHINE	Average (hrs/day)	9.1	9.6	9.7	9.4	6.5	5.1	5.5	5.2	7.2	8.2	9.6	9.3	7.9

Source Climate Data Publications, 4-13 Department of Meteorology, Lusaka.

TABLE 2:

KABWE: Percentage Probability of Rainfall totals reaching stated limits

RAINFALL LIMIT(mm)	OCT	NOV	DEC	JAN	FEB	MAR	APR
25	25	95	100	100	100	98	26
51	7	79	99	99	99	86	7
76	3	56	98	95	95	70	4
102	2	40	95	92	85	54	1
127	1	26	91	86	70	40	-
152	-	16	84	81	58	27	-
203	-	3	62	60	35	9	-
254	-	-	40	40	21	3	-
305	-	-	21	22	14	1	-
356	-	-	10	13	7	-	-
406	-	-	5	8	-	-	-
457	-	-	2	5	-	-	-

Source: Climate Data Publication No. 10
Lusaka 1969

TABLE 3

Probability of Annual Rainfall reaching stated limits

ANNUAL RAINFALL (mm)	% PROBABILITY
635	96
762	89
889	54
1016	26
1143	12
1270	2

Source: Climate Data Publication No. 10
Lusaka 1969

TABLE 4

Dates of Beginning and End of Rainy Season

	RAINY SEASON	
	BEGINNING	END
MEAN	12 November	20 March
20% Probability	25 October	10 March
40% Probability	3 November	18 March
60% Probability	17 November	24 March
80% Probability	21 November	31 March

Source: Climate Data Publication No. 10
Lusaka 1969

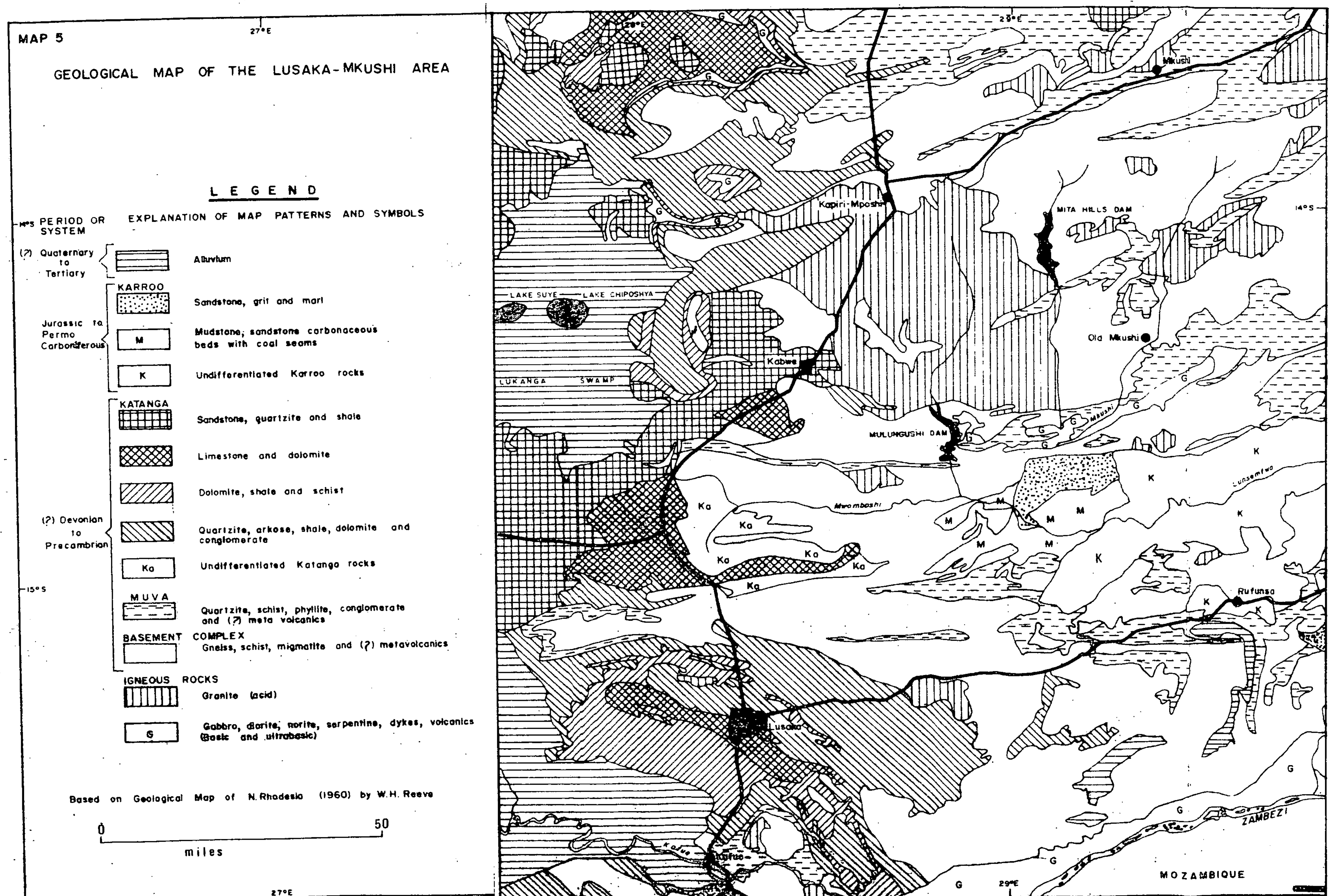
CHAPTER 6

GEOLOGY

The outline of the geology of the Lusaka-Mkushi area given below and shown on map 5 is based on Reeve's (1962) Geological Map of Northern Rhodesia (scale 1: 1,000,000). The most recent published map of the geology of Zambia is that of Drysdall et al. (1972) but this is at a scale of approximately 1: 6,500,000 and is of little practical use for detailed studies.

The oldest rock system in Zambia is the Basement Complex and it is very well represented in the Lusaka-Mukushi area. It may be divided into upper and lower parts, separated by a major unconformity. The rocks of the lower part (shown on the map as Basement Complex) are structurally complex. They have been folded and faulted and have undergone repeated metamorphism, so that their original character has been completely obliterated. The main rock types are gneisses, mica, hornblende and kyanite schists and micaceous quartzites.

The Muva Group represents the upper part of the Basement Complex and has a much lower grade of metamorphism. It is separated from the lower Basement by an unconformity which is believed to represent a period of as much as 1000 million years. The most characteristic rock types of this group are quartzites, schists and conglomerates. The quartzites are clean and fairly easily distinguishable from quartzites of other systems.


MAP 5
GEOLOGICAL MAP OF THE LUSAKA-MKUSHI AREA
LEGEND
PERIOD OR SYSTEM
EXPLANATION OF MAP PATTERNS AND SYMBOLS
(?) Quaternary to Tertiary
Alluvium
KARROO
Jurassic to Permo Carboniferous
Sandstone, grit and marl
M
Mudstone; sandstone carbonaceous beds with coal seams
K
Undifferentiated Karroo rocks
KATANGA
Sandstone, quartzite and shale
Limestone and dolomite
Dolomite, shale and schist
(?) Devonian to Precambrian
Quartzite, arkose, shale, dolomite and conglomerate
Ka
Undifferentiated Katanga rocks
MUVA
Quartzite, schist, phyllite, conglomerate and (?) meta volcanics
BASEMENT COMPLEX
Gneiss, schist, migmatite and (?) metavolcanics
IGNEOUS ROCKS
Granite (acid)
G
Gabbro, diorite, norite, serpentine, dykes, volcanics (Basic and ultrabasic)
Based on Geological Map of N.Rhodesia (1960) by W.H. Reeve
0
50
miles
27°E
28°E
29°E
14°S
15°S
Mkushi
Kapiri-Mposhi
MITA HILLS DAM
LAKE SUYE
LAKE CHIPOSHYA
Old Mkushi
Kabwe
LUKANGA SWAMP
MULUNGUSHI DAM
Mwombashi
Lunsemfwa
Rufunsa
Lusaka
Kafue
ZAMBEZI
MOZAMBIQUE

The Basement Complex* (as a whole)has been extensively intruded by granites and parts of the lower Basement have been granitized. Mineralization of the Basement Complex is limited, but some gold, silver mica and iron have been worked, and tin, asbestos and graphite are also present.

After the deposition and folding of the Muva group, there was considerable erosion of the entire Basement Complex. This left an irregular surface on which Katanga sediments were deposited late in the Pre-Cambrian era. On the Copperbelt the Katanga System has been divided into Roan, Mwashia and Kundelungu groups. In the remainder of the country, it has been usual to divide the Katanga simply into upper and lower divisions, since it is not yet possible to make precise correlations with the Copperbelt area. The main rock types are sandstone, shale, schist, quartzite, arkose, conglomerate, limestone and dolomite. Lead and Zinc deposits in dolomites and argillites at Kabwe are now believed to belong to the Kundelungu group. Limestone from the Katanga System is widely used for metallurgical processing, for cement (Chilanga Cement) agricultural lime and road stone.

The next youngest group of rocks, the Karroo System, extends in age from the Upper Carboniferous to the Jurassic period. This system is best represented in the rift block valleys (e.g. Lunsemfwa) but outcrops also occur on the

*Drysdall et. al. (1972) have now divided the Basement Complex into Kibaran and pre-Kibaran elements. The Muva System is included in the Kibaran element. Drysdall's map (1972) shows a large granite massif (the Mkushi granite massif) occupying a very large block bounded approximately by Kawbe, Mkushi and the Munchinga Escarpment. This massif, according to Drysdall is probably of pre-Kibaran age. The granite massif is shown to have a much more restricted extent on Reeve's (1962) map.

plateau. The lowest part of the sequence is represented by a possible tillite indicating a glacial phase of Carboniferous age. This is followed by sandstones and then by coal formations (the latter not being represented in the Lusaka-Mkushi area). Higher in the sequence, the Karroo System consists mainly of mudstones, grit and sandstones.

Recent deposits of alluvium are extensive on the Kafue Flats and Lukanga Swamps.

CHAPTER 7

GEOMORPHOLOGY

In his pioneer studies of the geomorphology of Central and Southern Africa, Dixey (1938, 1945 and 1956) classified landforms into a simple system of denudational cycles. Dixey widely identified his 'mid-Tertiary' and 'Late-Tertiary' landscapes as planed surfaces at about 1200m (4,000 ft) and 600m (2,000 ft) respectively, throughout the greater part of Southern Africa.

King (1962) also described various cycles of sedimentation and denudation and advanced the hypothesis of cymatogeny under which cyclic landsurfaces are thrown into great waves.

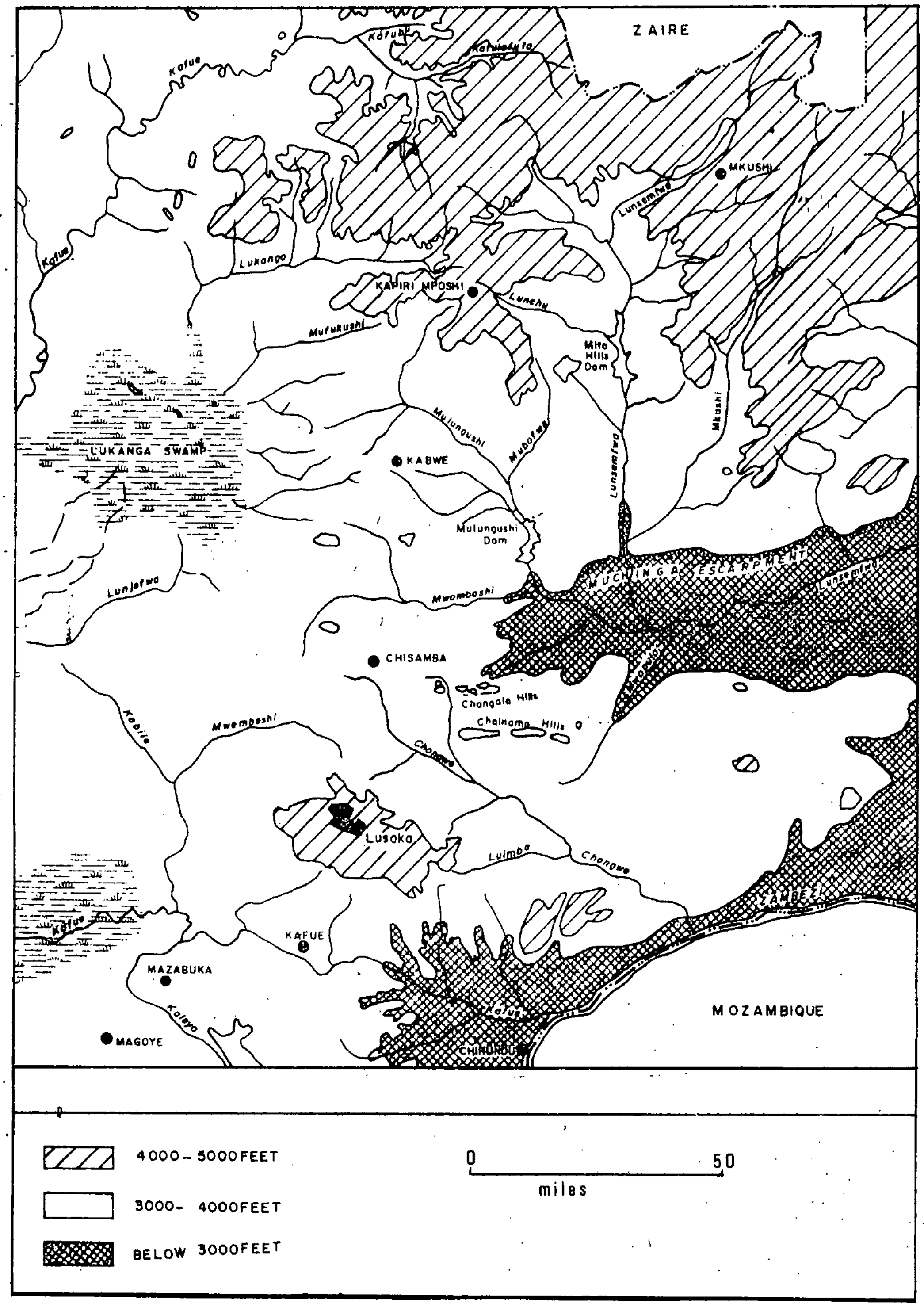
The formation of the present day landscape began towards the close of the Karroo period (Triassic) - a period of extensive sedimentation - when warping occurred along a S.W. - N.E. axis. This gave rise to the Congo - Zambezi watershed (Kabwe - Mkushi - Isoka) along an upfold with the down - warped basins of the two river systems on either side. The Zambezi drainage was redirected from the Kalahari to the Indian Ocean.

During the Jurassic, erosion of Karroo sandstone produced the smooth Gondwana landsurface. In the early Cretaceous, Gondwanaland disrupted and this was accompanied by the dissection of the Gondwana surface. During the Cretaceous, Zambia was subjected to a series of shock waves which caused upwarping along N.W. - S.E. axes.

Upwarping between Chisamba and Feira diverted the Lunsemfwa and Luangwa Rivers which had previously joined the

MAP 4 Overleaf

MAP 4 DRAINAGE AND RELIEF OF THE LUSAKA - MKUSHI AREA



Zambezi River near the Kafue River junction. In addition, upwarping west of Namwala blocked the Kafue River and caused the ponding of the Lukanga swamp and Kafue Flats.

By the late Cretaceous erosion had reduced most of the continental interior to a plain of extraordinary smoothness known as the African surface.

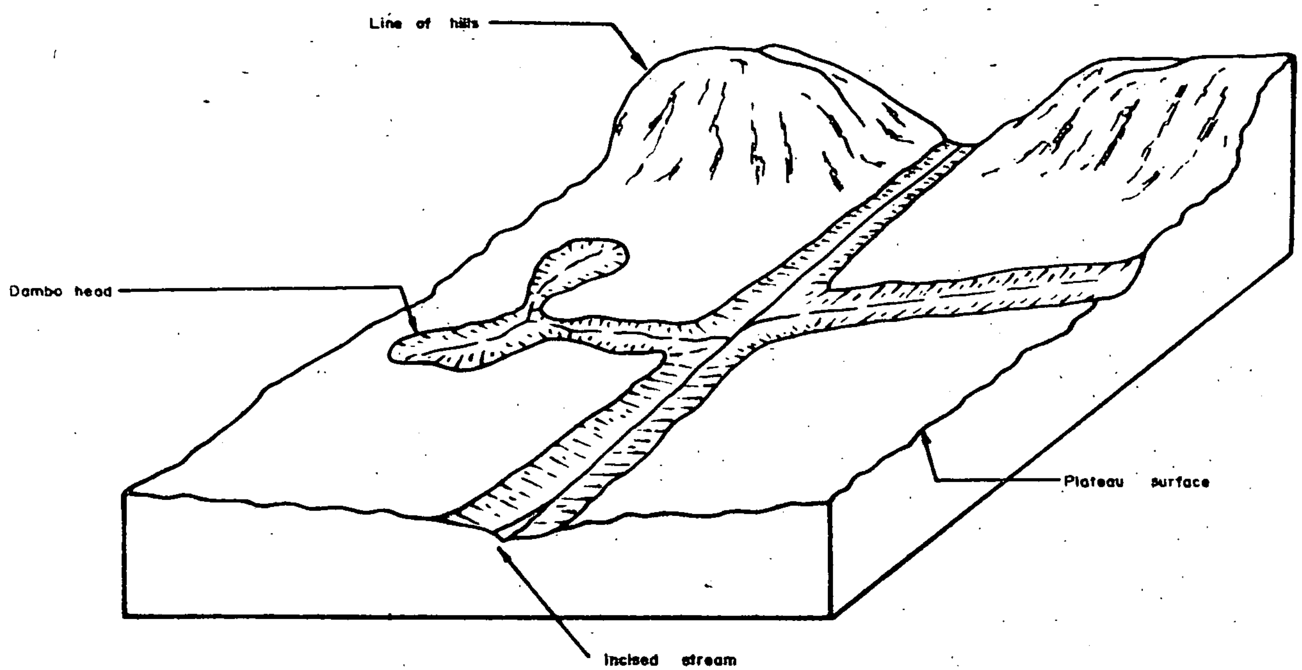
Further uplift and continental flexing was followed by a new period of erosion which by the mid-Tertiary period produced the Miocene peneplain - the present main plateau of Zambia.

CONTEMPORARY GEOMORPHOLOGY

The relief of the Lusaka - Mukushi area is shown on Map 4. It is mainly a gently undulating plateau, occasionally broken by isolated hills (i.e. Kapiri Mposhi Mountain) or low ranges of resistant rocks (i.e. Chainama, Changala, Chikonkomene and Mita Hills) and is dissected by dambos. Figure 1 illustrates the general type of land form.

The major part of the plateau in the area lies at 1065-1220m (3,500-4,000 ft) and is considered to correspond with Dixey's (1945) mid-Tertiary (Miocene) surface or King's (1962) post-African Late-Cainozoic (Miocene) surface. The remaining part of the plateau (except for areas exceeding 1515m, (5000ft) N.E. and N.W. of Mkushi) stands between 1200 and 1350m (4,000 -4,500 ft). It is possible that parts of this 'higher' plateau level may correspond with the African surface. Archer (1972) considers the Lusaka plateau to be a remnant of this surface but Drysdall and Money (1975) disagree and consider it to also correspond with Dixey and King's Miocene surface. Many

FIGURE 1 GENERAL SANDVELDT LANDFORM



of the flat topped hills which rise above the general level of the plateau may correspond with stages in erosion cycles which preceeded the Miocene surface but correlation is very difficult.

The Lunsemfwa valley in the eastern part of the Lusaka-Mkushi area has been affected by trough faulting and is a subsidiary rift valley of the Luangwa trough. The main faulting that initiated the Lunsemfwa trough occured during Karroo times, but faulting has occured to a reduced extent since that time. The original fault scarps were erased by peneplanation. Following subsequent uplift, new valleys were formed in the same position on the weaker Karroo rocks. The present valley is thus a secondary feature and its present outline is the result of differential erosion adjusted to variation in structure rather than to the direct effect of faulting. The Lunsemfwa valley, which stands at 300-600m (1,000-2,000 ft), is therefore a 'rift block valley' and the Muchinga Escarpment a 'fault line scarp'.

DRAINAGE

The Lusaka-Mkushi area is drained by two main rivers, the Kafue and the Lunsemfwa, both of which drain to the Zambezi river. The watershed approximately follows the line of the Great North Road from Lusaka to the Copperbelt. The Lukanga Swamp acts as a sump for the Kafue River.

On the plateau the drainage pattern is developed as a dendritic dambo network with broad wooded interfluves (Plates 1-3). Most dambos dry up during the hot season so that streams with dambo sources are impersistent. Although the plateau can

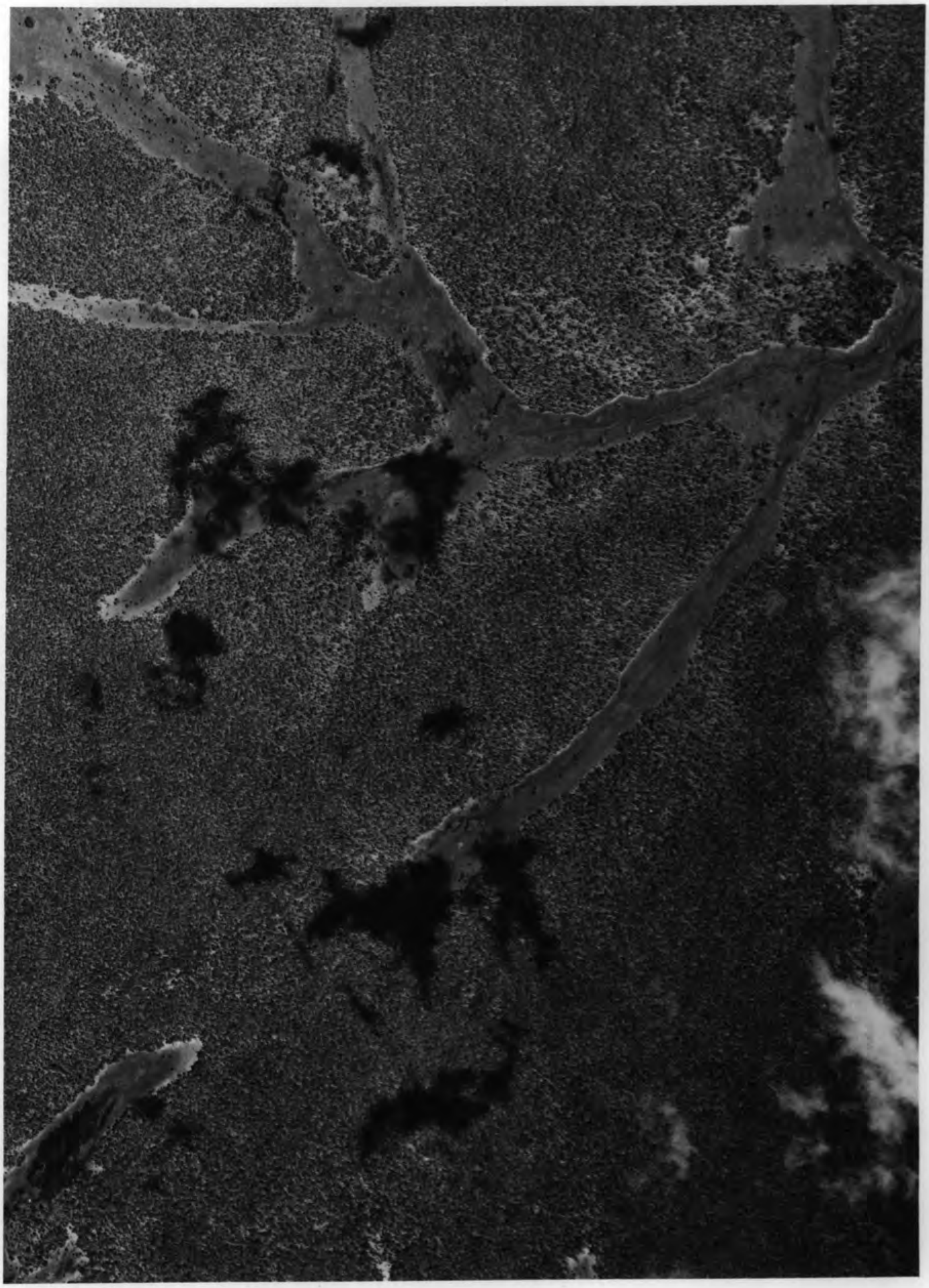


PLATE I

Aerial Photograph Illustrating
Dambo Drainage Pattern

PLATE 2

PLATE 3

<u>Dambo scenes in dry season (August 1976)</u>

Note abrupt margin to woodland; exposed soil surface following dry season fires; parched nature of grasses be described as generally gently rolling, interfluve crests are usually flat (1% slopes) while shoulders and middle slopes are convex with moderate slopes (1-3%). The interfluves form part of the Central African plateau (i.e. The Miocene Surface). Elevation differences between interfluves and dambos are relatively small but main streams (i.e. Lunchu, Mulungushi), which drain to the main rivers, are generally incised some 45-75m (150-250ft) into the plateau surface and usually have been regionally rejuvenated. Quartzite almost always outcrops in such streams. Dambo interfluves vary from 0.5 to several kilometres in breadth. Crests of narrow interfluves often have shallow soils with gravel and quartzite outcrops. Generally dambos are widest near their heads becoming narrower downstream as flow becomes strong enough to form incised courses. Dambos vary from 50m to 1 km (rarely more) in width.

By contrast the tract of limestone in the Lusaka area gives rise to gently rolling country with little surface drainage.

WEATHERING AND EROSION

While the major rivers flow perenially in well defined courses, the remaining streams are largely in dambos with only indistinct drainage lines and intermittent flow. These streams have little transporting power and the major movement of material is effected by sheet erosion during the rainy season. The interfluve soil profiles have been subjected to intensive chemical weathering. This has resulted in removal of the fine fraction and produced generally sandy soils with a relatively clay-rich illuvial horizon in the subsoil between 60 and 200cm. This horizon is commonly iron-rich and the result of lateral illuviation (by seepage). Sandveldt soils dry out suffiently for this iron layer to harden on aeration to form ferricrete, loosely termed laterite in Zambia. This laterite layer is often exposed at dambo margins sometimes due to sheet erosion and sometimes due to local gullying. Other such exposures may be attributed to iron in solution oxidising on contact with soil air. Brammer (1975) believes laterite outcrops at dambo margins to belong to a past climate or geomorphological phase. Spring lines often coincide with the bases of exposed laterite sheets during the rainy season.

Annual dry season fires destroy the sparse grass cover and the first rains fall on almost bare soil. Despite the fact that Miombo trees put out new leaves before the rains, thereby providing considerable protection to the soils, some sheet wash is inevitable (even on fairly gentle slopes). Sheet flow water is, however, conspicuously clear. This is attributed by Brammer (1975) to vertical clay eluviation leaving predominantly sand on the surface and the velocity of surface flow being inadequate to pick up and transport sand particles. Exceptions occur on a small scale where flow is temporarily concentrated between or alongside obstacles. On cleared land, however, sheet and gully erosion is widespread, particularly on the steeper slopes. Under natural conditions, therefore, slopes are probably paene-stable.

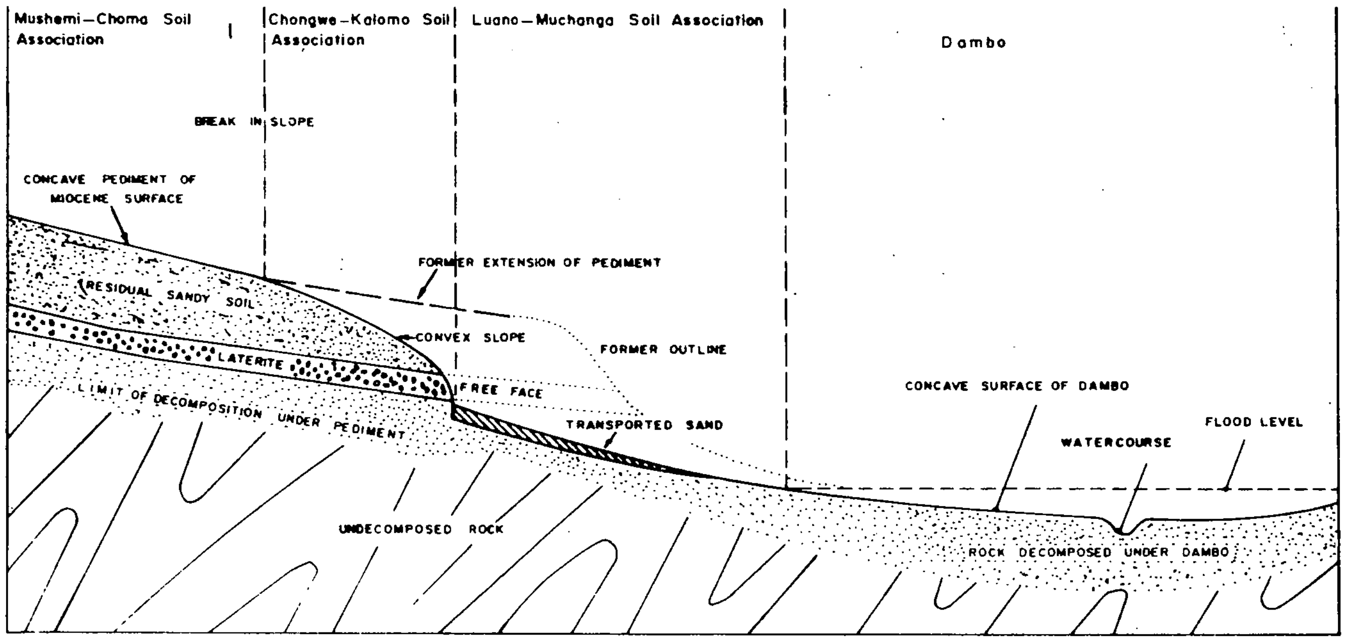
A conspicuous feature on air photos is a white collar to the woodland along dambo margins (Plate 4). This collar is white sand commonly found below laterite outcrops where the latter occur. This sand is possibly residual, bleaching having occurred either in the zone below the oxidised laterite layer

PLATE 4

Aerial Photograph Illustrating
Dambo Sand Collars

FIG. 1A Overleaf

FIGURE 1A CROSS SECTION OF TYPICAL DAMBO
vertical scale exaggerated
(adapted from Smith 1965)



or possibly under a former peat cover. Another possible explanation (Young, 1976, p 278) is that such sand is the result of differential deposition by surface wash, fine material being carried on into the dambo centre.

The dambos are generally mantled by sandy clay which impedes surface drainage. This sandy clay represents the weathered rock of the dambo floor which has been autochthonously mixed, by termites. Smith (1966) describes dambo formation as follows:

> "During sheet-floods the banks of streams are eroded, and a considerable volume of detritus is discharged into the water courses. If the streams are able to clear their courses this may continue indefinitely and the eroded banks may be cut back until they lie some distance from the stream beds. The banks have in miniature all the features of retreating scarps (Figure 1A). The thick perennial grass cover of dambo floors inhibits erosion. If the grass is removed (e.g. along a footpath), the sand is eroded and miniature dongas* form. The 'scarp retreat' is continuous even if stream beds are not lowered and each dambo forms part of a widening depression".

Dambos with streams may erode as Smith suggests but many dambos do not have streams and many merge into the adjoining

*Donga: (East African Term.) A sunken river bed or stream, the result of severe erosion during the rainy season and usually dry for part of the year.

forested scarp. There are examples in the Central Province of 'closed dambos' where gullying and scarp retreat have clearly not been involved. Our knowledge of the formation of dambos would benefit from further study.

The down cutting of the Lunsemfwa River and other main rivers to produce terraces may indicate the initiation of a period of erosional activity which has not yet reached the dambo areas. Stillman (1965) believes this rejuvenation to represent the earliest of the post-Tertiary erosion cycles which are very active in the escarpment country. Stillman (op. cit.) further postulates the representation of three cycles of erosion:

1. the 'mid-Tertiary' (Miocene) plateau surface
2. the general dambo erosion level
3. the incised courses of the major rivers.

Stillman's theory may not be generally applicable however. Smith (1966) records that in the Kapiri Mposhi area, the main streams (upper Mubalashi, Mulungushi, upper Lukanga) have only been lowered slightly from the level at which they stood during the development of the pediments.

The various rock types weather differently. Mechanical disintegration is subordinate except in rocks most resistant to chemical attack, such as quartzite and, in certain circumstances, granite-gneiss. Even quartzite hills are fluted and worn by solution weathering, and granite gneiss survives unrotted only in bare well drained outcrops which remain dry for most of the year. Schist weathers easily and is seldom exposed. The few outcrops of Schist are frequently capped by laterite and intensely ferruginised.

TERMITE MOUNDS

An important and conspicuous feature of the sandveldt landscape are large and medium domed termite mounds. The dominant species of mound building termite is likely to be *Macrotermes bellicosus* (Bryden, 1975) although *M. falciger* may also play an important role. Observation in the Chisamba area revealed that, on average, there were 2 mounds per hectare, covering 5-10 per cent of the land surface. They ranged from 2m to 4m in height and 10m to 20m in diameter. The mounds peculiarly contain calcium carbonate concretions. Watson (1962) noted similar features in *Macrotermes* mounds in Southern Rhodesia. Brammer (1975) postulates that such mounds are 'fossil' and developed under a previous, possibly wetter, climate and possibly built by different, even extinct, species.

CHAPTER 8

VEGETATION

CLASSIFICATION

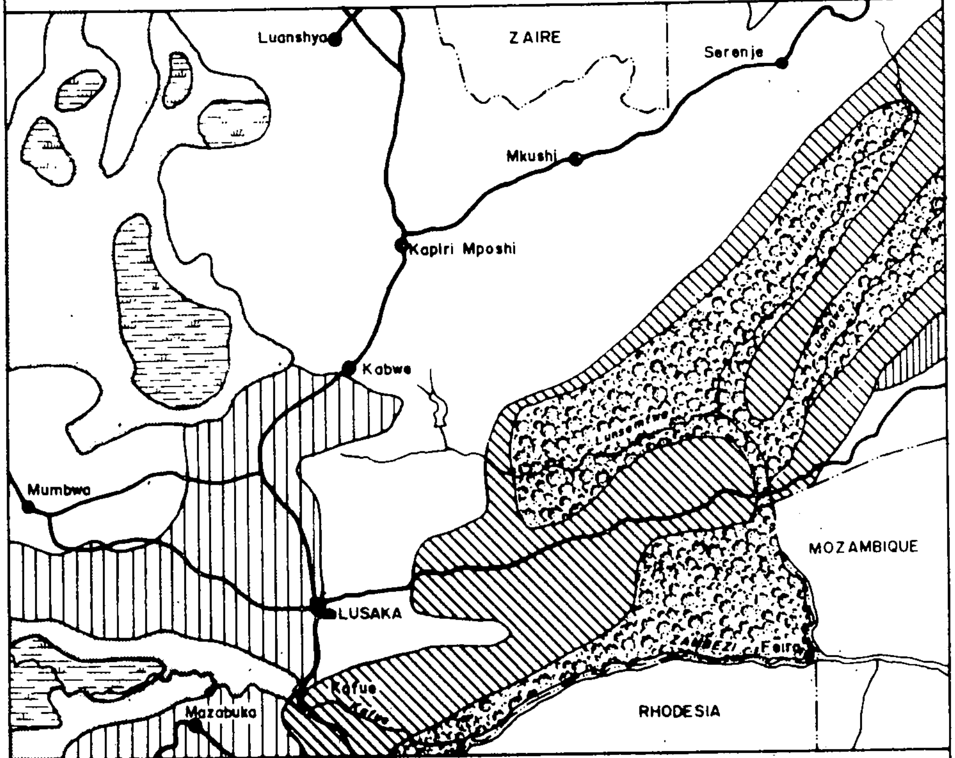
Trapnell (1937-43) in his pioneer work on the vegetation of Zambia recognised a number of vegetation types in the Lusaka-Mkushi area. These types (and their notation) from Trapnell's Vegetation-Soil Map are correlated below with those used by Fanshawe (1971).

TABLE 5: VEGETATION TYPES IN THE LUSAKA-MKUSHI AREA

TRAPNELL'S TYPES	NOTATION	FANSHAWE'S TYPES
Brachystegia-Isoberlinia Woodlands	P2-8 K2-5 B2.R.Ip.Ul E.El-2	Miombo Woodland
Mopani woodlands	Ll. Sl.	Mopane Woodland
Acacia-Combretum Woodlands	U2. U3. K12.L3.R.	Munga Woodland
Grasslands	SK6.S4-5 SW	Grasslands

MAP 6 Overleaf

MAP 6 GENERALISED VEGETATION MAP OF THE LUSAKA – MKUSHI AREA



Hyparrhenia grassland.

Swamp and Papyrus sudd.

Brachystegia woodlands often with Julbernardia globiflora and J. paniculata. (MIOMBO)

Brachystegia escarpment woodlands usually with high proportion of B. boehmii or B. allenii. (HILL MIOMBO)

Colophospermum mopane woodlands. (Zambezi, Kafue, Luangwa valleys, sometimes merging into savanna woodland) (MOPANE)

Combretum - Afromosia - Pterocarpus - Acacia Savanna (MUNGA)

Based on compilation map of Rattray and Wild, 1960
Bracketed terms after Fanshawe, 1971

Fanshawe's (1971) classification broadly follows that proposed for 'African Vegetation Types' at the 1957 Yangambi Conference (Aubreville, 1957) and draws a major distinction between closed and open forest. The woodlands of the Lusaka-Mkushi area are all open forest (Miombo, Mopane, Munga). The term 'Munga' was coined by White (1965) to replace the Yangambi term 'savanna'. 'Savanna' is a 'blanket term' whereas Munga (a vernacular name for Acacia, meaning thorn) refers to the composition of the particular type. The terms 'Miombo' and 'Mopane' are local descriptive terms.

VEGETATION DISTRIBUTION

According to Fanshawe (1971) the present-day vegetation as far as species content is concerned, arose in early Tertiary times. Quaternary times saw major distributional changes of species concomitant with a succession of pluvials and inter-pluvials. During these fluctuations, the vegetation of Zambia varied from evergreen forest to semi-desert at the two extremes.

The present day distribution of vegetation in the Lusaka-Mkushi area (Map 6, complied by Rattray and Wild (1961), and based on Trapnell's Map), shows most of the plateau to be covered by Miombo (Brachystegia-Isoberlinia) woodland. Munga (Acacia) woodland dominates areas to the north and south of the Kafue Flats and to the south east of the Lukanga Swamp. Mopane (Colophospermum mopane) occupies the lower Lunsemfwa and Luangwa Valleys. The swamplands of the Lukanga and Kafue Flats are surrounded by grassland.

SANDVELDT VEGETATION OF THE PLATEAU

On the plateau in the Lusaka-Mkushi area vegetation is closely associated with drainage conditions. A simple, yet distinct, vegetation catena may be observed.

The interfluves are dominated by an open to lightly closed Miombo woodland, 10-20m (30-60ft) high and designated by Trapnell (1937) as his unit P7 in the south of the area, and units P5 and P5/6 in the north of the area. It is characterised by species of Brachystegia (B. boemhmii, B. longifolia, and B. spiciformis) and Julbernardia (J. paniculata and J. globiflora). The dominant species vary from area to area. Associated with the above are Albizzia antunessiana, Burkea africana, Erythrophleum africamum, Marquesia macroura, Monotes spp., Parinari curatellifolia, and Pericopsis angolensis. Diplorhyncus condylocarpon and Pterocarpus angolensis are common smaller trees.

Plateau Miombo grades imperceptibly into 'hill Miombo' woodland of inselbergs, rock outcrops and escarpments in which Brachystegia microphylla dominates and in which relic evergreen thickets are found. Hill Miombo is especially prevalent in the Mkushi area, and on the Muchinga escarpment.

The woodland floor becomes covered by a grass/suffrutex layer following the onset of the rains. Suffrutices are a marked feature of Miombo woodland with the following genera being especially common:
Abrus, Combretum, Desmodium, Diospyros, Dolichos, Fadogonia, Indigofera, Lannea, Tephrosia and Vernonia.

The grass carpet may be moderately dense, dense or very dense. Common genera represented include: *Andropogen*, *Aristida*, *Brachiaria*, *Digitaria*, *Eragrostis*, *Hyparrhenia*, *Panicum*, *Rhynchelytrum*, *Setaria*, *Sporobolus*, *Tristachya*.

According to Fanshawe (1971), a seasonal rhythm is apparent in the appearance of grasses in Miombo woodland more or less as follows:

October/November.	*Brachiaria*, *Eragrostis*, *Rhynchelytrum*, *Setaria*, *Sporobolus*.
December/January.	*Andropogon*, *Digitaria*, *Rhynchelytrum*, *Sporobolus*, *Tristachya*.
February/March.	*Andropogon*, *Aristida*, *Eragrostis*, *Hyparrhenia*, *Panicum*, *Setaria*.

On the lower slopes the woodland gives way abruptly at the dambo margin to sparse grassland (Plates 1-4). This vegetation change is often marked by sheets of laterite outcrops and spring lines. The woodland just above the dambo margin is usually thin with abundant *Protea* trees, which, according to Schmidt and Njos (1974, p 12), is indicative of moving groundwater.

Most of the dambos are covered with a moderately dense mat of grasses, sedges and perennial herbs. The grasses are perennial bunch-grasses, cushion-like or tussocky with *Loudetia simplex* as the characteristic species.

The dambos often carry a stream or incised drainage channel in their centres where water may flow all year or where stagnant pools may form in the dry season. Swamp vegetation is usually associated with such conditions with Cyperus papyrus and Phragmites dominating and with the occasional relic tree.

In a sense Miombo is secondary woodland, since all, or nearly all, Miombo today is regrowth from one year old to apparently mature woodland. Mature woodland grows back following fire, cultivation or exploitation virtually unchanged. Past population pressure on the plateau has been so high that all, or nearly all, Miombo woodland has been cultivated at one time or another, even those areas which today look as if they have never been touched. Roberts (1976, p 67) suggests that chitemene agriculture has been practised on the plateau since about 1500 A.D.

Miombo woodland is economically important in the heavily populated areas for the supply of timber, poles, firewood and charcoal.

CHAPTER 9

PEDOLOGICAL SIGNIFICANCE OF ENVIRONMENTAL FACTORS

Whereas in temperate latitudes Pleistocene ice ages eroded or buried weathered soil mantles, on the tropical plateau of Central Africa the deeply weathered mantle has been preserved. This soil mantle has probably been weathered under different - presumed wetter - climatic conditions during one or more past climatic/geomorphological phases. In relation to present environmental conditions the soil parent material may be regarded as 'pre-weathered'.

Rainfall everywhere exceeds potential evaporation during the wettest months of the rainy season. This means that all except impervious soils tend to be leached. The potential for leaching increases northward as excess of rainfall over evaporation increases. In the Central Province this excess is sufficient to through - leach permeable soils so that they show no lime accumulation in the subsoil. It is also sufficient to leach clay from the topsoil to lower layers where the surface layer is not highly organic, ferruginous or calcium saturated. Topsoils are, therefore, lighter textured than subsoils in the leached sandveldt soils of the plateau.

A line approximately following the 1000mm isohyet marks a significant boundary in Zambia. South of this line - actually a transition zone between about the 1000 and 1100mm isohyets (shown on Map 3, p24) - soils formed over basic and intermediate rocks (e.g. limestones, biotite, granite, arkosic sandstone, shales) are generally only moderately leached and incompletely weathered. Cation exchange capacity (CEC) percent clay is generally higher than 16 m.e. implying the presence of some 2:1 clay minerals (Profile 4, Appendix 1). They have satisfactory reserves of calcium and magnesium. Where not limited by thick subsoil gravel layers, steep slopes or imperfect drainage, these provide good agricultural soils. Soils over more felsic (acidic) Basement Complex rocks have low mineral reserves and are less resistant to leaching. Under the moderate rainfall conditions of the Central Province these soils are strongly weathered and leached with CEC often lower than 16 m.e. percent clay implying the presence of predominantly kaolinitic clay (Profile 2, Appendix 1). Since, in addition, such soils are often very gravelly or steep on Basement Complex rocks they are generally poor for agricultural purposes.

North of the 1000mm isohyet, the influence of geology becomes less important. All soils, except those over hard ultrabasic and quartzitic rocks or on steep slopes, are strongly weathered and deeply leached. Mineral reserves are very low and CEC percent clay around 10 m.e. or less (Mansfield et. al., 1976, Vol 4, pp 143-145). The soils are very strongly acid throughout. They are, therefore, generally poor agricultural soils because of their low capacity to retain applied nutrients, the need for expensive liming to counteract acidity and their unstable structure when exposed to cultivation.

By comparison, sandveldt soils in the Southern Province, where rainfall is considerably lower (c.800mm/year), are much less strongly leached and CEC/clay ratios can be as high as

40 m.e.% (Schmidt and Njos, 1974, profile 19).

Central Province sandveldt soils, therefore, occupy a transitional position between those of the higher and lower rainfall regimes. This presents classification problems which are discussed in Chapter 13.

In the Central Province, soils on the plateau surface are generally more deeply and strongly weathered than soils on the flanks of the valleys cut below the plateau level. This is because soils on the plateau have been exposed to weathering over a very long period, part of it under wetter conditions than the present during Pleistocene pluvial periods.

Many - perhaps the majority - of the dambo soils in the Central Province are not formed in valley alluvium but have developed in seepage zones on the flanks of the major valleys. Especially over arenaceous rocks these seepage zone soils are usually sandy, strongly leached, and almost white. They commonly have laterite in the subsoil, at least along their upper slope margin.

Because of relatively cooler temperatures associated with the plateau altitude, uncultivated Central Province soils generally have darker topsoils and higher organic matter contents than equivalent soils formed under savannah woodland conditions in lowland tropical areas. (This darker colour is reflected in the frequency with which colours of 10YR or 7.5YR 3-4/6-8 are experienced for which chips are not provided on the standard Munsell Soil Colour Charts.)

In areas of strongly leached soils, the natural wood-land plays an important role in maintaining soil fertility. This it does partly, it is assumed, by bringing up sparse nutrients by way of its roots from deep soil layers for concentration in the topsoil by way of leaf fall and decay; and partly by cycling nutrients concentrated in the topsoil. In this way, the nutrients released by decomposition of organic matter are immediately absorbed by plant roots. At any one time, on such soils, the bulk of the nutrients may actually be contained in the living vegetation growing on them. Clearing the vegetation for cultivation can lead to serious depletion of soil fertility since the nutrients released from the vegetation may be leached totally from the soils. This is the basis for the traditional chitemene* practice on such soils, in which the trees are merely lopped or coppiced, but not killed, so that their root system continues to function and take up nutrients released by plant decomposition; (the roots also continue to bind the topsoil and protect it against erosion).

*Chitemene: The system of shifting cultivation practised in parts of Zambia, characterised by the burning of branches cut from the surrounding woodland on a circular cleared garden site. (Ruthenberg, 1971, p 32.)

PART THREE : THE SOILS

CHAPTER 10

GENERAL FEATURES OF SANDVELDT SOILS

The widespread so-called 'sandveldt' soils of the Lusaka-Mkushi area were mapped as Plateau Soils on Trapnell's (1947) Vegetation - Soil Map of Northern Rhodesia. Trapnell (1957) described Plateau Soils as "a term used to comprise a wide range of coarser and fine-grained sandy to sandy clay soils which have common characteristics as eluvial soils formed through long periods of seasonal leaching on a maturely eroded topography". Closely related soils in Southern Rhodesia have been called Pallid Plateau Soils by Watson (1962). Trapnell's description broadly fits sandveldt soils which characteristically have a light textured topsoil overlying a more clayey subsoil.

Subsoil textures of the various soils range from loamy sand to sandy clay. Topsoil textures range from sand to sandy loam in different soils. They are usually dark grey to brown (somewhat paler when cultivated) depending on the content of organic matter. It is sometimes possible to discern a weakly granular structure in the topsoil when moist but this is not apparent in the dry state.

Subsoil textures characteristically become more clayey with increased depth. For instance, in two different soils, Chongwe series and Mushemi series, textures grade from loamy sand to sandy clay loam, and from sandy clay loam to sandy clay, between the upper and lower subsoils respectively. Subsoil colours range from yellowish red to yellowish brown but imperfectly drained soils have 'paler' colours and are usually mottled. Subsoils are typically friable when moist, generally sticky and plastic when wet, and set hard when dry. They are also porous. Some cultivated soils are rather compact in the subsoil but structure is mainly lacking and can be described as massive. In general terms, sandveldt soils are acid, low in exchangeable bases and of low organic matter content.

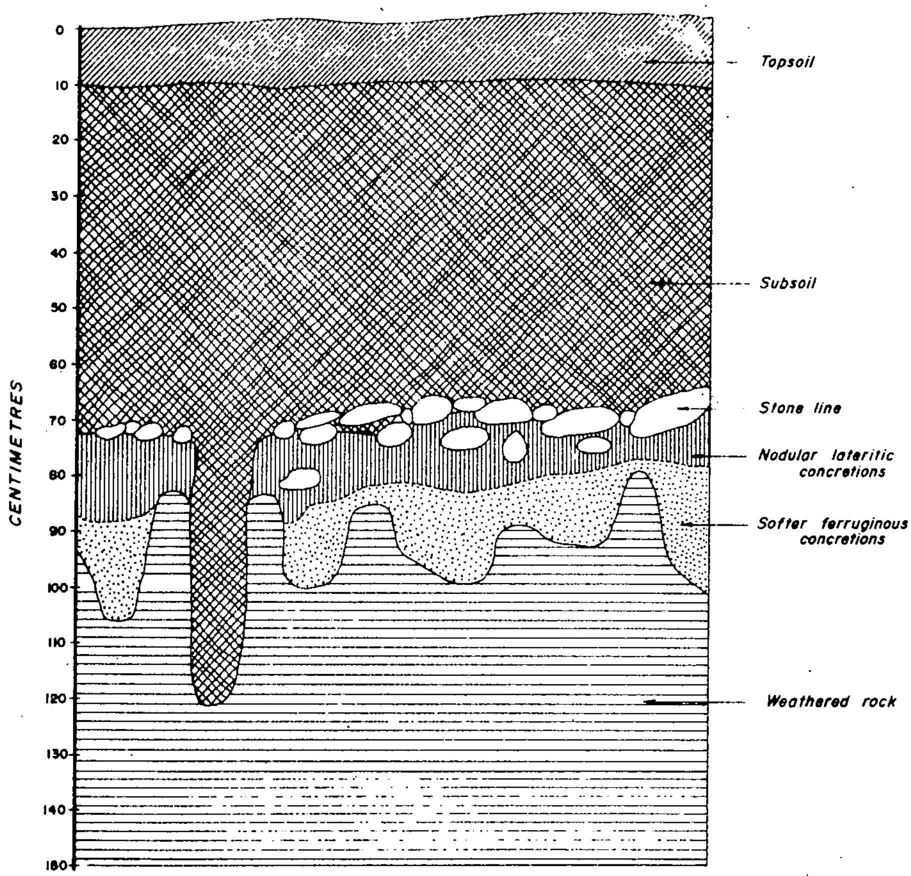
It is considered that an argillic subsoil horizon (see p 100) is present in most profiles reflecting the illuvial nature of the soils. The increase in clay content may or may not constitute a textural class difference.

Another common feature is the presence of a lateritic layer containing ferruginised coarse gravel and small stones separating the subsoil from the underlying mottled and highly weathered rock. It usually occurs below 120cm but is sometimes found higher in the profile (Profile 1, Appendix 1). The gravelly laterite horizon varies in its extent, but is most marked where subsoil drainage is poor, in extremely flat country, and on lower slopes in proximity to dambos where it outcrops (as sheet laterite). Large blocks of laterite sometimes occur along the dambo margin below outcrops, indicating that the laterite sheet formerly continued further downslope.

A more marked stone-line of quartz fragments is sometimes present in the subsoil associated with the lateritic horizon and usually resting on it. These quartz fragments are mainly angular to slightly subangular in shape, and range in size from fine gravel to large stones. Their exterior is iron stained to varying extents in different profiles, and sometimes within the profile. The nature of the quartz frag-

FIGURE 2

DIAGRAMMATIC SOIL PROFILE SHOWING STONE LINE AND LATERITE HORIZON



ments indicates that they have been derived from quartz veins in the parent rock.

Trapnell (1957) also noted the presence of stone-lines in these soils. Stone-lines in the south Chisamba area occur at variable depth, separating the lower subsoil from the underlying weathered rock, both of which are often laterized. Commonly a bed of nodular lateritic concretions within and below the stone-line gives way to softer ferruginous concretions which surround vertical cores of weathered rock. Tongues of subsoil (illustrated in Figure 2) sometimes plunge into the weathered rock presumably filling old root cavities. Such tongues were also recorded by Wilson (1965) who noted that in some parts of the Mukonchi area "the soil is underlain at depth between 36 inches to 60 inches by hard weathered granitic material with tongues of soil".

The depth to the gravelly lateritic layer varies without observable pattern. In some cases it can lie at a depth of 2m or more, in other cases it can lie above 60cm and even at the surface.

The depth at which the horizon occurs can vary over a very short distance. Figure 3 (after Haugbotn, 1974b) shows the 'broad-scale' variation of depth location of the gravel at Kabwe Research Station (observations made by augering in a row of 2m deep wells, spaced every 6 and 20m over a distance of 300m). Figure 4 shows the result of a detailed investigation carried out at Chisamba Farms with observations made at every 1.5m.

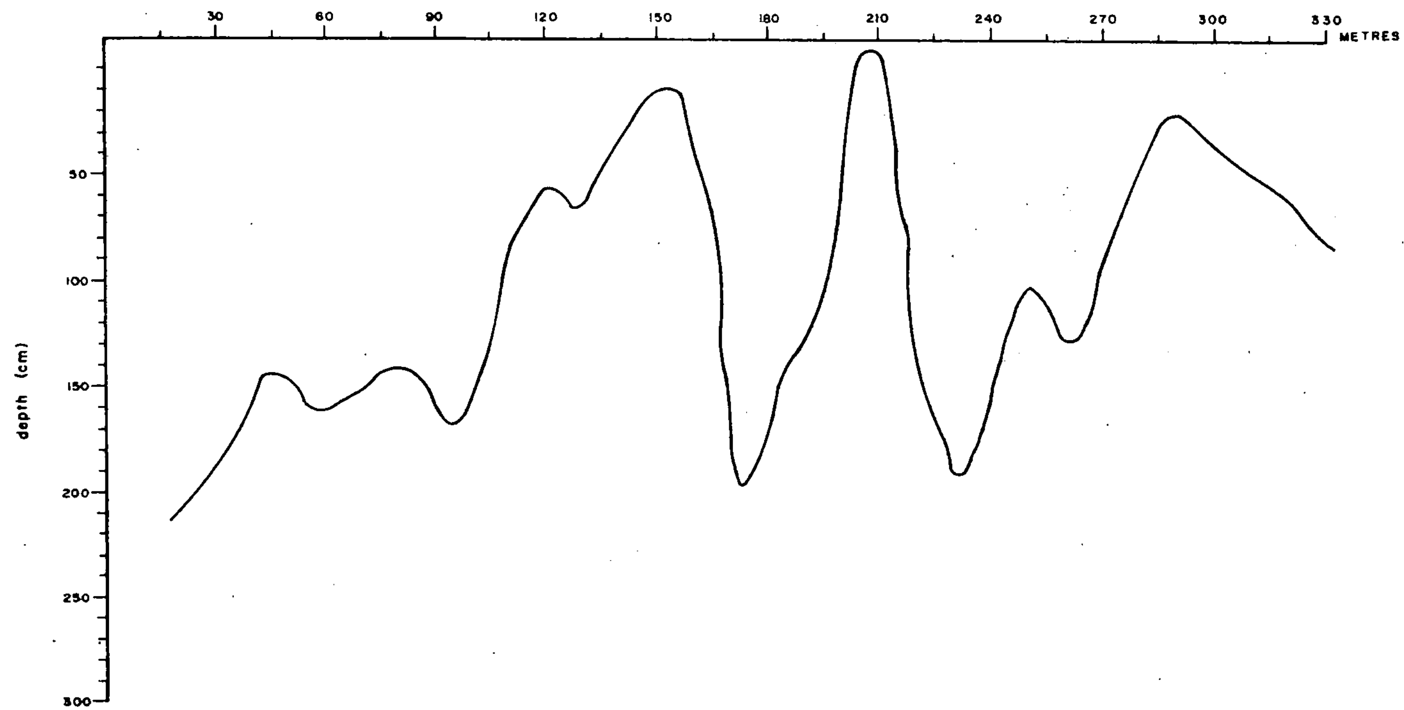


FIGURE 3 BROADSCALE VARIATION OF DEPTH TO GRAVEL AT KABWE RESEARCH STATION
(AFTER HAUGBOTN, 1974)

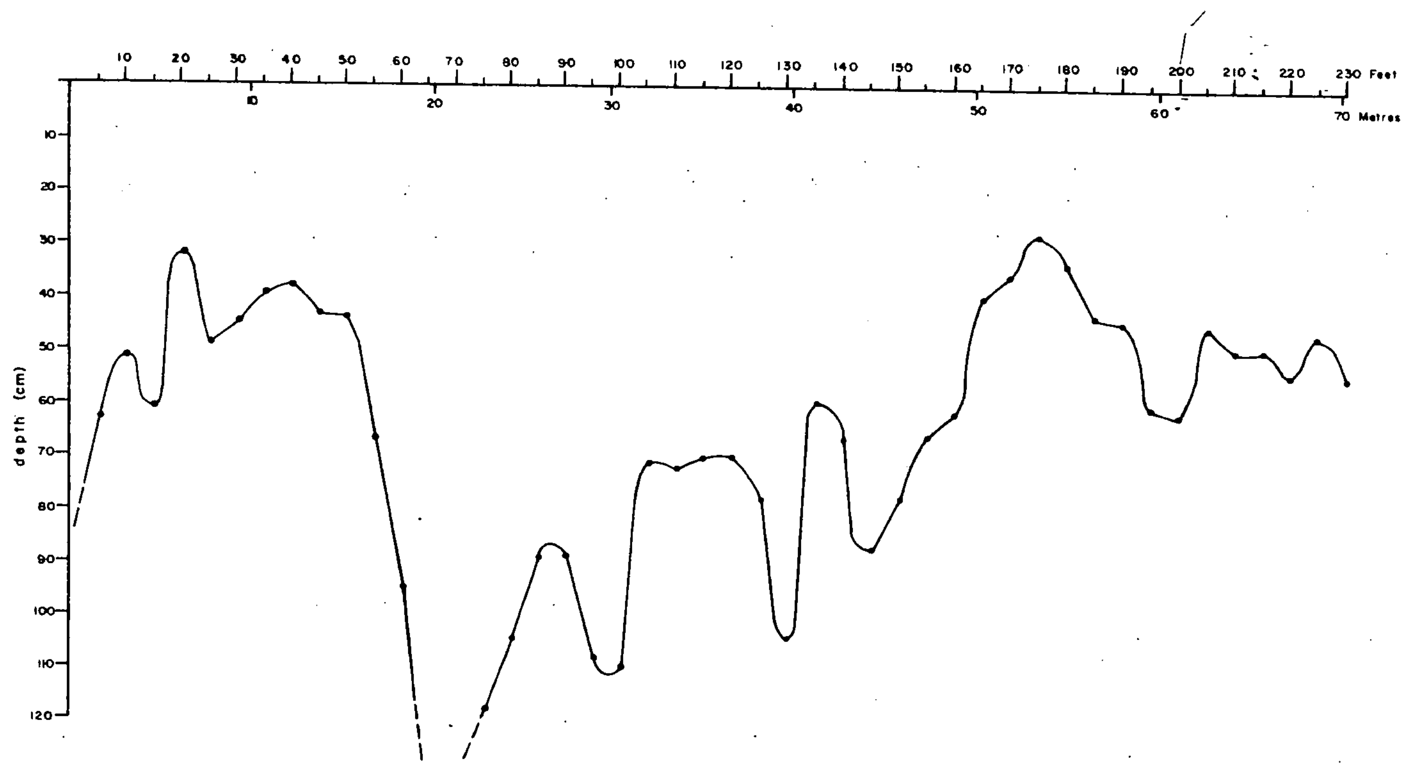


FIGURE 4. DETAILED VARIATION OF DEPTH TO GRAVEL AT ZAMIC CHISAMBA FARMS

The subsoil, laterized layer and weathered rock are normally all very porous. Roots penetrate the lateritized layer well into the weathered rock. The lateritic horizon, where it occurs below normal ploughing depth, is, therefore, not normally a major restriction for agriculture.

The zone of weathered rock lying beneath the lateritic horizon is usually quite thick. Webster (1965) reports that "examination of a well shaft on a lower slope site showed that the rock was partially weathered at 30ft (9m) to a soft friable mass, with few remaining hard lumps of rock". Regolith thickness is commonly as much as 50m (Young, 1976, p 265) although it may vary over short distances. Such variations are not necessarily related to surface topography (Thomas, 1966).

CHAPTER 11

THE SANDVELDT CATENA

The sandveldt catena in the Lusaka-Mkushi area typically comprises a succession of soils (from crest to dambo) from yellowish red, through yellowish brown to grey. Typically on crest sites the soil beneath the organic stained surface layer is yellowish red to strong brown (5YR or 7.5YR on the Munsell notation) whilst lower down the slopes the soils become progressively yellower with 10YR before hydromorphic conditions produce their associated characteristic grey colours in the lower slope, dambo margin and dambo soils.

This tendency for the soil to become less red and more yellow downslope is typical of savanna catenas and has in the past been attributed to lower slope soils remaining moist for longer periods than those further upslope, with consequent hydration of iron minerals. Webster (1965) was, however, unable to identify such differences in iron mineral type in the Masaiti catena and in fact showed higher percentages of free iron oxides in the redder soils.

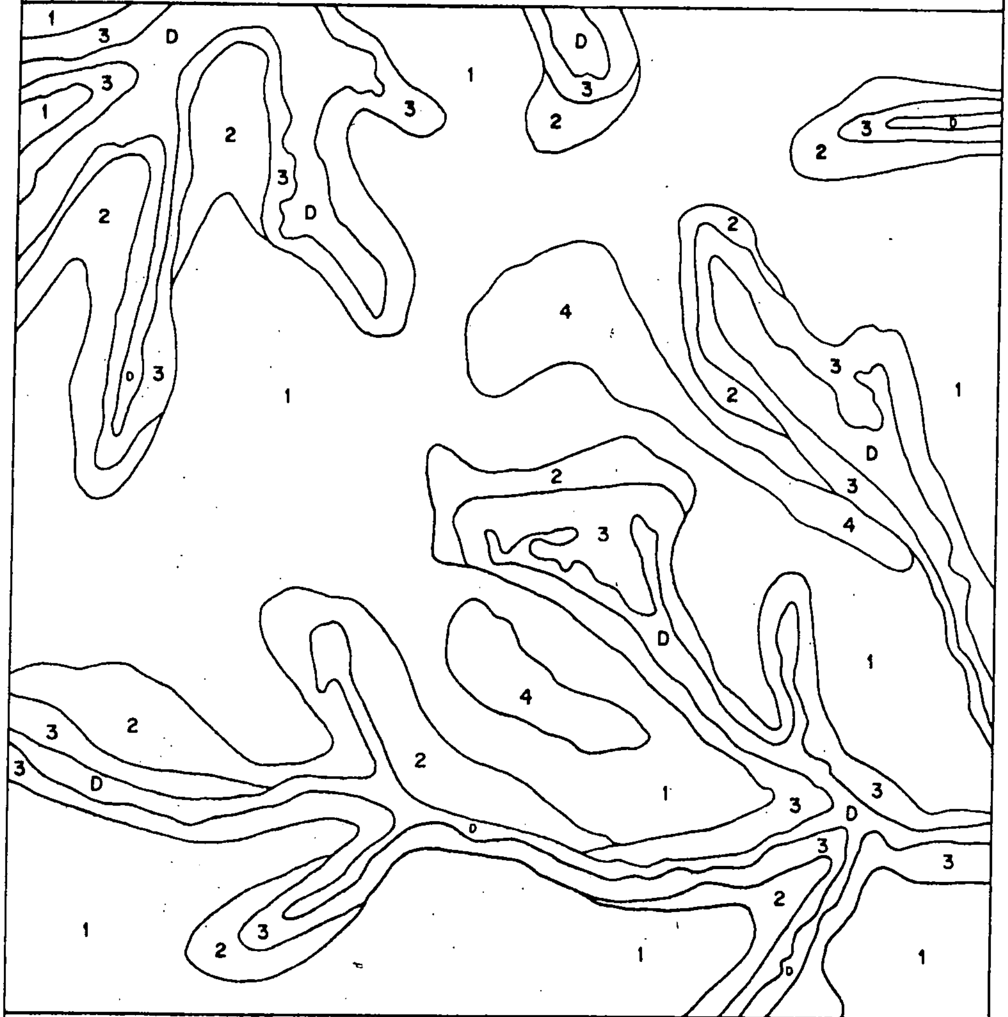
The sandveldt catena incorporates three soil associations, each confined to specific topographical positions as outlined below and illustrated in Figure 1A. (p45)

SOIL ASSOCIATION		TOPOGRAPHICAL POSITION
Mushemi-Choma	....	Crest to upper slope
Chongwe-Kalomo	....	Middle Slope
Luano-Muchanga	....	Lower slope and dambo margin

The position is complicated by the occurence of a number of associated soils (discussed in Chapter 12) and by the occurrence of a land-type mainly comprising shallow soils

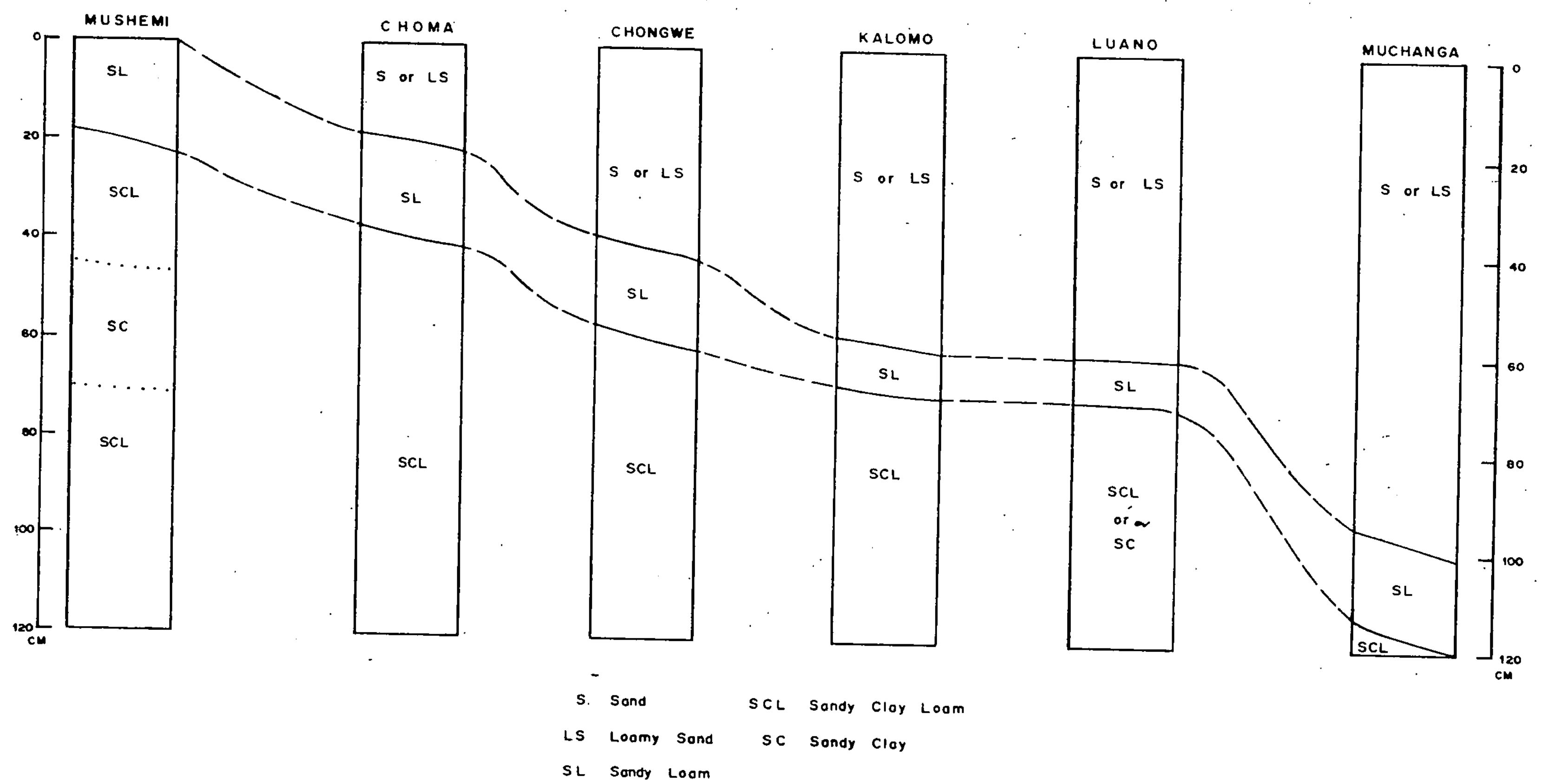
FIGURE 5

NORMAL DISTRIBUTION PATTERN OF THE SOIL ASSOCIATION AND LAND TYPES OF THE SANDVELDT CATENA



UNIT	SOIL ASSOCIATION / LAND TYPE
1	Mushemi — Choma Soil Association
2	Chongwe — Kalomo Soil Association
3	Luano — Muchanga Soil Association
4	Nsato shallow land + rock/gravel outcrops
D	Dambos

FIGURE 5A COMPARISON OF TEXTURAL PROFILES IN THE SANDVELDT CATENA



with gravel and rock outcrops (Nsato gravel), usually on the main watersheds but also frequently found on interfluve crests (particular where interfluves are narrow and slopes steep, > 3%), and as narrow bands along slope breaks.

Table 6 shows the approximate percentage of the sandveldt landform that each soil association or land-type is likely to occupy and indicates the estimated extent of each association in the Central Province.

TABLE 6:

PERCENTAGE OF LANDFORM OCCUPIED BY SOIL ASSOCIATIONS AND LAND TYPES OF THE SANDVELDT CATENA AND THEIR ESTIMATED EXTENT IN THE CENTRAL PROVINCE:

SOIL ASSOCIATION/LAND TYPE	% OF LANDFORM	EXTENT Ha
Mushemi-Choma	40	202,000
Chongwe-Kalomo	10	50,500
Luano-Muchanga	25	126,250
Nzato gravel	15	75,750
Dambos	10	50,500
	TOTAL	505,000

Figure 5 shows the normal distribution pattern of the soil associations and land-types of the sandveldt catena. The pattern illustrated represents part of the Mukonchi East Block (Clayton, 1974c) and can be correlated directly with plate 1 (page 40). The various soil series represented in the catena exhibit an increasing degree of sandiness from crest to dambo (Figure 5A) - as if a layer of clay has been lost by leaching at successive stages downslope. Detailed descriptions of each soil association follow.

THE MUSHEMI-CHOMA ASSOCIATION

This is the most important of the sandveldt soil associations as far as arable potential is concerned. It is located on the upland interfluves on the crests and upper slopes (although crests, particularly along the line of the main watersheds, are sometimes occupied by shallow gravelly soils).

The association comprises two soil series, Mushemi and Choma. It is considered that the distribution of the two series within the association is closely linked with local variations in the mineral composition of the underlying rock, Mushemi series having developed in general over rock with a relatively high concentration of dark minerals (biotite, horneblend etc.) and Choma series having developed in general over rock in which the concentration of such minerals is relatively lower and where the quartz content is relatively higher. The width of the interfluves (they vary from 0.5 to 2.0km) also seems to have some influence on the distribution of the two series, Mushemi series being generally dominant on the wider and flatter crests, Choma series often dominating the narrower crests.

MUSHEMI SERIES

Mushemi series was given 'established' status at the 1974 Zambian Soil Correlation Meeting. Previously soils with Mushemi characteristics, particularly with a sandy loam topsoil and a subsoil argillic horizon (normally sandy clay in texture) had been classified within Choma series.

The soils of Mushemi series are deep, massive in structure, very porous, well drained and of moderate permeability. Subsoil colours are generally yellowish red to strong brown (5-7.5YR 5/6) but colours in the range 5-7.5YR 4-5/4-8 are not uncommon. An organic stained sandy loam topsoil overlies a sandy clay loam upper subsoil* and sandy clay loam to sandy clay lower subsoil**. In most of the profiles described to date sandy clay dominates the lower subsoil, but sandy clay loam in the lower subsoil is accepted within the concept of the series. An argillic horizon is considered to be characteristic of the subsoil (see p100) although it does not always constitute a textural difference.

The subsoil gives way to highly weathered rock usually below 120cm (of sandy clay loam or sandy clay texture). A layer of quartz gravel is sometimes encountered where the subsoil gives way to weathered rock. Lateritic concretions sometimes occur with the gravel and weathered rock often fused together with them by iron cementation.

The soils are medium to slightly acid throughout the profile (pH 5.0-6.0). A variant of Mushemi series, at present termed the <u>Ntendere variant</u>, is strong to very strongly acid with pH in the subsoil in the range 4.0-4.6 (profile 1, Table 7 and Appendix 1).

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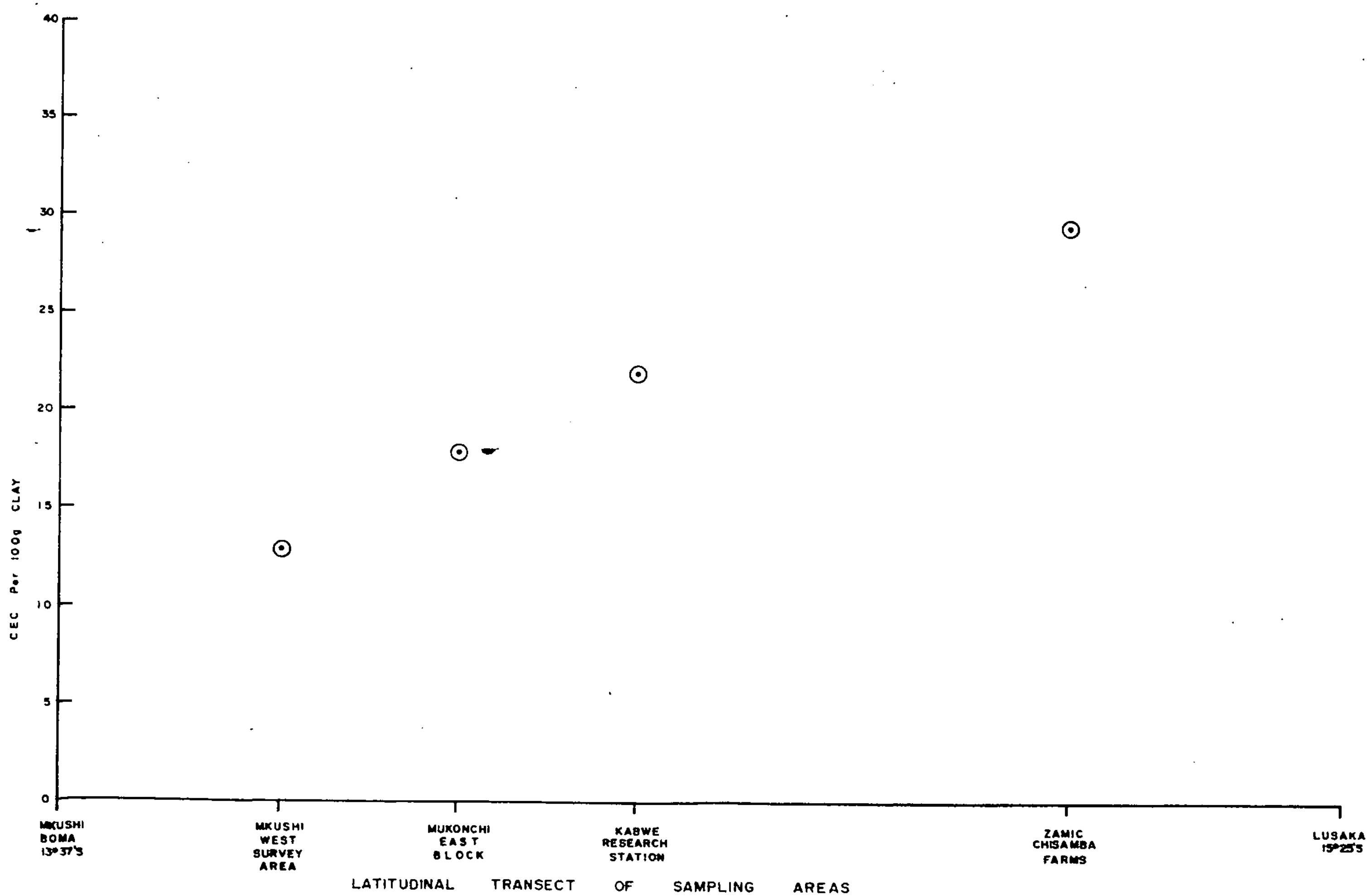
*Upper subsoil = 20-50cm.
**Lower subsoil = 50-90+cm.

FIG, 6 Overleaf

FIGURE 6

COMPARISON OF AVERAGE VALUES OF CEC per 100g CLAY (at 50cm depth) WITH LATITUDE FOR MUSHEMI SERIES.



A generalised profile description follows:

Depth (cm)	Description
0 - 10	Dark greyish brown, organic stained, sandy loam.
10 - 40	Strong brown, friable (hard when dry), sandy clay loam.
40 - 80	Same, but sandy clay.
80 - 120	Same, but sandy clay loam.
120+	Highly weathered rock (of sandy clay loam or sandy clay texture).

Analytical data for a number of profiles of Mushemi series (profiles 1-4) are summarised in Table 7. Detailed profile descriptions and analytical data are given in Appendix 1.

Cation exchange capacity (CEC) in the control section varies between 5-10m.e. percent fine earth. Whilst wide local variations in CEC percent clay occur, available data suggests that CEC percent clay at 50cm generally decreases northward, from about 33m.e. near Lusaka (profile 1) to about 22m.e. near Kabwe (profile 3) and about 13m.e. in the Mkushi West Block (profile 2). This decreases in CEC which is illustrated in Figure 6 presumably indicates increasing intensity of weathering associated with the gradually increasing rainfall between Lusaka and Mkushi.

Base saturation in the subsoil varies considerably between individual profiles (<20% in profile 1; >75% in profile 4) reflecting differences in the degree of leaching of soils developed over relatively felsic and relatively basic rocks (profiles 1 and 4 respectively).

TABLE 7: SUMMARISED ANALYTICAL DATA FOR PROFILES 1–8

Profile No.	Depth cm	Coarse Sand % 2.0–0.5 mm	Medium Sand % 0.5–0.2 mm	Fine Sand % 0.2–0.05 mm	Silt % 0.05–0.002 mm	Clay % <0.002 mm	Org.C. %	Total N %	Ca m.e.%	Mg m.e.%	K m.e.%	CEC m.e.%	BSP	pH $CaCl_2$	Av.P ppm	CEC me/100g Clay	Texture
1	0–8	9.4	27.1	40.8	11.1	11.6	0.78	0.040	1.40	0.55	0.16	4.8	44.0	5.2	26	41.4	SL
	20–34/50	14.5	18.8	29.5	11.6	25.6	0.58	0.034	0.30	0.35	0.11	4.7	16.2	4.2	3	18.4	SCL
	90–130	13.2	18.3	29.1	18.8	20.6	N.D.	N.D.	0.25	0.25	0.09	7.0	8.0	4.0	N.D.	33.9	SCL
2	0–14	23	33	27	11	6	1.25	0.076	2.95	1.00	0.62	5.2	88	5.8	44	15	LS
	14–13	22	28	21	9	20	0.47	0.030	2.20	0.81	0.55	3.8	94	6.1	32	11	SCL
	55–79	15	13	17	7	48	N.D.	N.D.	2.60	1.48	0.74	6.3	92	6.3	N.D.	13	SC
	79–107	17	13	20	10	40	N.D.	N.D.	3.05	1.18	1.87	5.1	60	6.3	N.D.	12	SC
3	0–10	7	18	52	14	9	1.01	0.070	3.7	1.3	0.6	5.4	100.0	6.3	40	60.0	SL
	23–45 *	5	10	32	12	41	0.41	0.037	2.0	1.3	0.3	7.2	49.3	5.3	20	17.6	SC
	66–96	5	10	32	12	41	N.D.	N.D.									
4	0–9	18	31	32	5	14	1.25	0.066	3.50	1.75	0.43	6.4	88.7	6.1	24	45.7	SL
	20–30	14	22	36	5	23	0.16	0.028	2.00	1.42	0.76	6.1	68.5	5.8	35	26.5	SCL
	50–80	12	19	22	5	42	N.D.	N.D.	2.70	2.00	1.26	7.5	79.5	5.7	N.D.	17.8	SC
	80–110	11	17	34	6	32	N.D.	N.D.	1.90	1.15	1.20	6.2	76.6	5.6	N.D.	19.4	SCL
5	0–10	4.4	29.4	42.6	14.4	9.2	0.86	0.056	1.95	0.40	0.28	5.8	45.4	5.2	32.5	63.0	LS
	25–43	0.3	26.2	39.2	11.1	14.2	0.57	0.028	1.15	0.12	0.06	4.2	31.7	4.4	3.0	29.5	SL
	64–90	9.6	24.5	35.1	8.6	22.2	N.D.	N.D.	0.90	0.35	0.07	4.6	28.7	4.4	N.D.	20.7	SCL
	115–144	6.4	22.5	29.0	11.9	30.2	N.D.	N.D.	0.50	0.60	0.07	5.6	20.9	4.0	N.D.	18.5	SCL
6	0–21	8.1	30.7	42.6	9.6	9.0	0.90	0.050	3.95	0.85	0.29	6.2	82.1	6.8	36	34.4	LS
	31–47	8.4	28.1	37.4	8.1	18.0	0.35	0.020	0.90	0.60	0.26	3.5	50.3	5.2	8	19.4	SL
	65–96	2.8	27.3	25.9	9.0	35.0	N.D.	N.D.	0.50	0.98	0.97	5.4	45.4	5.8	N.D.	15.4	SCL/SC
7	0–5	4.9	27.0	46.7	11.4	10.0	0.70	0.034	1.25	0.32	0.25	4.5	40.5	4.9	46	45.0	LS/SL
	18–30	5.5	24.3	46.1	8.1	16.0	0.27	0.010	0.90	0.20	0.15	3.4	36.8	5.0	14	21.0	SL
	49–70	3.3	27.2	31.1	8.4	30.0	N.D.	N.D.	1.30	0.65	0.16	5.3	40.5	5.6	N.D.	17.7	SCL
	92–119	6.2	20.4	35.6	10.8	27.0	N.D.	N.D.	0.80	1.00	0.14	4.4	44.1	6.0	N.D.	16.3	SCL
8	0–10	15	41	28	7	9	1.21	0.050	2.75	1.25	0.43	5.3	83.6	5.9	20	58	LS
	20–40	12	18	32	23	15	0.31	0.020	1.00	1.00	0.57	5.1	50.4	5.2	16	26.6	SL
	40–60	11	27	23	7	32	N.D.	N.D.	2.40	0.82	1.05	5.4	79.1	4.6	N.D.	16.1	SCL
	80–110	10	19	17	7	47	N.D.	N.D.	2.10	2.15	1.11	8.8	60.9	5.5	N.D.	18.7	SC

N.D. = Not determined
* Particle size data appears erroneus (≡ 66–96cm)

CHOMA SERIES

Choma series was established by Yager in 1967. The soils of Choma series resemble those of Mushemi series in that they are very porous and well drained and yellowish red to strong brown (5-7.5YR 5/6) in colour - the latter colour being more common. Colours in the range 5-7.5YR 4-5/4-8 are included in the series. The two series differ, however, in their textural profiles. Whereas Mushemi series has a sandy loam topsoil and a sandy clay loam upper subsoil, Choma series has a loose sandy or loamy sand topsoil overlying a loamy sand upper subsoil. The lower subsoil is sandy clay loam (and occasionally sandy clay). An essential difference in the two series is, therefore, that in Choma series sandy loam continues into the control section but does not in Mushemi series.

Highly weathered rock is usually found below 120cm. A gravel layer is sometimes encountered in the subsoil as in Mushemi series. Similarly, lateritic concretions may also sometimes occur with the gravel and weathered rock often fused together with them. The soils range from strongly to slightly acid (pH 4.5-6.0) in the subsoil, are structureless and of moderate permeability.

A generalised profile description is given below.

Depth (cm)	Description
0 - 20	Very dark greyish brown, organic stained, loamy sand.
20 - 40	Strong brown, very friable, sandy loam.
40 - 70	Strong brown, very friable (hard when dry), sandy clay loam.
70 - 120	As above (sometimes sandy clay).
120+	Highly weathered rock.

Analytical data for a number of profiles of Choma series (profiles 4-8) are summarised in Table 7. Detailed profile descriptions and analytical data are given in Appendix 1.

The CEC percent fine earth in the subsoil varies between 3-10m.e. for Choma series. Values of CEC percent clay show a similar trend to those shown by Mushemi series in that the values generally decrease with decreasing latitude, again reflecting the increased intensity of weathering with the higher rainfall in the north of the area. Values are, on average, highest towards Lusaka and lowest towards Mkushi (where they may fall below 16m.e. percent clay). The trend, however, is far less distinct than it is for Mushemi series. Indeed the occurrence of marked local variations in values is not uncommon (e.g. from 25.0 to 16.2m.e. percent clay on Chisamba Farms - see profiles 5 and 6 respectively in Appendix 1). Such local variations probably reflect local differences in the degree of leaching of soils developed over rocks with variable mineralogy.

Base saturation in the subsoil, as with Mushemi series, shows wide variations, (profiles 5 and 8) in soils developed over different rock types.

Yager (1967) originally classified Choma series as psammentic Haplustox. (USDA Soil Taxonomy). Classification is discussed in Chapter 13.

THE CHONGWE-KALOMO ASSOCIATION

The soils of the Chongwe-Kalomo association occupy a middle slope position. They are intermediate in colour, textural profile and topographical position between the soils of the Mushemi-Choma and the Luano-Muchanga associations. Chongwe and Kalomo are the two series represented, the former normally occupying approximately 75% of the association and the latter occupying the remaining 25%.

Chongwe series was given 'established' status at the 1974 Zambian Soils Correlation Meeting. The original concept of Kalomo series (established by Yager, 1967) was at the same time extended to include soils with sand extending to a depth of 60cm.

Wilson (1965) describes two variants of a soil type in a land class (class S2) mapped in the Mukonchi area which broadly correspond to Chongwe and Kalomo series. "The lighter textured soil in this class (≡Kalomo series) consists of about 20 inches of medium to coarse loamy sand or sand over sandy loam or sandy clay loam with a rather abrupt transition to the more clayey subsoil. The heavier textured variant (≡Chongwe series) in this class is about 12 inches of a medium to coarse grained sand or loamy sand over sandy loam over sandy clay loam at about 18 inches". This is the earliest (and only previous) reference to the two series occuring as an association, although Wilson treats them as textural variants of the same land class.

CHONGWE SERIES

The soils are deep, well to moderately well drained and strong brown to yellowish brown (7.5-10YR 5/6) in colour. They have a sandy topsoil with a loamy sand upper subsoil over a sandy loam to sandy clay loam lower subsoil. The soils are very porous and structureless. Permeability is rapid in the upper horizons becoming moderate in the lower ones. The soils are slightly acid to neutral in the subsoil (pH 5.0-6.5).

A generalised profile description follows:

Depth (cm)	Description
0 - 20	Dark greyish brown, organic stained, loose sand (or loamy sand).
20 - 40	Yellowish brown, extremely friable, loamy sand.
40 - 60	Yellowish brown, extremely friable, sandy loam.
60 - 100+	Yellowish brown, extremely friable, sandy clay loam.

Analytical data for two profiles (profiles 9 and 10) are summarised in Table 8. Detailed profile descriptions and analytical data are given in Appendix 1.

A gravelly laterite horizon is commonly present. It occurs at a variable depth. It is usually deeper than 120cm, but its upper surface lies between 30-75cm in the moderately shallow phase, often at only 30-50cm.

The CEC of the fine earth fraction in the subsoil is usually in the range 3-6m.e. percent. CEC percent clay in the control section ranges between 10 and 20 m.e. in profiles 9 and 10 (Table 8 and Appendix 1). There are insufficient data to indicate trends in CEC:clay ratios with climate. As with Mushemi and Choma series subsoil base saturation varies considerably (>90% in profile 9, 40-60% in profile 10).

TABLE 8: SUMMARISED ANALYTICAL DATA FOR PROFILES 9–11

Profile No.	Depth cm	Coarse Sand % 2.0–0.5 mm	Medium Sand % 0.5–0.2 mm	Fine Sand % 0.2–0.05 mm	Silt % 0.05–0.002 mm	Clay % < 0.002 mm	Org.C %	Total N %	Ca m.e.%	Mg m.e.%	K m.e.%	CEC m.e.%	BSP	pH Ca Cl2	Av.P ppm	CEC me/100g Clay	Texture
9	0–12	20	51	24	5	0	1.05	0.062	2.80	0.80	0.25	4.0	96	5.9	19	-	S
	12–31	20	45	23	6	6	0.31	0.020	1.80	0.62	0.19	2.8	93	6.3	15	29	LS
	55–90	14	30	17	5	34	N.D.	N.D.	2.40	1.62	0.57	4.5	100	6.4	N.D.	13	SCL
	90–133	13	32	22	3	30	N.D.	N.D.	2.00	0.90	0.60	3.6	100	6.5	N.D.	12	SCL
10	0–23	7.0	33.6	44.3	7.7	7.4	0.62	0.026	1.25	0.20	0.10	3.5	44.3	4.9	28.0	47.3	LS
	23–48	5.2	31.2	37.4	8.8	17.4	0.31	0.018	1.40	0.40	0.12	4.4	43.6	5.9	4.5	25.3	SL
	70–100/123	8.3	26.3	32.2	8.8	24.4	N.D.	N.D.	0.90	0.90	0.16	3.8	51.6	6.3	N.D.	15.6	SCL
	100/123–137	13.6	30.4	26.0	9.6	20.4	N.D.	N.D.	1.00	0.73	0.24	4.4	44.8	6.2	N.D.	21.6	SCL
11	0–16	4.8	37.2	45.4	7.2	5.4	0.74	0.34	1.65	0.30	0.11	4.1	50.3	4.8	33.0	29.6	S
	33–60	7.1	32.1	42.5	9.9	8.4	N.D.	N.D.	0.65	0.30	0.10	1.5	70.0	5.4	N.D.	17.9	LS
	85–120	3.1	28.2	33.4	4.9	30.4	N.D.	N.D.	1.15	1.08	0.46	5.4	49.8	5.6	N.D.	17.8	SCL
	120–170	5.0	26.1	37.0	4.5	27.4	N.D.	N.D.	0.95	0.80	0.45	4.6	47.8	5.7	N.D.	16.8	SCL

N.D. = Not determined

KALOMO SERIES

The soils are deep, somewhat excessively drained and strong brown to yellowish brown (7.5-10YR 5/6) in colour. They have sand or loamy sand to a depth of approximately 60cm over a rapidly changing textural profile through loamy sand and sandy loam to sandy clay loam. Structure is entirely lacking. The soils are very porous and permeability is rapid in the upper horisons becoming more moderate in the lower ones. A gravelly lateritic horizon usually occurs below 120cm. The soils are medium to slightly acid in the subsoil (pH 4.0-6.0).

A generalised profile description follows:-

Depth (cm)	Description
0-15	Dark greyish brown, organic stained, loose sand.
15-60	Yellowish brown, loose sand.
60-70	Yellowish brown, loamy sand.
70-80	Strong brown, sandy loam.
80-120+	Strong brown, sandy clay loam.

Analytical data for Kalomo Series (profile 11) is summarised in Table 8. A detailed profile description and analytical data is given in Appendix 1.

The CEC percent fine earth in the subsoil is usually in the range 1.5-5.5 m.e. Data is available for only a restricted number of profiles and trends regarding CEC percent clay cannot be established. In general, however, values are mainly above 16 m.e. percent clay (profile 11, Table 8 and Appendix 1).

Variations in base saturation are wide. In profile 11 it is in the range 50–70%.

Yager (1967) considered these soils to be Oxic Ustropepts but this is doubtful since the temperature range is too great for them to be classified as 'Tropic' *.

THE LUANO - MUCHANGA ASSOCIATION

The soils of this association occupy lower slope positions often immediately below laterite outcrops and spring lines. They often cover the entire dambo head. They may occupy either narrow strips only a few metres wide at the dambo margin, or belts of over a hundred metres in width extending well into the woodland. Slopes are generally 1–2 percent.

The soils of both series have an abrupt textural change from sand to sandy clay loam or sandy clay in the subsoil. At depth is strongly mottled highly weathered rock of sandy clay loam to sandy clay texture. The upper layers comprise coarse sandy material.

The main difference between the two series is the depth at which the sandy material abruptly overlies the strongly mottled heavier material (at approximately 70cm for Luano series and below 100cm for Muchanga series).

Detailed descriptions of each series follow:

LUANO SERIES

The series was established by Yager in 1967. The soils are imperfectly to poorly drained. The topsoil is usually a

*By definition Tropepts require an isomesic or warmer iso temperature regime and sandveldt soils are considered to have a thermic temperature regime (see page 100, and Appendix 6).

very dark grey (10YR 3/1) organic stained sand. Pale brown to light grey (10 YR 6/3-7/2) or light yellowish brown (2.5Y 6/4) coarse sand or loamy sand lies below and extends to approximately 60-70cm where it rests, with an abrupt wavy boundary, on sandy clay loam or sandy clay.

The sandy horizons are completely structureless and are normally strongly mottled from 30cm. The heavier lower horizons are massive in structure and have a greyish matrix and are similarly mottled to the overlying sandy horizons. Mottling colours are generally yellowish brown to strong brown. The soils are strongly to slightly acid (pH 4.5-6.0) in the subsoil.

Permeability is rapid in the upper sandy horizons and very slow in the lower heavier horizons. According to Yager (1967) bulk density in the topsoil in undisturbed areas ranges between 0.80 and 1.2 g/cm^3 while that of the heavier subsoil is quite high and ranges between 1.6 and 1.8 g/cm^3 (sometimes reaching 2.1 g/cm^3). The CEC ranges generally between 1 and 5 m.e. percent soil in the sandy horizons and between 5 and 10 m.e. percent soil in the heavier lower horizons. According to Yager (op.cit.) the CEC percent clay in the heavier horizons is below 16 m.e., usually between 10 and 13 m.e., In soils sampled by the author, CEC/clay ratios ranged between 13-30 m.e. in the heavier horizons.

Analytical data for Luano Series (profile 12) is summarised in Table 9. A detailed profile description and analytical data is given in Appendix 1.

A general profile description follows:-

Depth (cm)	Description
0 - 10	Very dark grey, organic stained, loose sand.
10 - 65	Pale brown, mottled, loose sand.
65 - 70	Light grey, mottled, loose loamy sand to sandy loam.
70 - 120	Light grey, mottled, very friable sandy clay loam to sandy clay.

Yager (op. cit.) tentatively placed Luano series in the Umbraquox (USDA Soil Taxonomy) on the basis of oxic properties in the 75-100 cm layer. Since the CEC percent clay exceeds 16 m.e. in the author's soils, they are regarded as Typic Albaqualfs (USDA Soil Taxonomy) and Eutric Gleysols (FAO - Unesco legend). Classification and genesis is discussed in Chapter 13.

TABLE 9: SUMMARISED ANALYTICAL DATA FOR PROFILES 12 and 13.

Profile No.	Depth cm	Coarse Sand % 2.0–0.5 mm	Medium Sand % 0.5–0.2 mm	Fine Sand % 0.2–0.05 mm	Silt % 0.05–0.002 mm	Clay % < 0.002 mm	Org.C. %	Total N %	Ca m.e.%	Mg m.e.%	K m.e.%	CEC m.e.%	BSP	pH $CaCl_2$	Av.P ppm	CEC me/100g Clay	Texture
12	0–10	7	34	50	6	3	0.82	0.042	2.30	2.00	0.15	6.0	74.2	5.1	1	106	S
	20–30	10	36	45	5	4	0.31	0.020	0.70	0.55	0.11	2.4	56.7	5.5	1	33	S
	65–77	6	27	44	6	17	N.D.	N.D.	1.20	0.82	0.65	5.0	53.4	4.7	N.D.	29	SL
	77–90	5	19	44	6	26	N.D.	N.D.	1.95	1.25	0.90	7.6	53.9	4.7	N.D.	29	SCL
13	0–10	8	26	57	8	1	0.09	0.048	3.70	1.08	0.20	8.2	60.7	5.0	1	-	S
	30–50	15	28	48	6	3	N.D.	N.D.	1.00	0.65	0.14	1.1	100.0	6.4	N.D.	37	S
	90–110	7	20	56	6	11	N.D.	N.D.	1.30	1.45	0.63	4.4	76.8	5.7	N.D.	40	LS
	100+	8	22	46	8	16	N.D.	N.D.	2.90	1.48	0.74	5.4	94.8	4.5	N.D.	34	SL

N.D. = Not determined.

MUCHANGA SERIES

The series was given 'established' status at the 1974 Zambian Soils Correlation Meeting. The soils are imperfectly to poorly drained. They comprise a loose light grey to grey (10YR 7/1-6/1) sand becoming almost white (10YR 8/1) below 30cm and extending to approximately 100cm where it may grade into loamy sand and sandy loam, before abruptly overlying sandy clay loam. This abrupt change to heavier texture often occurs below 120cm and is accompanied by a marked increase in CEC and exchangeable calcium. Distinct yellow (10YR 7/6) mottles are found below 70cm. The topsoil is sometimes covered by a 1cm layer of coarse white transported sand. Structure is completely lacking in the sandy horizons but may be massive at depth in the sandy clay loam. Permeability is rapid in the sandy horizons becoming slow in the deeper heavier horizons.

pH ranges from 4.5 to 6.5. Analytical data for Muchanga series (profile 13) is summarised in Table 9. A detailed profile description and analytical data is given in Appendix 1.

A generalised profile description follows:

Depth (cm)	Description
0 - 10	Brownish grey loose sand
10 - 30	Light grey loose sand
30 - 70	Whitish loose sand
70 - 100	Whitish and light grey, mottled sand
100+	Ditto, but becoming loamy sand and heavier, before abruptly overlying sandy clay loam.

The soils of Muchanga series are considered to be Typic Psammaquents (USDA Soil Taxonomy) and Eutric Gleysols (FAO - Unesco Legend).

LAND TYPES OF THE SANDVELDT CATENA

NSATO GRAVEL

This land type is mostly confined to broad watersheds but is also frequently found on interfluve crests, particularly where they are narrow and where slopes are steep (>3%), and as narrow bands along slope breaks.

It comprises shallow light textured soils with gravel at or above 30cm depth and with extensive gravel, and sometimes rock, outcrops.

Yager established Nsato series in 1967 and stated that "large areas of Nsato soils occur in complex with Miscellaneous Land Types such as Rock Land, Rock Outcrop, Rubble Land, etc., and a shallow to moderately shallow soil". Nsato was discontinued as a soil series at the 1974 Zambian Soil Correlation Meeting but the name was retained for the sandveldt land type which includes the shallow soils and outcrops as described above. Soils of the Nsato gravel land type are Lithic Ustorthents (USDA Soil Taxonomy) and Lithosols (FAO - Unesco legend).

DAMBOS

Little soil investigation work has been carried out in the dambos due to their low arable potential. Webster (1965) considers that the dambo soils are the hydromorphic counterpart of Trapnell's plateau soils. In the Lusaka-Mkushi area sandveldt dambo soils consist of a thin, dark organic-stained surface horizon underlain by a pale-grey or bleached sandy clay, nearly always strongly mottled. Indications of ferrolysis* are common. According to Trapnell (1957), "there are zonal differences from dambo margin to centre according to the degree of water logging during the rains". Trapnell classified these soils as Grey Dambo Soils and noted that "the majority are sour soils, although sandier incised dambos with sloping flanks allow a native ridge cultivation of root crops along their margins".

Dambos in the Central Province are subject to seasonal imperfect drainage but most dry out after the rains. The few sandveldt dambo soils examined in the Central Province are probably Typic Haplaquents (USDA Soil Taxonomy).

*Ferrolysis: A process of clay destruction or alteration taking place during alternating cycles of reduction and oxidation (Brinkman, 1970).

CHAPTER 12

ASSOCIATED SOILS

Survey work throughout the Central Province has revealed a range of sandveldt soil types which do not seem to be part of the general sandveldt catena described in Chapter 11, the extent of which are not fully known at present. They are described below.

PEDIMENT SOILS

Such soils occur as a narrow band developed on the pediments at the foot of the linear hills which are characteristic of the Lusaka -Mkushi area. The pediments probably developed under past semi-arid conditions, but have weathered under later, more humid, conditions. They resemble Choma series texturally and in being deep to moderately deep and very well drained. They are distinguished from Choma series on the basis of colour being distinctively red to yellowish red. (2.5-5YR 5/6) and by the absence of lateritic gravel in the subsoil. They comprise a sandy or loamy sand topsoil with a sandy loam to sandy clay loam upper subsoil and a sandy clay loam lower subsoil. The soils occur on slopes of 1-3 percent, occasionally steeper. Acidity in the subsoil ranges from medium to slight (pH 5.0-6.0). Porosity is high and permeability rapid.

A generalised profile description follows:

Depth (cm)	Description
0 - 20	Dark reddish brown, organic stained, loose sand.
20 - 35	Reddish brown, very friable, loamy sand.

35 - 50	Red, very friable, sandy loam.
50 - 150	Red, very friable, sandy clay loam to sandy clay.

Only a limited amount of data is available at present. Analytical data for a typical profile (profile 14) is summarised in Table 10. A detailed profile description and analytical data is given in Appendix 1.

KABWE SERIES

This series was established by Yager in 1967 and takes its name from Kabwe Research Station which is located on a sizeable area of this soil (Haugbotn 1974b). Kabwe series, according to Yager (op. cit.) is one of the soils formerly considered within Trapnell's (1957) "Pallid Plateau Soils". The soils occur in association with the well drained soils of the Mushemi-Choma association and the Chongwe - Kalomo association and with the Nsato gravel land type as well as with the more poorly drained soils of the Luano - Muchanga association.

The soils of Kabwe series are generally deep. The topsoil consists of sand or loamy sand which is generally very dark greyish brown (10YR 3/2) in colour but includes colours in the range 10YR 2-5/1-2. This is underlain by a generally light coloured, usually brown (10YR 5/3), loamy sand or sandy loam. This gives way, at depths ranging from 35 to 60cm, to a pale brown to yellowish brown (10YR 6/3 - 5/4 , but including colours in the range 10YR - 2.5Y 5-6/3-8) sandy clay loam or sandy clay. The lower subsoil is characterised by prominent red, yellowish red, reddish brown, and/or brown, and grey mottles. In many profiles it is difficult to

TABLE 10: SUMMARISED ANALYTICAL DATA FOR PROFILES 14-17

Profile No.	Depth cm	Coarse Sand % 2.0–0.5 mm	Medium Sand % 0.5–0.2 mm	Fine Sand % 0.2–0.05 mm	Silt % 0.05–0.002 mm	Clay % <0.002	Org.C. %	Total N %	Ca m.e.%	Mg m.e.%	K m.e.%	CEC m.e.%	BSP	pH Ca Cl_2	Av.P ppm	CEC me/ 100g Clay	Texture
14	0-18	5.5	30.5	46.2	9.2	8.6	0.66	0.032	2.20	0.30	0.24	4.7	58.3	N.D.	70	54.6	LS
	37-49	6.2	30.2	35.1	7.9	20.6	0.31	0.022	1.50	0.40	0.27	5.0	43.4	5.0	34	24.3	SL/SCL
	78-115	4.1	31.5	31.5	6.3	26.6	N.D.	N.D.	1.10	0.78	0.18	7.4	27.8	6.0	N.D.	27.8	SCL
	150-190	5.9	21.5	35.2	9.8	27.6	N.D.	N.D.	0.40	0.40	0.17	4.3	22.6	5.3	N.D.	15.6	SCL
15	0-7	2	38	48	8	4	1.11	0.048	2.5	0.6	0.1	5.9	54.4	5.4	20	52.5	S
	18-34	3	31	54	8	4	0.15	0.010	0.6	0.4	0.05	1.2	77.5	5.8	18	30.0	S
	54-63	5	37	34	11	13	N.D.	N.D.	1.3	0.8	0.2	3.1	70.9	5.6	N.D.	23.8	SL
	80-100	8	31	24	11	26	N.D.	N.D.	1.5	1.1	0.3	6.0	46.5	5.5	N.D.	23.1	SCL
17	0-20	5	26	54	11	4	0.41	0.024	1.0	0.3	0.1	2.2	60.4	5.4	12	55.0	LS
	38-55	5	26	54	11	4	N.D.	N.D.	0.7	0.4	0.1	1.6	70.6	5.1	N.D.	40.0	LS
	75-94	3	26	43	11	17	N.D.	N.D.	1.3	0.7	0.2	3.8	56.0	4.8	N.D.	22.4	SL
	138-180	9	28	43	8	12	N.D.	N.D.	0.9	0.6	0.1	2.4	60.8	4.8	N.D.	20.0	SL
		Coarse Sand % 2.0–0.2 mm	Fine Sand % 0.2–0.02 mm	Silt % 0.02–0.002 mm	Clay % <0.002 mm												
16	0-25	56	38	1	5		0.35	0.026	1.0	0.1	0.1	1.4	84	6.3	N.D.	-	S
	25-60	60	32	1	7		0.12	0.022	0.5	0.1	0.1	1.2	57	6.3	N.D.	17	S
	60-100	57	32	2	9		0.08	0.016	0.13	traces	0.2	1.2	43	5.6	N.D.	13	LS
	125-150	52	38	2	8		0.12	0.014	0.5	0.1	0.1	0.8	76	5.8	N.D.	10	LS

N.D. = Not determined.

determine the matrix colour as it is nearly equal parts of red, browns and greys.

The upper horizons are structureless but the heavier lower subsoil has a weak subangular blocky structure and is friable when moist. Drainage ranges from somewhat poor to moderately good. Permeability is rapid in the upper horizons becoming moderate in the lower ones. The series usually occurs on slopes of less than 1 percent. Acidity ranges from strong to neutral (pH 4.5-6.5).

A generalised profile description is given below:

Depth (cm)	Description
0 - 10	Very dark greyish brown sand or loamy sand.
10 - 35	Brown loamy sand.
35 - 60	Yellowish brown sandy loam
60 - 120	Yellowish brown mottled sandy clay loam.

Analytical data for Kabwe series (profile 15) is summarised in Table 10. A detailed profile description and analytical data is given in Appendix 1.

CHAPYA SERIES

This series was recognised by Haugbotn (1974b) at Kabwe Research Station and is associated with Kabwe series. The description which follows is based on that of Haugbotn (op. cit.).

Chapya series is a moderately well drained soil with sandy loam texture even in the lower part of the control section. It is a mainly deep soil but the depth to gravel varies within short distances.

The soil has a dark greyish brown (10YR 4/2) loamy sand topsoil and a yellowish brown (10YR 5/4) loamy sand upper subsoil. The change in texture is gradual and the loamy sand may extend as deep as 80 cm. The lower subsoil is a light yellowish brown to light grey (2.5Y 6/4–7/2) sandy loam or sandy clay loam and has distinct yellowish red mottles. Structure is massive in the main but the lower part of the control section may have a very weak subangular blocky structure. Slopes are usually less than 1 percent. Acidity ranges from strong to medium (pH 4.5–5.5).

A generalised profile description follows: Analytical data for a typical profile (profile 17) is summarised in Table 10. A detailed profile description and analytical data is given in Appendix 1.

Depth (cm)	Description
0 – 75	Dark greyish brown to yellowish brown, loamy sand.
75 – 130+	Light yellowish brown sandy loam, yellowish red mottles.

KABUYU SERIES

This series was established by Yager in 1967. It consists of deep, loose, structureless quartz sands and loamy sands, occupying nearly level to gently undulating upland sites with slopes between 1 and 3 percent. The topsoil is usually a brown (7.5YR 5/4–4/4) sand (colours in the range 10YR – 5YR 3–4/3–4 are included). Sand or loamy sand extends to below 120cm with colours generally in the range 7.5YR 4–6/4–8 but becoming gradually paler with depth. Subsoil boundaries are diffuse. According to Yager (op. cit.), the pH ranges from

4.9 to 6.4 in the topsoil and from 4.6 to 6.3 in the subsoil. Permeability is rapid and drainage excessive.

Analytical data for Kabuyu Series (profile 16) is summarised in Table 10. A detailed profile description and analytical data is given in Appendix 1. A suitable profile from the Central Province is not available. Profile 16 is from the Southern Province where rainfall is significantly lower than in the Lusaka - Mkushi area.

A generalised profile description follows:

Depth (cm)	Description
0 - 40	Brown sand.
40 - 120+	Strong brown loamy sand.

The extent of this series is unknown but during survey work it was noted that narrow bands of these soils are sometimes associated with the Chongwe-Kalomo association. Yager (1967) considered them to be Typic (or Oxic) Quartzipsamments (USDA Soil Taxonomy).

CHAPTER 13

SOIL GENESIS AND CLASSIFICATION

GENESIS

Climate and geology are important factors in soil formation in Zambia and their effects on the genesis of sandveldt soils have been described in Chapter 9.

Sandveldt soils are generally acid, low in exchangeable bases and low in organic matter content. Trapnell (1957) recognised their low fertility and described them as "eluvial soils formed through long periods of seasonal leaching on a maturely eroded topography".

Webster (1965) concluded that sandveldt soils in a catena developed on gneiss at Masaiti near Ndola were autochthonous since heavy minerals (sp. gr. $>$ 2.9) counts showed that the same minerals occurred in roughly the same proportions in both the profiles studied and the underlying rock.

By comparison, Watson (1964/5), from a study of a catena of similar soils on granite in Rhodesia, suggested an evolutionary sequence of soil formation since Tertiary times. The sequence suggested involves various phases of erosion, planation, deposition, weathering and laterite formation, with soil formation attributed to the seventh phase.

The divergent conclusions of Webster (op. cit.) and Watson (op. cit.) reflect their difference of approach - the former concentrating on the pedological characteristics of the upper 200cm whilst the latter included the upper 200cm within the 'mineral horizon', a single layer amongst a number of others.

Central Province sandveldt soils have developed over a range of intermediate and felsic (Basement Complex) rocks containing variable amounts of biotite, hornblende and other dark minerals which release supplies of bases and iron on weathering.

The supply to the soil of bases and iron is, therefore, modest where soils are moderately leached. The relatively high silt content of such soils (profile 3) suggests that mineral weathering is still incomplete, so that supplies of calcium and magnesium, etc., are probably still being released to replace those lost by leaching, thus maintaining a relatively high base saturation and slight to medium acidity. Cation exchange capacities of 20 m.e. percent clay or more in such soils (profile 3) indicate the presence of a proportion of illite, vermiculite or montmorillonite together with a predominantly kaolinitic clay, but similar figures could also be provided by a purely kaolinitic clay supplemented by exchange capacity contributed by the silt fraction. This requires investigation.

In the more strongly leached sandveldt soils with long-continued development on the plateau surface, probably including periods of more severe leaching than the present during Pleistocene pluvials, weathering has advanced to the stage where there is a far greater proportion of insoluble residues (quartz sand and gravel, kaolinitic clay, iron hydroxide and presumably aluminium hydroxide). The clay fraction has a significantly lower cation exchange capacity than in moderately leached soils, approximately 10-15 m.e. percent clay (profile 2, Appendix 1).

To the eye moderately and strongly leached sandveldt soils are indistinguishable. They have the same physical characteristics and occupy identical topographical positions. They often occur in fairly close proximity and their distribution is related to variations in the dark mineral content of the underlying parent material.

The upper horizons of the soils of the sandveldt catena show an increased degree of sandiness from crest to lower slope (see figure 5A, Chapter 11). This is probably due to the increasing effect of weathering downslope. Clay destroyed in the upper horizons would have been leached to lower horizons leaving residual sandy material. The effect is most marked in the soils of Luano and Muchanga series.

Both Luano and Muchanga series have a distinctive profile with an abrupt change from light grey or whitish sand to strongly mottled sandy clay loam or sandy clay in the subsoil. The sand is residual. Both series occupy seepage zone sites at dambo margins and have been subject to excessive leaching of fine particles. This leaching can be attributed to weak aggregation of materials by ferric iron in these seasonally wet sites. Ferrolysis may also have been involved in clay destruction leaving residual clay and silt (silica aggregates) to be subsequently leached. Yager (1967) describes a Luano series profile from Southern Province with subsoil bulk density ranging between 1.6 and 2.1. These figures suggest the influence, or former influence, of sodium in clay dispersion. Central

Province profiles are considerably less dense in the heavier subsoil and sodium influence is not likely. It is, therefore, probable that future investigations will reveal the need to split Luano series to differentiate between sodic and non-sodic affected soils.

A common feature of sandveldt soils is the presence of a hardpan, especially in old Chitemene gardens. It is probably attributable to slight baking of the soil under the intense heat of the fires rather than to illuviation of fine material from the topsoil during the exposed cultivated phases. The resulting ash cover followed by a dense crop cover would tend to aggregate and protect the soil against clay eluviation.

CLASSIFICATION

Webster (1965) considers that the sandveldt soils conform to the definition of 'Soils Ferralitiques' of the Soil Map of Africa (d'Hoore, 1960) with dambo soils as their hydromorphic counterparts. The Soil Map of Zambia (Department of Agriculture, Lusaka, 1965) uses, in part, the CCTA legend of the Soils Map of Africa (d'Hoore 1964) and shows the Lusaka-Mkushi area to be mantled by "Undifferentiated Ferrallitic Soils" and "Undifferentiated Ferrisols".

Botelho da Costa (1965) in discussing plateau soils in Angola recognised the difficulty of classifying ferrallitic soils in terms of the USDA Soil Taxonomy. He describes two broad categories of soil - those typifying ferrallitic soils which are clearly Oxisols and those which are not Oxisols and do not fall within the definition of any of the Soils Orders of the USDA system.

Young (1977) also recognised this problem and distinguishes between "leached ferrallitic soils" and "weathered ferrallitic soils". Whilst the two types share a general absence of weatherable minerals and low CEC, the latter may have saturation values above 40 percent and lack stable microstructure. The leached ferrallitic soils are considered to be those typifying ferrallitic soils and to result from "very intensive current processes" whilst the weathered ferrallitic soils are considered to "result from long-contained processes of moderate intensity".

The sandveldt soils of the Lusaka-Mkushi area generally seem to conform to Young's weathered ferrallitic soils whilst the intensely leached sandveldt soils of Zambia's Northern Province would appear to conform more to Young's leached ferrallitic soils.

Neither the USDA Soil Taxonomy nor the FAO - Unesco classification are very satisfactory for categorising sandveldt soils since no one class in either system adequate covers their characteristic range of properties. For international correlation purposes, however, it is sometimes deemed desirable to attempt classification using these two systems.

Certainty of classification within these two systems is difficult and the correlations made in Table 12 (p103) must be regarded and tentative and provisional. This is partly due to the lack of laboratory data required to establish or confirm certain properties used as classification criteria and partly because of the present lack of information on soil temperature and moisture regimes which determine placement of many soils at great group and subgroup levels in the USDA Soil Taxonomy. Some of the major problems in correlating the soils with two classification systems are discussed below.

Argillic Horizon: The presence of an argillic horizon is diagnostic for Alfisols and Utisols (USDA Soil Taxonomy) and for Luvisols and Acrisols (FAO - Unesco legend).

The recognition of argillic horizons in the field depends on the recognition of illuvial clay coatings on ped faces and pore walls, but this was difficult to do with confidence in sandveldt soils, especially since they are structureless and were usually sampled when dry. Thin section studies and laboratory data giving fine clay to total clay ratios (neither of which were available) are needed for certainty. The presence of an argillic horizon has, therefore, been assumed in most sandveldt soils, based on laboratory data showing a sufficient increase in clay content between topsoil and subsoil and a clay rich subsoil horizon, and on an assumption of the presence of clay coatings based on field observations and on correlation with similar soils elsewhere in which such coatings have been seen (Brammer, 1973).

Temperature regime: Data for soil temperature at 50cm, as required for use in the USDA Soil Taxonomy, are lacking in Zambia. Readings at 60cm taken at Mt. Makulu Research Station during the period March - November 1973 are the only data available for plateau conditions (Brammer 1973a, p8). They show a range between 19.2° and 26.2°C for the coldest and hottest months (July and October). The mean air temperatures for these months were 16.5° and 24.8°C respectively (compared with long-term averages of 18.2° and 25.1°C respectively). The mean annual air temperature at Mt. Makulu is 20.6°C. These data suggest that Mt. Makulu is on the boundary between thermic+ and hypothermic+ soil temperature regimes, and is close to that for isothermic+ and isohyperthermic+ regimes. Since mean annual temperature on the plateau in Central Province is below 22°C and the range between the hottest and coldest months is more than 5°, it has been assumed that plateau soils in the Central Province have a thermic regime.

On this basis no sandveldt soils are classified as Tropepts (see p82) or in the tropic great groups.

<u>Moisture Regime:</u> No measurements have been made of actual moisture regimes but Brammer (1973b) assumed on the basis of field observations made during surveys, and on the assumption that the temperature regime was thermic, that most Zambian upland soils have an 'ustid'* moisture regime. Poorly drained and dambo soils may have other moisture regimes (udic, perudic or aquic**)

As mentioned above the USDA Soil Taxonomy and the FAO - Unesco legend are both unsatisfactory for classifying sandveldt soils in Central Province.

The specific chemical characteristics of different individual profiles vary quite considerably. In the subsoil base saturation ranges from above 85 percent to below 25 percent

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+Temperature Regimes: See Appendix 6.
*,**: Moisture " : " " "

and CEC percent clay ranges between 40 m.e. and 12 m.e. (occasionally below). Individual profiles (even within the same series) may, therefore, be classified either within Alfisols or Ultisols (USDA), or within either Luvisols or Acrisols (FAO - Unesco). Although some profiles have CEC percent clay ratios below 16 m.e. they have been excluded from the Oxisols (USDA) and Ferrasols (FAO - Unesco) on the basis of an assumed argillic subsoil horizon, as discussed above.

Table 12 correlates the soil series and land types described in Chapters 11 and 12 with both classification systems. It illustrates the general difficulty of applying 'artificial' (as opposed to 'natural' and 'genetic') systems of classification to sandveldt soils. It also illustrates the fact that sandveldt soils in the Central Province, particularly those towards the north, are transitional between the strongly leached soils of the Northern Province and the more moderately leached soils of Southern Province, and, therefore, possess characteristics of both types.

TABLE 12: INTERNATIONAL CLASSIFICATION CORRELATION

PROFILE	SERIES/LAND TYPE	U S D A SOIL TAXONOMY	FAO - UNESCO LEGEND
1	Mushemi	Typic Haplustult	Ferric Acrisol
2	Mushemi	Oxic Haplustalf	Ferric Luvisol
3	Mushemi	Oxic Haplustalf	Ferric Luvisol
4	Mushemi	Oxic Haplustalf	Ferric Luvisol
5	Choma	Oxic Haplustult	Ferric Acrisol
6	Choma	Oxic Haplustalf	Ferric Acrisol
7	Choma	Oxic Haplustalf	Ferric Acrisol
8	Choma	Oxic Haplustalf	Ferric Luvisol
9	Chongwe	Oxic Haplustalf	Ferric Luvisol
10	Chongwe	Oxic Haplustalf	Ferric Acrisol/Luvisol
11	Kalomo	Oxic Haplustalf	Ferric Luvisol
12	Luano	Typic Albaqualf	Ochric Planosol
13	Muchanga	Typic Psammaquent	Eutric Gleysol
14	Pediment soil	Oxic Haplustalf	Ferric Luvisol/Acrisol
15	Kabwe	Arenic Haplustalf	Ferric Luvisol
16	Kabuyu	Ustoxic Quartzipsamment	Xanthic Ferralsol
17	Chapya	?	Ferric Luvisol?
	Dambos	Typic Haplaquents	? Gleysols
	Nsato gravel	Lithic Ustorthents	Lithosols

CHAPTER 14

INFILTRATIONS STUDIES AND PHYSICAL INVESTIGATIONS

INFILTRATION STUDIES

Water infiltrations studies on Mushemi and Choma series at Chisamba Farms show that infiltration rates are higher on uncleared and newly cleared land than on long-cultivated land (Table 11 below).

In both cases, infiltration rates decrease with time.

TABLE 11. INFILTRATION RATES ON MUSHEMI AND CHOMA SERIES

Site	Soil Series	Vegetation or land use	Mean Infiltration Rate cm/hr	
			First hour	Third hour
Pit 1	Choma	Long Cultivated	3.5	1.3
Pit 2	Mushemi	Long Cultivated	12.5	2.9
Pit 3	Choma	Long Cultivated	4.0	1.5
Pit 9	Choma	Newly Cleared	20.4	9.2
Pit 10	Mushemi	Newly Cleared	13.8	5.5
Pit 11	Choma	Miombo Woodland	30.7	9.3
Pit 12	Mushemi	Newly Cleared	16.4	8.8

Note: Detailed results are given in Appendix 4.

Infiltration is a reflection of the physical condition of the soil and these results, therefore, suggest that soil structure has deteriorated in those soils which have been continuously cultivated for many years.

PHYSICAL INVESTIGATIONS

Core samples were taken in respect of Mushemi and Choma series from those soil pits on which the infiltration studies were based, and were used for bulk density determinations.

Particle size, porosity, moisture retention at $\frac{1}{3}$ and 15 bars pressure, and soil texture were also determined. The results of these investigations are tabulated in Appendix 5.

Bulk density is quite high even in the topsoil (average 1.5). This is due to the compact nature of the soil surface which also shows little sign of aggregation. Organic matter is low in most cases.

An interesting feature in the decrease in bulk density with depth and a concurrent increase in total porosity in almost all profiles studied.

Compact surface layers are probably due to tractor and tillage implements causing disaggregation of soil particles aided by depletion of organic matter. This compaction in reducing pore space increases bulk density and thereby explains the lower infiltration rates mentioned above.

In the soils studied, the moisture retained at $\frac{1}{3}$ and 15 bars* ranged from 14 to 20 percent and from 4 to 8 percent respectively up to the depths of about 40 cm.

Available moisture varied from 6 to 13 percent. Moisture retained at $\frac{1}{3}$ bar increased with increasing clay content in most of the soils but this was not so with the amount of available moisture. When crops are to be grown in the dry season, frequent irrigation will have to be given to meet the moisture requirements of the crops.

*Moisture retained at $\frac{1}{3}$ bar pressure gives the approximate field capacity of the soil (i.e. upper limit of available moisture). The 15 bar percentage is a reliable estimate of wilting point.

PART FOUR : AGRICULTURAL EVALUATION

CHAPTER 15

LAND USE CAPABILITY

During the course of survey work, and as part of a general objective to make soil information more readily understandable to non-specialists involved in planning, an improved land capability classification was devised for Zambia.

The old CONEX* classification provided a useful basis. This had four classes of arable land (ranging from good to poor) and four classes of non-arable land (suitable for grazing or forestry, if usable at all). The classification which was developed and which is used in this thesis uses two classes of arable land (good, and moderately good) and two classes of marginal arable land (poor, and very poor) each divided into sandy and clayey types; and there are classes for grazing and land unsuitable for any form of agriculture (mainly rocky hills).

The classification system is designed to indicate the relative suitability of land for rain-fed, medium and large-scale commercial farming.

For arable land, maize, tobacco and to a lesser extent, soya beans, sunflower and groundnuts are the main cash crops considered. The use of ox or tractor cultivation and adequate use of fertilizers, pesticides and weed-control measures are assumed, together with a high level of management or technical supervision which will ensure that the land does not deterior-

*CONEX: Federal Department of Conservation and Extension.

ate under arable use. For non-arable land, it is assumed that grazing will be the major use and that this will be practised in such a way that the land does not deteriorate, whether under intensive or extensive grazing management.

This classification places greater stress on soil physical factors than on chemical fertility. Factors such as texture, gravel content and depth to a limiting horizon determine the ability of the soil to store water for crop use - without which no amount of chemical fertility will produce high crop yields. Factors such as slope, topsoil texture and subsoil permeability affect water infiltration, and consequently, susceptibility to run-off and erosion, and therefore the need for conservation works of various types. Soil physical properties such as texture, depth and, to a large extent, permeability are permanent features, difficult and expensive if not impossible to alter whereas chemical fertility can readily be altered by fertilizer applications.

THE CLASSIFICATION

The primary division is into arable, grazing and unsuitable land classes. This division reflects the degree of limitation present. It is based on freedom of choice of crops and management practices but with long-term safe use as the guiding principle.

Arable and marginal arable classes are separated into sandy or clayey types (bearing symbols S and C respectively) since sandy and clayey soils in Zambia tend to have different management requirements and to be suitable to different kinds of crop. All land classes are divided into subclasses on the basis of limitations.

The sandy types, into which all sandveldt soils fall, are distinguished on the basis of their topsoil texture being lighter than sandy clay loam; are generally developed over granites, acid gneisses, mica-schists, phyllites, quartzites and sandstones, or in colluvium/alluvium derived from such rocks; and carry Brachystegia-Julbernardia woodland. The clayey types have sandy clay loam or heavier topsoil textures; are generally developed over basic rocks; and carry Acacia - Combretum woodland.

ARABLE LAND

Classes C1,S1. Good Arable Land

Land capable of being maintained at a high level of productivity under an intensive cropping system. There are no special limitations, but good management should include normal soil conservation practices, adequate use of fertilizers and lime as well as suitable crop rotations.

Classes C2,S2. Moderately Good Arable Land

Land capable of being maintained at a high level of productivity under an intensive cropping system, but requiring special attention to soil conservation or management because of moderate limitations in respect of erodibility or wetness; or land capable of being maintained at only a moderate level of productivity due to limitations of depth, texture,wetness,etc. Response to improvements in management is high.

MARGINAL ARABLE LAND

Classes C3,S3. Poor Arable Land

Land with severe limitations for cultivation which either greatly increase the costs of production (due to cost of erosion control, drainage, liming, etc.) or reduce yields to marginal levels (due to droughtiness, wetness, salinity, difficulty of seed-bed preparation, etc.) or severely restrict the range of crops that can be grown satisfactorily.

Class S4 (No C4) Very Poor Arable Land

This class is restricted to deep Barotse (defined in Glossary) sands or other very deep sands occuring in moderate to high rainfall areas (probably more than 800mm (c.32in) annually).

The soils are easily cultivated but because of extremely low fertility and droughtiness, the range of crops that can be successfully grown is severely limited and does not include any of the general agricultural crops considered in the classification.

GRAZING LAND

Land subject to one or more severe limitations which preclude its sustained arable cropping. These limitations may be in respect of any of those defined below under land capability subclasses (except z).

Classes Gd,Ge,Gg,Gr,Gs,Gt, (or a combination of one or more of the limitations, eg. Grd.)

Land unsuitable for sustained arable cropping but suitable for summer grazing. This land can be grazed throughout the year, but the value of the grazing becomes low in the dry winter months.

Class Gw

Land unsuitable for sustained arable cropping and for summer grazing because of wetness in the rainy season, but suitable for winter grazing.

UNSUITABLE LAND

This class normally has no worthwhile agricultural use under commercial farming conditions (although it may have non-agricultural uses). Two broad subclasses are recognized.

Class Uw

Swamp, or that part of dambo land remaining permanently wet and, therefore, unsuitable for arable cropping or grazing at any time. Some land in this class may be suitable for rice cultivation. Some may have use for fishing, watering points, collection of thatching material, etc.

Class Ue, Ur, and Uz

Land unsuitable for any agricultural purpose. Most such land is too rocky or steep for cultivation. It may have use for forestry, provision of fuelwood, watershed protection or recreation purposes.

LAND CAPABILITY SUB-CLASSES

The arable and moderately arable land classes, except classes Cl and Sl, are sub-divided into sub-classes in order to indicate the nature of the major limitation or limitations which have led to the land being classified in a class below land classes Cl or Sl. The sub-classes are indicated by one or more of the letter symbols listed below. Where two limitations are present, the symbol for the more important of the limitations is given first.

Similar subclasses can be set up for the grazing land class (G) and the unsuitable land class (U) to indicate the nature of the limitation(s) present.

The symbols used are:

d - depth (to a limiting layer)

e - erosion

g - gravelly or stony topsoil

m - termite mounds

r - rock outcrops or irregular surface relief

s - slope

t - texture (either cracking clay in C - class soils or sand or loamy sand to below specified class limits in S - class soils)

w - wetness

z - gravelly or stony subsoil layer

These symbols are given in small letters immediately following the land class e.g. C2s; S3ds; Gds.

Table 13 summarises the criteria used for determining the arable land capability classes for sandveldt soils, and Table 14 gives the land capability classes of the various soils and land types.

TABLE 13.

CRITERIA FOR DETERMINING ARABLE LAND CLASSES OF SANDVELDT SOILS

	ARABLE		MARGINAL ARABLE	
LAND CLASS	GOOD	MODERATELY GOOD	POOR	VERY POOR
Designation	S1	S2	S3	S4
Minimum effective depth, cm.	90	60	30	90
Minimum texture of 0-20 cm layer	loamy sand	sand	sand	sand
Minimum texture of upper subsoil 20-40 cm	sandy loam	loamy sand	sand	sand*
Minimum texture of subsoil 40-60cm	sandy loam	sandy loam	loamy sand	sand*
Maximum hinderance to cultivation(%)	1	5	10	5
Maximum slope(%)	1-3	3-5	5-8	5-8
Maximum erosion**	-	slight	moderate	moderate
Maximum wetness**	-	none	slight	slight

*not heavier than loamy sand, even in 60-90cm layer
**erosion and wetness are defined in Appendices 2 and 3 respectively.

CHAPTER 16

MANAGEMENT AND PRODUCTIVITY

LAND CAPABILITY CLASSES

Arable Land (classes S1 and S2) is suitable for intensive use on a sustained economic basis. Either annual or semi-perennial cultivated crops can be grown. The soils in this class have a sufficient buffering capacity against violent changes in environmental factors such as extreme rainfall variations. Long-term high-yield production is dependant on suitable crop rotation.

Marginal Arable (classes S3 and S4) land will not support long-term intensive use for arable crops without great risk of poor yields in dry or wet years. Freedom of choice of crops is limited and a high degree of environmental control is required. The introduction of leys in rotations is generally recommended. Net income over a period of years tends to be low.

Moderately good and poor arable land (classes S2 and S3) can sometimes be made as highly productive for general agricultural crops as good arable land (class S1) but this requires more effort and consequentially expenditure, which reduces profitability and may be uneconomic. With very intensive management, it may be possible to obtain high yields and high economic returns from selected crops (e.g. vegetables) grown on low class land.

TABLE 14

LAND CAPABILITY CLASSES FOR SANDVELDT SOILS

SOIL SERIES/LAND TYPE	LAND CAPABILITY CLASS
Mushemi	S1
Choma	S1
Chongwe	S2t
Kalomo	S3t
Luano	Gwt
Muchanga	Gtw
Nsato gravel	Gd
Dambos	Gw
Pediment soils	S1 or S2s
Kabwe	S2tw
Chapya	S3t
Kabuyu	S3t

Grazing Land (except class Gw) can be used for cattle grazing throughout the year. Miombo and dambo grasses are, however, of low nutritive value with low crude protein content and their value for grazing diminishes progressively from the start of the dry season. The overall carrying capacity will vary from year to year depending on rainfall but is likely to be of the order of one beast per 4 ha (Mansfield, 1975).

Preliminary studies of the value of Miombo trees for browse (Rees, 1974) indicated that such browse could make a significant contribution to both crude protein and energy requirements of grazing cattle - especially towards the end of the dry season when the sparse grasses are at their poorest and

Miombo trees produce the new season's flush of leaves.

Dambos (usually class Gw) are normally too wet for grazing during the rainy season but can be usefully grazed during the dry season when the erosion hazard is considerably less.

For the major part of the year Grazing Land is, therefore, unable to support large numbers of cattle. Supplementary fodder rations, the use of concentrates and rotations which allow improved grass/legume pasture grazing is recommended.

It is possible to re-classify land in a higher class after permanent improvements have been made which reduce or eliminate the natural limitation on which the original classification was based. Such improvements include the provision of major soil conservation works, drainage, irrigation, land-levelling, etc. Re-classification may bring previously non-arable land into an arable or marginal arable land class. For example, drainage of wet land may make it suitable for cultivation. Classes such as Us, Ur, or Uz, however, generally cannot be upgraded since there is no economic possibility of a removal of their limitations.

SOILS

Sandveldt soils in the Central Province are generally moderately leached and are of medium acidity holding nutrients fairly well under the moderate rainfall conditions. They respond well to use of fertilizers, especially in wet years, but some become hard when dry.

The main problems are drought when the rains are late in commencing, are interrupted, or finish early; the risk of erosion if soil conservation practices are not used; and rapid leaching of nitrogen during periods of heavy rainfall, so that additional fertilizer top-dressings may be needed.

Over felsic rocks where the soils may be more strongly leached and are strong to very strongly acid, the clay is kaolinitic and has low nutrient reserves and a low capacity to hold applied nutrients. Such soils are often gravelly. Liming is necessary to correct acidity under arable cropping. Heavy applications of nitrogen and other fertilizers are necessary to maintain good crop yields.

Soils of the Luano-Muchanga Association have sandy upper layers abruptly overlying mottled sandy clay loam or sandy clay. This heavy layer is friable and porous but the abrupt textural change causes a relative impedence to drainage. Cultivation of crops on ridges helps to improve drainage but seepage in the rainy season and early part of the dry season makes lower subsoils difficult to adequately drain.

Gravel in the shallow and moderately deep phases of sandveldt soils is not limiting to root development but it reduces the soils' moisture storage capacity where it is thick, which may reduce crop yields in years of low or irregular rainfall.

Where the gravel layer occurs in the topsoil the soils are unsuitable for cultivation.

Under cultivation topsoils of the more strongly leached soils become structureless and susceptible both to capping and erosion. Erosion is a general problem with all sandveldt soils especially on cultivated land. Hudson (1971, p 36) estimates the average annual loss to be 10 metric tons per hectare per year (4 tons per acre per year) for sandveldt soils in Central Africa.

Erosion is selective due to the fact that fine silt, clay and organic matter are removed more quickly than sand fractions. Once these binding materials are lost erosion increases year by year if not checked. Table 15 shows soil loss figures (Hudson, 1959) for Rhodesian sandveldt soils. The greatest increases are on the steep slopes.

TABLE 15: SOIL LOSSES DUE TO EROSION (HUDSON, 1959)

CROP	SOIL LOSS. Tons per Acre		% INCREASE
	1st Year	2nd Year	
Maize on steep slope	2.5	10.5	420
Tobacco on steep slope	12.3	48.0	390
Maize on medium slope	1.8	4.5	250
Tobacco on medium slope	3.6	10.9	300

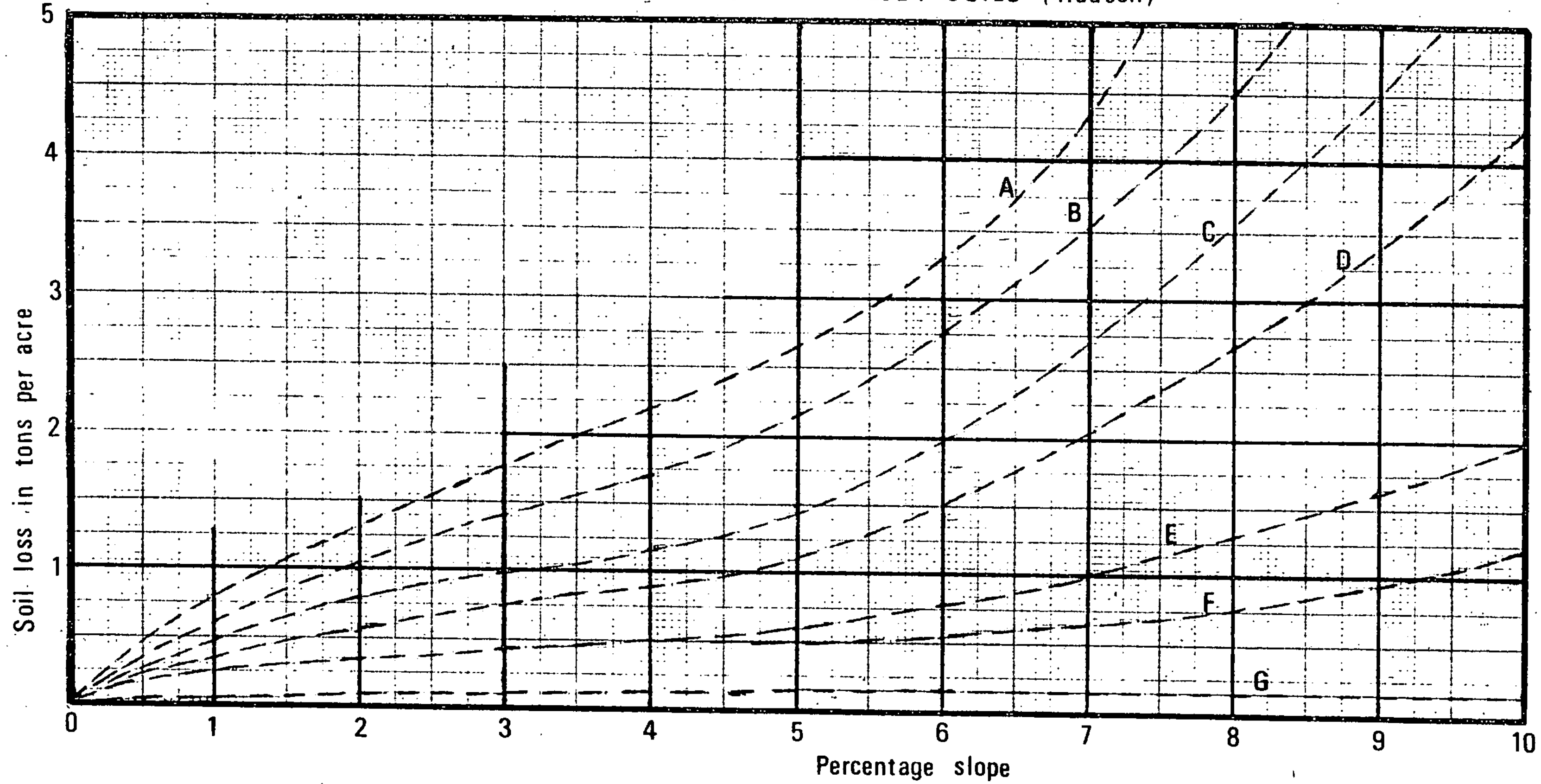
Rotations involving leys are effective in controlling erosion. Grass builds up a strong erosion resistance in the soil, but unlike the structure-building of temperate climates, the effect is built-up quickly in a year or two, and disappears equally rapidly. Hudson (1957b) showed that erosion in Rhodesia fell off rapidly following grass establishment and continued at a low level. When the grass was replaced by maize there was a strong residual effect with low erosion for the first year, an increase in the second year and 'normal erosion thereafter, irrespective of the length of grass cover. Hudson (1971) concluded that "from the erosion control point of view there is little advantage gained by continuing grass leys beyond 2 years" and recommended short cropping periods and equally short leys in Central Africa.

With respect to tobacco cropping resistance to both erosion and nematodes is gained by introducing pastures of grass species inimical to the latter (e.g. lovegrass, <u>Eragrostis curvula</u>). This practice is particularly important when the rotation also includes maize since it is also a host plant.

As far as tobacco-grass rotations are concerned the two best alternatives are 1 year tobacco followed by 2 years ley: or, 2 years tobacco followed by 4 years ley. Although both alternatives have similar crop-ley ratios, Hudson (1971, p 202) computed a lower soil loss under the former option. The reason is that erosion increases more rapidly under successive tobacco crops than it declines under successive leys (Figure 7).

Large reductions in erosion can result from quite small changes in management practice. For instance, higher plant densities reduce the exposure of bare ground and the latter is directly proportional to erosion. Hudson (1971, p 207) showed that a 50% increase in maize plant density led to a 75% reduction in bare ground exposed. Time of planting is

FIGURE 7 SLOPE – SOIL LOSS RELATIONSHIP FOR SANDVELDT SOILS (Hudson)



A: 3rd year tobacco
B: Maize after 2 years tobacco
C: 2nd year tobacco
D: Maize after 1 year tobacco

E: 1st year tobacco
F: 1st year grass
G: 2nd and subsequent year grass

also important. Field experiments (Hudson, 1957a) have shown a soil loss of 2.1 tons/acre (4.7 metric tons/ha) from early planted tobacco compared with 3.9 tons/acre (8.7 metric tons/ha) from late planted tobacco. Early planted tobacco also produces better yield and quality. Early planting of tobacco is, therefore, desirable both for erosion control and better crop management.

The combination of improved varieties with sufficient fertilizer applications to get the best out of the variety and dense stands lead at the same time to better crop, higher profits and reduced erosion.

Annual crops are unable to provide cover in the early season in their young growth stages. Soil protection must, therefore, be provided by alternative means. A common method, which also increases bulky organic matter, is to return crop residues from the previous year's crop to the land. One satisfactory solution to the problem is to combine 'trash' farming* and high yield cropping.

The trash is most effective at the beginning of the sea son but the effectiveness declines as the trash decays, is buried during cultivation and consumed by termites. At the same time the young growing crop progressively provides increasing cover. Alternative 'minimum tillage' operations developed in America have been tested (Meyer and Mannering, 1961) and show greatly reduced soil losses over conventional

*Trash Farming: the spreading of cut crop residues on the surface, as in stubble farming, and ploughing and then cultivating in the normal manner.

crop management practices but there is little increase in production efficiency, and weed control is a major problem (Brook, 1970).

In conclusion, to counter erosion a maximum crop cover should be maintained; new lands should be contoured in the first year because considerable erosion occurs then, even though not necessarily apparent; steep slopes should be avoided, particularly for tobacco; short periods of maize and tobacco should be rotated with leys; where erosion has become apparent pastures should be quickly established.

Tobacco and maize cropping can economically be combined with cattle keeping on sandveldt land. Pasture leys can be grazed and in any case on average 25% of sandveldt land is non-arable (Table 6, p 70) and suitable mainly for grazing. Cattle are thus able to make use of the extensive (but relatively poor) bush grazing and planted pastures aided by concentrate supplements.

The returns from cattle husbandry are comparatively steady whereas those from tobacco and maize vary with widely fluctuating yields. Pasture legumes help improve soil fertility during non-arable years, but innoculations with Rhizobium bacteria may be necessary to stimulate satisfactory root nodulation.

Termite mounds are an obstacle to mechanized farming, particularly as far as ploughing and irrigation is concerned. Mechanical levelling may seem practical but may not always be beneficial. In the Chisamba area it is estimated that levelling would result in the land surface being covered by a layer of termite mound material 5-10cm thick (Clayton, 1974a). Such levelling could result in great soil variability and could pose serious problems to drainage and soil management.

Ploughpans readily form in the more strongly leached soils and periodic ripping is needed to break these up. Ripping may also be required to break up hardpans sometimes found in old chitemene gardens.

Infiltration studies (described in Chapter 14) show that continued arable cropping leads to deterioration of soil structure. This further demonstrates the advisability of rotations. On lands which have been 'worked-out' by long continued cropping a combination of grass-legume pastures and green manuring will be necessary to try to restore fertility, organic matter and structure to the soil.

CHAPTER 17

CROP SUITABILITY

Sandveldt soils in Central Province are especially suitable for Virginia tobacco. Maize and other crops requiring good drainage can also be grown satisfactorily. An index to the suitability of the various soil series for a variety of the commoner crops likely to be grown under rainfed or irrigated conditions on Central Province sandveldt soils is given in Tables 16 and 17 respectively. Soils are classified according to their present condition or that expected to exist following clearing and land preparation. Major capital improvements such as intensive conservation works, irrigation or drainage would necessitate re-classification to take account of the improved conditions. The ratings given in Tables 16 and 17 are based upon present levels of technology. Improvements in agricultural technology may also require re-classification. The crop suitability rating is also based on the assumption that crops will be grown with an above average level of management. Absence of a crop from Tables 16 and 17 is not an indication of unsuitability for the conditions in the Province.

The soils are divided into four suitable classes, in respect of the various crops defined as follows:

Suitability Class 1; Well Suited

Under good management the crop grows well and can produce high yields. For the crop under consideration the soil has favourable physical properties, has a moderate or high fertility level and is responsive to good management.

Suitability Class 2: Moderately Suited

Under good management the crop grows moderately well or is subject to occasional hazard of failure, or requires extra effort (expenditure) to produce high yields. The soil has somewhat unfavourable physical properties (including wetness), a medium or low fertility level, or the response to management may be low. Alternatively or additionally, there may be limitations due to climate, such as occasional frost or drought, or high humidity and cloudiness in the growing season.

Suitability Class 3: Poorly Suited

The crop either will not grow, will produce poor yields, or will be subject to great hazard of failure. The soil has unfavourable physical or chemical characteristics that can not easily be amended, or occurs in an unfavourable climatic environment for the crop. Response to management is low.

Suitability Class 4: Not Suited

The crop will not grow or will only grow after expensive land improvement (such as drainage). The crop cannot be recommended for cultivation.

TABLE 16: RELATIVE SUITABILITY FOR SPECIFIC CROPS, PASTURE AND GRAZING UNDER RAINFED CONDITIONS

SOIL SERIES OR LAND TYPE	LAND USE CAPABILITY CLASS	VIRGINIA TOBACCO	BURLEY TOBACCO	MAIZE	GROUND NUTS	SOYA BEAN	SUNFLOWER	COTTON	SORGHUM	BULRUSH MILLET	CITRUS	BEANS	PASTURE FODDER CROPS	SUMMER GRAZING	WINTER GRAZING
Mushemi	S1	2	1–2	1	1	1	1	1	1	1	1	1	1	2–3	2–3
Choma	S1	1	2	1	1	1–2	1	1	1	1	1	2	1	2–3	2–3
Chongwe	S2t	1	3	2	1–2	2	2	2–3	2	2	2–3	2–3	1	2–3	2–3
Kalomo	S3t	2	3–4	3	2	3	3	3	2–3	2	3	3	1	2–3	2–3
Luano	Gtw	3–4	4	4	4	4	4	4	4	4	4	4	3	2–3	2–3
Muchanga	Gtw	3	4	3–4	3–4	3–4	3–4	3–4	3–4	3–4	4	4	3	2–3	2–3
Nsato gravel	Gd	4	4	4	4	4	4	4	4	4	4	4	4	2–3	2–3
Dambos	Gw	4	4	4	4	4	4	4	4	4	4	4	4	3–4	1
Pediment soils	S1 or S2s	1	3	1	1	1	1	1	1	1	1	2	1	2–3	2–3
Kabwe	S2tw	2	3	2	2	2	2	2	2	2	3	3	2	2–3	2–3
Chapya	S3t	2	3–4	3	2	3	3	3	3	2–3	3	3	2	2–3	2–3
Kabuyu	S3t	2	3–4	3	2	3	3	3	3	2–3	3	3	2	2–3	2–3

NOTES: 1. Ratings such as 2–3 indicate borderline classification in respect of the particular crop.
2. Ratings are for soils without a depth or slope limitation.

TABLE 17: RELATIVE SUITABILITY OF SOILS FOR SPECIFIC CROPS UNDER IRRIGATED CONDITIONS

SOIL SERIES OR LAND TYPE	LAND USE CAPABILITY CLASS	MAIZE	WHEAT	TOMATOES	POTATOES	CITRUS	PINE-APPLES	BANANAS	TEA	ARABICA COFFEE
Mushemi	S1	1	1	1	1	1	1	1	1	1
Choma	S1	2	2	1	2	1	1	1	1	1
Chongwe	S2t	3	3	2	3	2	2	2	2–3	2–3
Kalomo	S3t	3	4	3	4	3	3	3–4	3–4	3–4
Luano	Gwt	3–4	4	3	3–4	4	4	4	4	4
Muchanga	Gwt	4	4	4	3–4	4	4	4	4	4
Nsato gravel	Gd	4	4	4	4	4	4	4	4	4
Dambos	Gw	4	4	4	4	4	4	4	4	4
Pediment soils	S1 or S2s	1	2–3	1	3	1	1	1	1	1
Kabwe	S2tw	3	3	3	3	2–3	2	2	2–3	2–3
Chapya	S3t	3	4	3	3	3	3	3–4	3–4	3–4
Kabuyu	S3t	3	3	2	3	3	3	3–4	3–4	3–4

NOTES: 1. Ratings such as 2–3 indicate borderline classification in respect of the particular crop.
2. Ratings are for soils without a depth or slope limitation.

Tobacco (Nicotiana tabacum): Flue cured Virginia tobacco is the dominant tobacco crop grown in Zambia and is extremely well suited to sandveldt soils. It thrives on the light soils where they are deep and well drained and easily toberates the generally acid soil conditions (Akehurst 1968). Adequate nitrogen fertilizer is especially required during early growth, less so during later stages. Best quality crops are produced on newly cleared lands. Continued over-cropping leads to soil deterioration and creates an erosion hazard.

Burley tobacco is generally less well suited to the light textures (although it grows well on Mushemi series) and low inherent fertility. Turkish tobacco is not considered since it is generally suited better to higher rainfall conditions but if grown in the Central Province it would not rate higher than class 2.

Maize (Zea Mays): Maize in many ways dominates Zambian agriculture, well over half the cultivated area in the country being planted with it. It represents a major cash crop, is a major subsistence crop in many areas, and is also the national staple food. Furthermore it is a basic input for poultry, intensive beef, dairy and pig production, while stover (stalks), silage and bran help carry cattle through the long dry season. Maize production is, therefore, vital to Zambia and is particularly important to the Central Province which produced 44% of the national crop in 1971 (Lombard and Tweedie, 1972).

Maize generally grows quite well on sandveldt soils. Yields can be high under good management (30 bags*/ac, 6736 kg/ha) and are aided by sunshine averaging more than 5 hours per day. Soils with pH below 5.0 require liming (Brammer, 1973b). Maize responds well to irrigation and highest yields are obtained from crops started with irrigation in October. The crop has a heavy nutrient demand and inherent supplies in newly cleared soils are soon depleted. Rotation and the use of fertilizers, especially nitrogen, is necessary (Purseglove, 1972). Maize monoculture exhausts soil nitrogen and organic matter, and should be avoided.

Dambo and dambo margin soils benefitting from subsurface seepage can be used for small scale maize production, but they generally are unsuited for commercial-scale production. Under these conditions, the crop is usually grown in the dry season on high ridges or raised beds to provide better aeration. Some dambos can be used for irrigated maize production where wetness is not a limitation during the growing season (whether in the rainy season or dry season).

The Rhodesian bred, late maturing seed, SR 52 is very responsive to fertilizers and is high yielding but planting must be co-ordinated with the start of the rains. New Zambian bred Hybrid I and Composite A are both very suitable to Central Province conditions and also produce good yields. The heavy applications of fertilizer encourage weed growth

*Maize bags are 200lb in Zambia.

and the use of herbicides is required for consistent high yields. Pesticides are also required to control attacks of Fat John (Dereodus recticollis and Diaecoderus sp.) and other pests. A recent problem has been the establishment of the fungal disease Fusarium and control measures are being studied.

Wheat (Triticum sp.) grown in the rainy season is susceptible to disease, is difficult to weed, and is not recommended at present. For commercial production, however, wheat requires to be grown with irrigation in the dry season. Temperature is an important limiting factor and it should preferably be sown in the latter half of May so that flowering occurs after the period of frost hazard has passed (mid-August) and so that as much of the growing period as possible occurs with temperatures below 25°C. (Brammer 1973b.) Wheat should only be grown on soils of Mushemi and Choma series and requires heavy applications of nitrogen. Rotation is necessary since soil organic matter tends to be exhausted and since in addition bare soil is exposed in the early growth stages and the erosion hazard is considerable.

Sorghum (Sorghum sp.) being moderately drought resistant grows well on sandveldt soils and responds well to nitrogenous fertilizer. Yields are normally lower than for maize although sorghum produces more satisfactory yields than maize on soils exhausted of nutrients by continued cropping. It thrives better than maize when sown immediately following a grass fallow since it can be sown later and has a much longer growing period. Malting sorghum is important in Zambia for brewing. Bird damage is a problem.

Bulrush Millet (*Pennisetum typhoides*) is also a drought resistant cereal which grows very well on sandy sandveldt soils. It tolerates the poor drainage of lower slope soils although yields are reduced. Response to nitrogen and potassium is good (Purseglove, 1972).

Finger Millet (*Eleusine coracana*), not shown in Tables 16 and 17, is a common crop under traditional chitemene cultivation, but can produce good yields on sandveldt soils under good management.

Cotton (*Gossypium hirsutum var. latifolium*). Mushemi and Choma series produce good yields but lower slope soils are poorly suited since drainage impedance is not tolerated. Response to irrigation is good. Cotton should be grown in rotation since monoculture causes soil nitrogen exhaustion and lowers organic matter. Liming may be necessary where topsoil pH is below 5.0.

Sunflower (*Helianthus annuus*) with its efficient root system is resistant to drought conditions and grows well in association with sorghum. It grows well on well drained soils of the Mushemi-Choma association and reasonably well on the middle slope soils of the Chongwe-Kalomo association. It cannot tolerate the impeded drainage conditions of the Luano-Muchanga soil association. It should not be grown where soil pH is below 4.5 without liming (Brammer, 1973b).

Beans (Phaseolus vulgaris), which are rich in vegetable protein grow well where drainage is free. Yields are reduced by short periods of water logging and the crop is not very tolerant of periods of drought. Liming is necessary where topsoil pH is below about 5.0.

Groundnuts (Arachis hypogaea) are moderately drought resistant and are very well suited to sandveldt soils. Peg penetration is easy on the light textured soils and there are no harvesting problems. Soils with a pH below 4.5 are not normally suitable. Less acid soils may need liming to satisfy calcium requirements but excess lime may be harmful. Generally no fertilizer is needed, particularly if grown following a previously fertilized crop - though there may be a requirement on virgin soils. Gypsum applications may be needed at flowering time in 'pops' areas (Lombard and Tweedie, 1972). Good planting population helps control weeds and Rosette virus disease. The fungal disease, Aflatoxin, also needs control. Suitable varieties of groundnut are Makulu Red and Chalimbana (African Giant) which produce good quality confectionary nuts.

Soya Beans (Glycine Max) grow well on sandveldt soils tolerating the wide range of pH. Well drained crest soils produce good yields but yields are adequate on the less well drained soils of Chongwe and Kalomo series. Response to balanced fertilizer applications is good.

Coffee (Coffee arabica) requires a deep well drained soil and a constant moisture supply (Purseglove, 1968), and therefore requires constant irrigation during the dry season.

Only soils of Mushemi and Choma series are suitable (although Chongwe series is marginally suitable). The other soils are unsuitable due to their inability to retain sufficient moisture owing to sandiness, or as a result of impeded drainage. Coffee is best grown at elevations above 1300m towards the north of the Central Province (Brammer, 1973b). Nutrient deficiency symptoms may appear where pH is below 4.6 but foliar sprays can correct these. There is a high demand for nitrogen. Mulching is recommended to keep the top soil 'open' and receptive to rainfall and irrigation, as well as to conserve moisture, moderate surface soil temperature and suppress weed growth.

Tea (Camellia sinensis) grows reasonably well on soils of Mushemi and Choma series with irrigation and responds well to nitrogen fertilizer. It tolerates strong acidity (Eden, 1965). It is suited best to those soils with a pH below 5.0 and at an altitude above 1300m (Brammer, 1973b). For these reasons tea would be best grown in the higher areas to the north of the Central Province. Mulching is less essential than for coffee, except during establishment, since tea bushes and their prunings provide cover to the soil surface.

Pineapples (Ananas comosus), although shallow rooting are relatively tolerant of drought due to the moisture storage capacity of the leaf cells and the ability to absorb dew through leaf axils. They are intolerant of waterlogging. They do best where soils are strongly acid (<pH 5.0) but can grow well where pH is higher if deficiency symptoms resulting from high calcium status are corrected by appropriate sprays.

Since Pineapple quality is sensitive to high temperature and wet soil conditions (Purseglove, 1968), interfluve sandveldt soils in the Central Province are well suited for commercial production. Heavy applications of nitrogen are required and irrigation is needed to maintain growth during the dry season. Dambo margin soils, if adequately drained, are well suited to pineapple production.

Bananas (Musa spp) grow well on Mushemi, Choma and Chongwe series and on Pediment soils with irrigation. The lower moisture retention properties of the other soils makes them unsuitable. Bananas tolerate a wide range of soil reaction so long as they are adequately fertilized, but liming may be needed where the topsoil pH is below 4.6 (Brammer, 1973b).

Citrus crops (oranges, mandarins, grapefruit, limes and pomellos) are all usually grown on rough-lemon root stock which tolerates the wide range of sandveldt soil conditions. It is susceptible to water logging, and lower slope soils are therefore poorly suited. Liming may be necessary where pH is below 4.6 (Brammer, op. cit.). Dambo margin soils are moderately well suited if waterlogging can be avoided. This will normally require drainage. (Hence, Luano and Muchanga series are given rating of 4 at present. With drainage their rating would be 2.)

Mangoes (Mangifera indica), not shown in Tables 16 and 17, do well on sandveldt soils. They are well suited to those dambo margin soils which benefit from year-round subsurface irrigation by seepage. For commercial production irrigation would be an advantage for upland sites.

Sugarcane (Saccharum officinarum), not shown in Tables 15 and 16, can be adequately well grown on soils of Mushemi and Choma series but irrigation is essential.

Vegetables: As far as vegetables are concerned most grow well under irrigation. There is a demand for potatoes (Solanum tuberosum) and tomatoes (Lycopersicon esculentum) in the towns. They require heavy use of fertilisers, especially nitrogen and potash. Up to three crops of potatoes per year can be grown with irrigation but if on the same land they are subject to build up of disease. Tomatoes require constant spraying against pests and diseases.

Pasture and Fodder Crops: In general, the grasses and legumes grown for pasture and fodder in Zambia are not particularly demanding as to soil conditions. High yields require heavy applications of nitrogen, and irrigation is usually necessary if they are to continue high production through the dry season.

In the Central Province suitable pasture legumes are (Van Rensburg, 1969) Macrotyloma axilare, formerly Dolichos axillaris (a short-lived perennial which tolerates poor sandveldt soils well), Rhyncosia sublobata (an indigenous species which grows rapidly after seasonal buring), Glycine wightii and Siratro (Macroptilium artropurpureum, formerly Phaselous artropurpureus), a legume capable of flowering and producing seed pods throughout the dry season without irrigation.

Suitable fodder legumes are (Van Rensburg, op. cit.) Velvet beans (Stizolobium deeringiamm) and Cowpea (Vigna sinensis).

Suitable grasses for improved pasture are Rhodes grass (*Chloris guyana*) and Star grass (*Cynodon plectostachyus*) and Van Rensburg (op. cit.) has shown the above mentioned legumes to be very compatible with these grasses.

PART FIVE : CONCLUSIONS AND SUMMARY RECOMMENDATIONS

CHAPTER 18

CONCLUSIONS

1. Soil Survey work in the Central Province has led to the identification of a range of sandveldt soil types which are estimated to cover 505,000 ha, 41% of the Province.

2. The distribution of these sandveldt soils and other Central Province soils is shown on Map 7.

3. Six soil series (Mushemi, Choma, Chongwe, Kalomo, Luano and Muchanga) together with two land types (Nsato gravel and dambos) are comprised in a widespread catena and their distribution pattern has been identified (Figure 5, p 68). Associated with, but distinct from the catena soils, are a number of other sandveldt soil types. These include Pediment Soils, Kabwe, Chapya and Kabuyu series. Their extent is not fully known.

4. The physical and chemical characteristics of the soils have been determined and discussed in relation to other environmental factors and soil genesis.

5. Sandveldt soils are light textured, developed over felsic and intermediate rocks. They are characteristically yellowish brown where well drained, structureless, low in organic matter content and low in C.E.C. Base saturation is very variable and acidity in the range strong to slightly acid (pH 4.5 - 6.0).

6. Central Province sandveldt soils are unsatisfactorily classified in terms of the U.S.D.A. Soil Taxonomy and the FAO-Unesco legend due to their transitional position between strongly leached soils to the north and more moderately leached soils to the south. They are best classified as Weathered Ferrallitic Soils.

7. The soils of the sandveldt catena and associated soils have been classified in terms of land use capability to provide a basis on which to plan agricultural development.

8. The Central Province sandveldt areas are estimated to comprise

    202,000 ha Good Arable Land (Class S1)
    37,875 ha Moderately Good Arable Land (Class S2)
    12,625 ha Poor Arable Land (Class S3)
    252,500 ha Grazing Land (Class G)

9. The soils have also been rated in terms of their suitability for a range of rainfed and irrigated crops.

10. Under rainfed conditions Virginia tobacco and maize, the present dominant crops, are well suited, but a number of other crops will also grow very well under good management and with adequate fertilizer applications. These include sunflower, cotton, sorghum, bulrush millet, groundnuts and soya beans.

11. Where irrigation can be provided a range of crops including citrus, pineapples, bananas, tomatoes and potatoes can be successfully grown. Tea and coffee

may be grown with a high level of management where altitude exceeds 1300 m. Wheat can be grown under irrigation on soils of Mushemi series. Maize, the staple crop, responds well to irrigation.

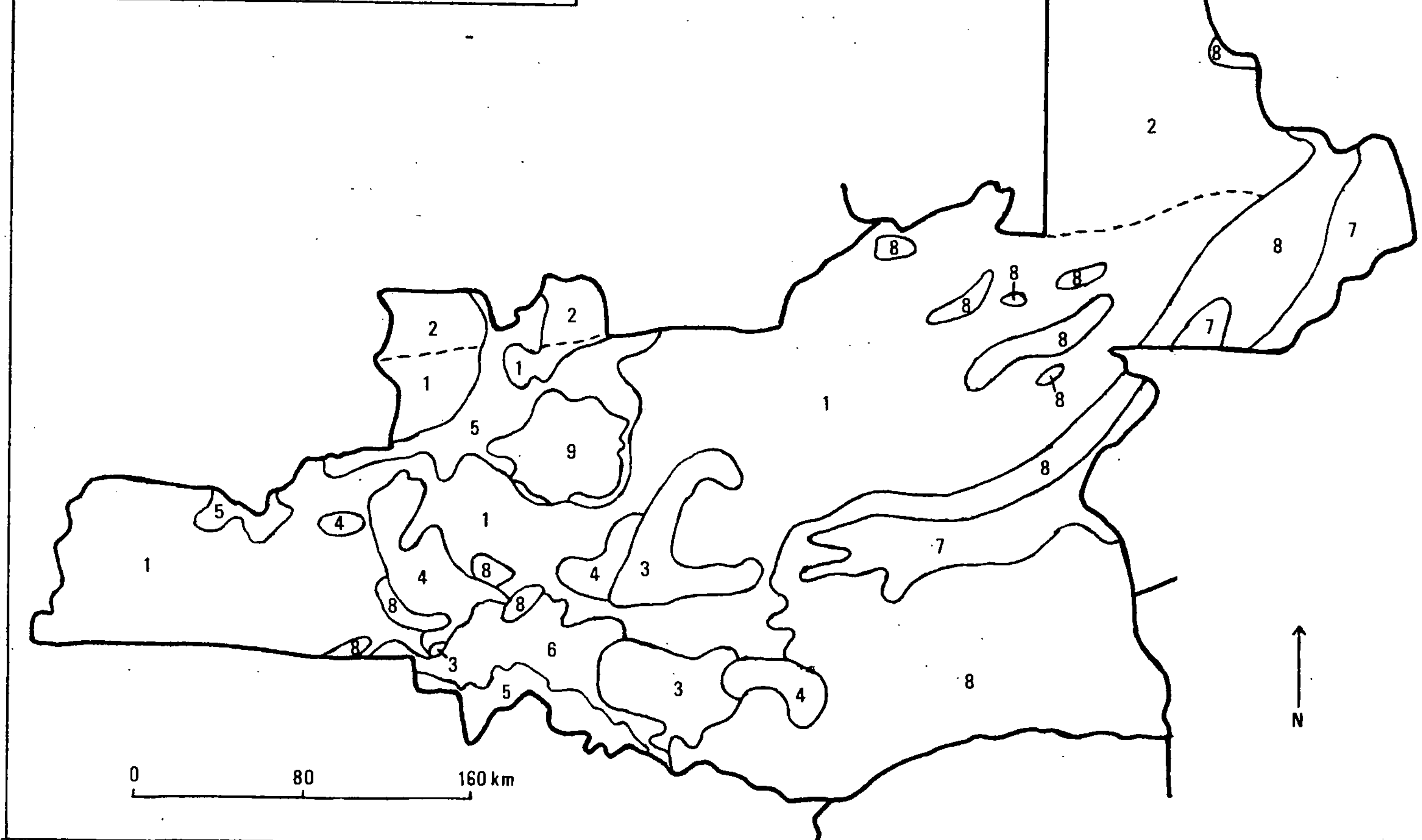
12. Management and productivity problems are dominated by the need to control erosion and to maintain soil fertility. Crop failure is strongly influenced by drought when the rains commence late, are interupted or finish early.

13. The Central Province is mantled with an estimated 239,875 ha of good and moderately good arable land (classes S1 and S2) in the sandveldt areas capable, under good management, of yeilding at least 60 bags of maize per ha and 1000 kg of dried tobacco per ha. The Central Province thus has the potential to provide all the nation's current needs in respect of maize leaving a surplus for stockpiling and export; to grow sufficient Virginia tobacco to make Zambia a major world exporter and provide valuable foreign exchange; to expand considerably the production of those crops mentioned in paragraphs 10 and 11; and thereby to achieve one of the top priorities of the Second National Development Plan - "to expand agricultural production and substantially cut food imports".

MAP 7 Overleaf

MAP 7 CENTRAL PROVINCE SOIL MAP

Legend opposite



LEGEND TO MAP 7

(Based on Soil Map of Zambia, Department of Agriculture, 1965).

A) SOILS FORMED FROM THE UNDERLYING ACID IGNEOUS OR SILICEOUS SED? SEDIMENTARY ROCK.

1. SANDVELDT SOILS (505,000 ha) Light textured (sandy loams to sandy clay loams, coarse grained, the clay content usually increasing with depth. Yellowish red to light yellowish-brown where well-drained, grey brown where poorly drained.
2. LEACHED SANDVELDT SOILS (153,000 ha). Similar to 1 but with more inert clay and low base saturation due to leaching by excessive rainfall.

B) SOILS FORMED FROM THE UNDERLYING SEDIMENTARY AND METAMORPHIC ROCKS WITH WEATHERED PRODUCTS RICH IN FERROMAGNESIAN MINERALS.

3. RED CLAYS (47,000 ha) Topsoil textures, clay to sandy clay loam. Dark red where well drained and brown to dark grey where poorly drained.
4. RED BROWN LOAMS (46,000 ha). Sandy clay loams or sandy loams, reddish-brown to yellowish-red where well drained or yellowish-brown to grey-brown where poorly drained.

C) ALLUVIAL SOILS

5. KAFUE CLAYS (68,000 ha) Black to dark grey clays of alluvial origin, mostly subject to seasonal flooding. Very slowly permeable when wet. Extensive cracks form on drying.
6. KAFUE BASIN ALLUVIUM (34,500 ha) A complex of well drained and poorly drained sandy clay loams and clay loams interspersed with sandy ridges, developed in old alluvium. Reddish-brown to grey.

D) SOILS OF THE LUANGWA AND LOWER ZAMBEZI VALLEYS

7. VALLEY SOILS (67,000 ha) Derived from Karroo sediments largely by colluvial and alluvial processes. A complex of deep sands, grey-brown alluvial soils, and solonetzic pale sands and dark grey clays.
8. ROCK AND RUBBLE (280,000 ha) Broken hilly country with mainly skeletal soils and flatter areas with much surface rock or laterite crust.

E) 9. SWAMP (28,000 ha)

CHAPTER 19

RECOMMENDATIONS

1. It is recommended that further soil survey work be undertaken in the Central Province sandveldt areas to produce a comprehensive soil map detailing the distribution of the soil types now identified.

2. Agronomic and crop variety trials should be commenced on the various soils identified to provide improved crop response predictions.

3. Special attention should be paid to physical and chemical soil parameters under various management practices. The following parameters should be measured a) before, and b) after, experimental agronomic work.

   i. Particle size distribution, dispersed and undispersed, in order to assess micro-aggregate changes under cultivation (a & b).

   ii. Total pore space using simple bulk density method to check on aeration problems (a & b).

   iii. Available water capacity in any experiment where water stress is likely to affect the result in order to check on possible large variations in particle size distribution (a).

   iv. Free and total iron content at surface and upper subsoil, to confirm the iron micro-aggregation relationship (a).

   v. A broad spectrum of micro and macro-nutrients except where the levels are already well known (a & b).

   vi. Presence of pathogens (a & b).

4. Kabwe Regional Research Station is unsuitable for these investigations since the soils of the sandveldt catena are inadequately represented. It is recommended that a representative site for a Sub-Station be located.

5. The land capability classification should be applied to land used for arable cropping on a permanent to semi-permanent basis.

6. Soil loss measurements should be made on the more important soils (Mushemi, Choma, Chongwe, Kalomo series) under different crops and management practices. Subsequently different soil conservation practices should be compared.

7. More immediately, erosion control measures should be undertaken on existing lands where slopes exceed 2% and all new lands should be contoured in the first year. Strips of natural woodland should be used at regular intervals along contours, even on flattish land, to reduce the likelihood of extensive erosion. Slopes greater than 2% should be avoided for arable cropping, particularly for tobacco, and periods of crops should be rotated with grass/legume leys.

8. Crops with relatively high fertilizer requirements should be grown on soils of Mushemi and Choma series in preferance to those of lighter upper subsoil texture, when this is practicable.

9. Liming is necessary to correct acidity under arable cropping where topsoil pH is below 5.0.

10. Caution should be exercised when termite mound levelling is considered. Such levelling can produce great soil variability.

11. Periodic 'ripping' is needed to break up ploughpans which readily form, especially in the more strongly leached soils.

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APPENDICES

1. Profile Descriptions and Analytical Data
2. Erosion Classification
3. Wetness Classification
4. Successive Hourly Infiltration Rates for Mushemi and Choma Series.
5. Physical Characteristics of Mushemi and Choma Series.

APPENDIX 1

PROFILE DESCRIPTIONS AND ANALYTICAL DATA.

PROFILE 1

SOIL NAME: Mushemi Series, Ntendere variant

LOCATION: Chisamba Farms

PHYSIOGRAPHY: Broad flat crest of interfluve

PARENT MATERIAL: Gneiss/Schist

DRAINAGE: Well drained

PERMEABILITY: Moderate

VEGETATION/USE: Cleared Miombo woodland

SLOPE: 1%

SAMPLED: AUTHOR , 30/11/73

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0-20	Yellowish brown (10YR 5/4) moist and light yellowish brown (10YR 6/4) dry, weakly organic stained, sandy loam becoming sandy clay loam below 8 cm; massive; slightly sticky, slightly plastic wet, very friable moist, slightly hard dry; many very fine, common fine, pores; many fine, few medium, roots; clear, smooth boundary.
B1	20-34/50	Yellowish brown (10YR 5/6) moist, sandy clay loam; massive; sticky, plastic wet, very friable moist, slightly hard dry; many fine and very fine, common medium, pores; many fine gravel; many fine, few medium, roots; clear, wavy boundary.
B2	34/50-90	Strong brown (7.5YR 5/6) moist, sandy clay loam; massive; sticky, plastic wet, friable moist, hard dry; many medium, fine and very fine, common coarse, pores; very many fine and coarse gravel, many stones; many yellowish brown and red (10YR 5/6 and 2.5YR 5/8) moist, indurated mottles; many small, few medium roots; gradual, wavy boundary.
C	90-170	Highly weathered rock of sandy clay loam texture; massive: sticky, plastic wet, friable moist, hard dry; many coarse, medium, fine and very fine, pores; many fine and coarse gravel; many indurated mottles (colours as above); many fine roots.

ANALYTICAL DATA

	International Classes				U.S.D.A. Classes			
Depth (cm)	C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-8	36.5	47.5	4.4	11.6	11.1	40.8	27.1	9.4
8-20	32.1	41.9	3.4	22.6	11.8	33.5	24.3	7.8
20-34/50	33.3	36.7	4.4	25.6	11.6	29.5	18.8	14.5
34/50-90	33.5	40.5	4.4	21.6	16.9	28.0	18.5	15.0
90-130	31.5	41.5	6.4	20.6	18.8	29.1	18.3	13.2
130-170	22.5	43.5	7.4	26.6	21.7	29.2	10.9	11.6

Depth(cm)	Org.C %	Total N %	Ex.Ca. m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0.8	0.78	0.040	1.40	0.55	0.16	4.8	44.0	5.2	26	41.4
8-20	0.70	0.040	0.95	0.70	0.13	4.8	37.1	4.4	14	21.2
20-34/50	0.58	0.034	0.30	0.35	0.11	4.7	16.2	4.2	3	18.4
34/50-90	N.D.	N.D.	0.45	0.35	0.08	7.2	12.2	4.2	N.D.	33.3
90-130	N.D.	N.D.	0.25	0.25	0.09	7.0	8.4	4.0	N.D.	33.9
130-170	N.D.	N.D.	0.25	0.20	0.06	6.9	7.4	4.2	N.D.	25.9

N.D. = Not determined

PROFILE 2

SOIL NAME: Mushemi Series

LOCATION: Mkushi West Block

PHYSIOGRAPHY: Flat interfluve

PARENT MATERIAL: Quartz-rich gneiss

DRAINAGE: Well drained

PERMEABILITY: Moderate

VEGETATION/USE: Miombo woodland

SLOPE: < 3%

SAMPLED: O. HAUGBOTN, 1/8/74

PROFILE DESCRIPTION

HORISON	DEPTH (cm)	
A1	0-14	Very dark greyish brown (10YR 3/2) loamy sand; massive; soft dry; many fine, common medium, pores; many fine and medium roots.
B1	14-23	Strong brown (7.5YR 4/6) sandy clay loam; massive; hard dry; many fine, common medium, pores; many fine and medium roots.
B21t	23-79	Strong brown (7.5YR 4/6) sandy clay; massive; hard dry; many fine, few medium, pores; common fine, few medium and coarse, roots.
B22t	79-107	Strong brown (7.5YR 5/8) sandy clay; massive; very hard dry; common fine, few medium, pores; few manganese concretions; common fine and medium roots.
C	107-170	Layer of strongly mottled weathered rock, iron and manganese concretions; very little fine material.

ANALYTICAL DATA

Depth (cm)	U.S.D.A. Classes Clay < 0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-14	6	11	27	33	23
14-33	20	9	21	28	22
33-55	44	8	15	18	15
55-79	48	7	17	13	15
79-107	40	10	20	13	17
107-170	24	6	22	17	31

Depth(cm)	Org.C %	Total N %	Ex.Ca. m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0-14	1.25	0.076	2.95	1.00	0.62	5.2	88	5.8	44	15
14-33	0.47	0.030	2.20	0.81	0.55	3.8	94	6.1	32	11
33-55	N.D.	N.D.	2.30	1.50	0.98	5.8	82	6.1	N.D.	13
55-79	N.D.	N.D.	2.60	1.48	0.74	6.3	92	6.3	N.D.	13
79-107	N.D.	N.D.	3.05	1.18	1.87	5.1	60	6.3	N.D.	12
107-170	N.D.	N.D.	4.40	2.40	1.56	10.2	82	6.3	N.D.	42

N.D. = Not determined

PROFILE 3

SOIL NAME: Mushemi Series

LOCATION: Kabwe Research Station

PHYSIOGRAPHY: Level upland

PARENT MATERIAL: ?

DRAINAGE: Well drained

PERMEABILITY: Moderate

VEGETATION/USE: Cleared Miombo

SLOPE: < 1%

SAMPLED: O. HAUGBOTN, Aug. 1973

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0-10	Dark greyish brown (10YR 4/2) sandy loam; massive; slightly hard dry; many fine and medium pores; penetrated by roots.
B1	10-23	Dark yellowish brown (10YR 4/4) sandy loam; massive; hard dry; many fine and medium pores; penetrated by roots.
B21	23-45	Strong brown (7.5YR 5/6) sandy clay; weak, fine and medium subangular blocky; very hard dry; many fine and medium pores; penetrated by roots.
B22	45-66	Strong brown (7.5YR 5/6) sandy clay; weak, fine and medium subangular blocky; very hard dry; many fine pores; penetrated by roots.
B23t	66-96	Strong brown (7.5YR 5/6) sandy clay; weak, fine subangular blocky; very hard dry; many fine pores; few manganese concretions; few roots.
C1	96-140	Strong brown (7.5YR 5/6) sandy clay with few medium, faint yellowish red mottles; weak, fine subangular blocky; hard dry; common fine pores; few manganese concretions; few small roots.
C2	140-196	Yellowish brown (10YR 5/6) sandy clay with common, fine and medium distinct yellowish red mottles; weak subangular blocky; slightly hard dry; common fine pores; few manganese concretions; few small roots.

ANALYTICAL DATA

U.S.D.A. Classes

Depth (cm)	Clay <0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-10	9	14	52	18	7
10-23	16	14	45	18	7
*23-45	41	12	32	10	5
45-66	36	14	32	16	2
66-96	41	12	32	10	5
96-140	39	10	34	15	2
140-196	39	10	34	15	2

Depth(cm)	Org.C %	Total N %	Ex.Ca. m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0-10	1.01	0.070	3.7	1.3	0.6	5.4	100.0	6.3	40	60.0
10-23	0.48	0.038	1.3	1.0	0.3	4.7	54.5	5.4	24	29.4
23-45	0.41	0.037	2.0	1.3	0.3	7.2	49.3	5.3	20	17.6
45-66	N.D.	N.D.	2.1	1.7	0.3	8.0	50.0	5.6	N.D.	22.2
66-96	N.D.	N.D.	2.3	1.8	0.3	8.6	49.9	5.9	N.D.	20.9
96-140	N.D.	N.D.	2.1	1.7	0.3	7.5	54.3	6.1	N.D.	19.2
140-196	N.D.	N.D.	2.3	2.0	0.3	8.0	57.2	6.1	N.D.	20.5

N.D. = Not determined

* Data appears erroneus (≡ 66 - 96 cm)

PROFILE 4

SOIL NAME: Mushemi Series

LOCATION: Mukonchi E. Block

PHYSIOGRAPHY: Very gentle upper slope

PARENT MATERIAL: Granite

DRAINAGE: Well drained

PERMEABILITY: Moderately rapid

VEGETATION/USE: Miombo woodland

SLOPE: 1%

SAMPLED: AUTHOR, 14/8/74

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0-9	Brownish black (10YR 3/2) moist and greyish yellow brown (10YR 5/2) dry, sandy loam; massive; slightly stick, sticky, slightly plastic wet, loose; many fine and very fine pores; many fine, few medium roots; clear, smooth to wavy boundary.
B1	9-20	Strong brown (7.5YR 5/6) moist and dull orange (7.5YR 6/4) dry, sandy loam; massive; slightly sticky, slightly plastic wet, extremely friable moist, slightly hard dry; many fine, few medium roots; gradual, smooth to wavy boundary.
B21	20-30	Strong reddish brown (5YR 5/6) moist and dull orange (5YR 6/4) dry, sandy clay loam; massive; sticky, plastic wet, very friable moist, hard dry; many fine, few medium pores; many fine, few medium and coarse roots, gradual smooth boundary.
B22t	30-50	Ditto but sandy clay.
B23t	50-80	Ditto but sandy clay.
B24t	80-100	Ditto but sandy clay loam.
C	110+	Ditto but weathered rock (Mottles 10R 5/6 and 10R 4/6 moist) of sandy clay texture.

ANALYTICAL DATA

U.S.D.A. Classes

Depth (cm)	Clay < 0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-9	14	5	32	31	18
9-20	17	4	31	29	19
20-30	23	5	36	22	14
30-50	36	5	27	19	13
50-80	42	5	22	19	12
80-110	32	6	34	17	11
110+	39	5	25	17	14

Depth(cm)	Org.C %	Total N %	Ex.Ca. m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0-9	1.25	0.066	3.50	1.75	0.43	6.4	88.7	6.1	24	45.7
9-20	0.43	0.029	3.25	1.10	0.51	6.0	82.0	6.1	23	35.2
20-30	0.16	0.028	2.00	1.42	0.76	6.1	68.5	5.8	35	26.5
30-50	N.D.	N.D.	2.30	2.45	0.89	7.0	80.6	5.8	N.D.	19.4
50-80	N.D.	N.D.	2.70	2.00	1.26	7.5	79.5	5.7	N.D.	17.8
80-110	N.D.	N.D.	1.90	1.15	1.20	6.2	76.6	5.6	N.D.	19.4
110+	N.D.	N.D.	2.30	1.15	0.92	7.0	62.4	5.6	N.D.	17.9

N.D. = Not determined

PROFILE 5

SOIL NAME: Choma Series

LOCATION: Zamic Chisamba Farms

PHYSIOGRAPHY: Wide very flat crest

PARENT MATERIAL: Gneiss/Schist

DRAINAGE: Moderate

PERMEABILITY: Moderately rapid

VEGETATION/USE: Cleared Miombo woodland

SLOPE: < 1%

SAMPLED: AUTHOR, 27/11/73

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A11	0–10	Dark greyish brown (10YR 4/2) moist and light brownish grey (10YR 6/2) dry, loamy sand; single grain; non-sticky, non-plastic wet, very loose; very many fine and very fine pores; many fine roots; gradual smooth boundary.
A12	10–25	Very dark greyish brown (10YR 3/2) moist and dark greyish brown (10YR 4/2) dry, sandy loam; massive; non-sticky, non-plastic wet, extremely friable moist, very soft dry; many fine and very fine pores; many fine roots; gradual, smooth boundary.
B1	25–43	Brown to dark brown (10YR 4/3) moist and yellowish brown (10YR 5/4)dry, sandy loam; massive; very slightly sticky, very slightly plastic wet, extremely friable moist, slightly hard dry; many very fine, few fine and medium, pores; many fine and few medium roots; gradual, smooth boundary.
B21	43–64	Brown (10YR 5/3) Moist and brown to pale brown (10YR 5.5/3) dry, sandy loam; massive; slightly sticky, slightly plastic wet, extremely friable moist, hard dry; many very fine, few fine and medium, pores; many fine, few medium and large, roots; gradual, smooth boundary.
B22t	64–90	Brown (10YR 5/3) moist and pale brown (10YR 6/3) dry, sand clay loam; massive; sticky, plastic wet, very friable moist, hard dry; many very fine, few fine and medium, pores; many small roots; gradual, smooth boundary.
B23t	90–115	Ditto, but, yellow (7.5YR 6/6); many fine and very fine pores; few fine roots.
B24t	115–144	Reddish yellow (7.5YR 6/6) moist and dry, sandy clay loam; massive; sticky, plastic wet, friable moist, hard dry; many fine and very fine, few medium and coarse, pores; few fine roots; clear, smooth boundary.
B3	144–180	Ditto, but with many, medium, prominent, yellowish brown (10YR 5/8) moist, indurated mottles; sandy clay; abrupt wavy boundary.
C	180+	Gravel overlying lateritic concretions and weathered rock.

ANALYTICAL DATA

Depth (cm)	International Classes				U.S.D.A. Classes			
	C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0–10	33.8	51.8	5.2	9.2	14.4	42.6	29.4	4.4
10–25	34.7	49.9	5.2	10.2	11.9	43.2	26.5	8.2
25–43	35.5	43.9	6.4	14.2	11.1	39.2	26.2	9.3
43–64	30.7	45.7	4.4	19.2	10.0	40.1	27.8	2.9
64–90	34.1	40.5	3.2	22.2	8.6	35.1	24.5	9.6
90–115	34.3	35.3	3.2	27.2	12.5	26.0	22.8	11.5
115–144	28.9	35.5	5.4	30.2	11.9	29.0	22.5	6.4
144–180	24.2	39.2	5.2	35.4	15.5	30.1	15.6	8.6

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–10	0.86	0.056	1.95	0.40	0.28	5.8	45.4	5.2	32.5	63.0
10–25	0.90	0.048	0.60	0.10	0.08	6.6	11.8	4.0	14.0	34.3
25–43	0.57	0.028	1.15	0.12	0.06	4.2	31.7	4.4	3.0	29.5
43–64	N.D.	N.D.	1.50	0.25	0.09	4.8	38.4	4.8	N.D.	25.0
64–90	N.D.	N.D.	0.90	0.35	0.07	4.6	28.7	4.4	N.D.	20.7
90–115	N.D.	N.D.	0.60	0.35	0.08	4.8	21.5	4.2	N.D.	17.6
115–144	N.D.	N.D.	0.50	0.60	0.07	5.6	20.9	4.0	N.D.	18.5
144–180	N.D.	N.D.	0.50	0.80	0.04	5.8	23.1	4.2	N.D.	16.4

N.D. = Not determined

PROFILE 6

SOIL NAME: Choma Series

LOCATION: Zamic Chisamba Farms

PHYSIOGRAPHY: Long gentle upper slope

PARENT MATERIAL: Gneiss/Schist

DRAINAGE: Well drained

PERMEABILITY: Moderately rapid

VEGETATION/USE: Cleared Miombo woodland

SLOPE: 1%

SAMPLED: AUTHOR, 3/12/73

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0–21	Yellow brown (10YR 5/4) moist, loamy sand, with dark greyish brown (10YR 4/2)moist, organic stained portions; massive; very slightly sticky, very slightly plastic wet, soft; many fine and very fine pores; very many fine roots; abrupt, wavy boundary.
B1	21–47	Yellowish brown (10YR 5/5) moist and brownish yellow (10YR 6/6) dry, sandy loam; massive; slightly sticky, slightly plastic wet, soft; many fine and very fine pores; many fine roots, with few medium and large roots below 31 cm.; gradual, smooth boundary.
B21t	47–65	Yellowish brown (10YR 5/6) moist and brownish yellow (10YR 6/6) dry, sandy clay loam; massive; sticky, plastic wet, very friable moist, hard dry; many fine and very fine pores; many fine and common medium roots; gradual smooth boundary.
B22t	65–96	Ditto; but sandy clay; very hard dry; few large roots; gradual, smooth boundary.
B23t	96–140	Ditto; but sandy clay; slightly hard dry; many fine and very fine, common medium pores; many fine, few medium and large, roots; gradual, smooth boundary.
B24t	140–195	Ditto; but sandy clay; slightly hard dry; many fine, very fine and medium, pores; many fine and few medium, roots.

ANALYTICAL DATA

Depth (cm)	International Classes				U.S.D.A. Classes			
	C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0–21	38.8	48.8	3.4	9.0	9.6	42.6	30.7	8.1
21–31	41.9	42.7	3.4	12.0	8.8	37.3	34.4	7.5
31–47	36.5	43.1	2.4	18.0	8.1	37.4	28.1	8.4
47–65	34.5	33.1	3.4	29.0	7.9	28.6	25.3	9.2
65–96	30.1	31.5	3.4	35.0	9.0	25.9	27.3	2.8
96–140	27.5	33.1	3.4	36.0	7.8	28.7	19.9	7.6
140–195	28.2	32.4	3.4	36.0	9.1	26.7	18.9	9.3

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–21	0.90	0.050	3.95	0.85	0.29	6.2	82.1	6.8	36	34.4
21–31	0.43	0.022	1.15	0.40	0.20	3.7	47.2	5.4	21	30.8
31–47	0.35	0.020	0.90	0.60	0.26	3.5	50.3	5.2	8	19.4
47–65	N.D.	N.D.	0.75	1.40	0.42	4.7	53.6	6.0	N.D.	16.2
65–96	N.D.	N.D.	0.50	0.98	0.97	5.4	45.4	5.8	N.D.	15.4
96–140	N.D.	N.D.	0.60	0.80	0.49	5.2	36.4	5.4	N.D.	14.4
140–195	N.D.	N.D.	0.60	0.68	0.28	5.2	30.0	5.2	N.D.	14.4

N.D. = Not determined

PROFILE 7

SOIL NAME: Choma Series

LOCATION: Zamic Chisamba Farms

PHYSIOGRAPHY: Broad Flat crest

PARENT MATERIAL: Gneiss/Schist

DRAINAGE: Well drained

PERMEABILITY: Moderately rapid

VEGETATION/USE: Cleared Miombo woodland

SLOPE: 1%

SAMPLED: AUTHOR, 26/11/73

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0-18	Greyish brown (10YR 5/2) moist and light brownish grey (10YR 6/2) dry, loamy sand; single grain and loose to 5cm, slightly coherent below; many very fine pores; many fine roots; clear smooth boundary.
B1	18-30	Strong brown (7.5YR 5/6) moist and light brown (7.5YR 6/4) dry, sandy loam; massive; slightly plastic wet, slightly sticky, extremely friable moist, slightly hard dry; many fine and very fine pores; many fine roots; gradual, smooth boundary.
B21t	30-70	Strong brown (7.5YR 5/6) moist and reddish yellow (7.5YR 6/6) dry, sandy clay loam; massive; plastic wet, sticky, extremely friable moist slightly hard dry; many fine and very fine pores, few medium pores below 50cm.; many fine roots; gradual, smooth boundary.
B22t	70-119	Ditto, but many fine and medium roots.
B23t	119-138	Ditto, but with many fine, few medium pores; many fine, few medium roots; abrupt, wavy boundary.
B3	138-157	Strong brown (7.5YR 5/6) moist and dry, sandy loam, massive; plastic, sticky, very friable moist, hard dry; many fine, few medium, pores; very many coarse gravel, many stones; many fine, few medium, roots; abrupt, wavy boundary.
C	157+	Weathered rock with many, small, soft, red lateritic concretions.

ANALYTICAL DATA

Depth (cm)	International Classes: C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %	U.S.D.A. Classes: Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-5	31.9	53.9	4.2	10.0	11.4	46.7	27.0	4.9
5-18	33.4	52.4	4.2	10.0	11.6	45.0	32.7	0.7
18-30	29.8	51.0	3.2	16.0	8.1	46.1	24.3	5.5
30-49	32.7	38.1	4.2	25.0	8.2	84.1	26.4	6.3
49-70	30.5	35.3	4.2	30.0	8.4	31.1	27.2	3.3
70-92	24.8	39.0	5.2	31.0	8.1	36.1	20.4	4.4
92-119	26.6	39.2	7.2	27.0	10.8	35.6	20.4	6.2
119-138	23.4	40.4	7.2	29.0	12.2	35.4	21.4	2.0
138-157	34.9	38.9	7.2	19.0	15.1	31.0	22.6	12.3
157+	27.3	44.5	11.2	17.0	22.0	33.7	18.9	8.4

Depth(cm)	Org.C %	Total N %	Ex.Ca. m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0-5	0.70	0.034	1.25	0.32	0.25	4.5	40.5	4.9	46	45.0
5-18	0.55	0.028	1.05	0.18	0.19	4.1	34.7	4.7	28	22.0
18-30	0.27	0.010	0.90	0.20	0.15	3.4	36.8	5.0	14	21.0
30-49	0.35	0.018	1.45	0.37	0.17	4.7	42.3	5.4	2	18.8
49-70	N.D.	N.D.	1.30	0.65	0.16	5.3	40.5	5.6	N.D.	17.7
70-92	N.D.	N.D.	0.90	1.08	0.11	5.1	41.0	5.8	N.D.	16.5
92-119	N.D.	N.D.	0.80	1.00	0.14	4.4	44.1	6.0	N.D.	16.3
119-138	N.D.	N.D.	0.90	0.95	0.18	5.0	40.6	6.0	N.D.	17.2
138-157	N.D.	N.D.	1.05	1.00	0.19	6.8	33.0	6.1	N.D.	35.8
157+	N.D.	N.D.	1.20	1.15	0.39	10.1	27.1	6.2	N.D.	59.4

N.D. = Not determined

PROFILE 8

SOIL NAME: Choma Series

LOCATION: Mukonchi East Block

PHYSIOGRAPHY: Very gentle upper slope

PARENT MATERIAL: Granite

DRAINAGE: Well drained

PERMEABILITY: Moderate to moderately rapid

VEGETATION/USE: Miombo woodland

SLOPE: 1 - 2%

SAMPLED: AUTHOR, 14/8/74

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0-10	Brownish black (10YR 3/2) moist and brownish grey (10YR 6/1) dry, loamy sand; massive; very slightly sticky, very slightly plastic wet, extremely friable moist, soft dry; many fine and very fine pores; many fine, few medium roots; clear smooth boundary.
B1	10-20	Yellowish brown (10YR 5/3) moist and dull orange (10YR 7/3) dry, loamy sand; massive; very slightly sticky, very slightly plastic wet, very friable moist, slightly hard dry; many fine, common medium, few coarse pores; many fine, few medium and coarse roots; gradual smooth boundary.
B21t	20-40	Strong brown (7.5YR 5/6) moist and dull orange (7.5YR 7/3) dry, sandy loam; massive; sticky, plastic wet, very friable moist, slightly hard dry; many fine and few medium pores; many fine, few medium and coarse roots; gradual smooth boundary.
B22t	40-60	Strong brown (7.5YR 5/6) moist and orange (7.5YR 7/6) dry, sandy clay loam; massive; sticky, plastic wet, very friable moist, slightly hard dry; many fine and medium, few coarse pores; many fine, few medium and coarse roots; gradual smooth boundary.
B23t	60-80	Ditto but sandy clay.
B24t	80-110	Ditto but sandy clay; many fine, few medium and coarse roots.
C	110+	Ditto, but sandy clay; weathered rock; with many medium prominent indurated red (10R 4/6) mottles; mottles slightly hard, matrix friable; many fine roots.

ANALYTICAL DATA

U.S.D.A. Classes

Depth (cm)	Clay < 0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-10	9	7	28	41	15
10-20	9	5	35	37	14
20-40	15	23	32	18	12
40-60	32	7	23	27	11
60-80	45	6	19	21	9
80-110	47	7	17	19	10
110+	45	8	16	19	12

Depth(cm)	Org.C %	Total N %	Ex.Ca. m.e.%	Ex.Mg. m.e.%	Ex.K. m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0-10	1.21	0.050	2.75	1.25	0.43	5.3	83.6	5.9	20	58
10-20	0.35	0.022	1.00	0.80	0.45	3.5	64.3	5.5	22	25.5
20-40	0.31	0.020	1.00	1.00	0.57	5.1	50.4	5.2	16	26.6
40-60	N.D.	N.D.	2.40	0.82	1.05	5.4	79.1	4.6	N.D.	16.1
60-80	N.D.	N.D.	2.70	2.28	1.20	8.2	75.4	5.0	N.D.	18.2
80-110	N.D.	N.D.	2.10	2.15	1.11	8.8	60.9	5.5	N.D.	18.7
110+	N.D.	N.D.	1.75	1.15	0.98	6.9	56.2	5.3	N.D.	15.3

N.D. = Not determined

PROFILE 9

SOIL NAME: Chongwe Series

LOCATION: Mkushi W. Block

PHYSIOGRAPHY: Gentle middle slope

PARENT MATERIAL: Biotite-Gneiss

DRAINAGE: Well drained

PERMEABILITY: Moderately rapid

VEGETATION/USE: Miombo woodland

SLOPE: < 3%

SAMPLED: O. HAUGBOTN, 31/7/74

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0-12	Very dark greyish brown (10YR 3/2) sand; massive; soft dry; many fine, common medium, pores; penetrated by roots.
B1	12-31	Dark yellowish brown (10YR 4/4) loamy sand; massive; slightly hard dry; many fine, common medium, pores; many fine, common medium roots.
B21	31-55	Strong brown (7.5YR 5/6) sandy loam; massive; hard dry; many fine, common medium, pores; many fine, few medium, roots.
B22	55-133	Strong brown (7.5YR 5/8) sandy clay loam; massive; hard dry; many fine, few medium, pores; common fine roots.
B23	133-170	Strong brown (7.5YR 5/8) sandy clay loam; massive; slightly hard dry; common fine pores; few fine roots.

ANALYTICAL DATA

U.S.D.A. Classes

Depth (cm)	Clay < 0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.5 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-12	0	5	24	51	20
12-31	6	6	23	45	20
31-55	16	4	22	41	17
55-90	34	5	17	30	14
90-133	30	3	22	32	13
133-170	34	2	20	28	16

Depth (cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0-12	1.05	0.062	2.80	0.80	0.25	4.0	96	5.9	19	-
12-31	0.31	0.020	1.80	0.62	0.19	2.8	93	6.3	15	29
31-55	0.31	0.030	2.35	0.98	0.24	2.8	100	6.7	N.D	10
55-90	N.D.	N.D.	2.40	1.62	0.57	4.5	100	6.4	N.D	13
90-133	N.D.	N.D.	2.00	0.90	0.60	3.6	100	6.5	N.D	12
133-170	N.D.	N.D.	3.05	1.80	1.32	6.8	91	6.2	N.D	20

N.D. = Not determined

PROFILE 10

SOIL NAME: Chongwe Series

LOCATION: Zamic Chisamba Farms

PHYSIOGRAPHY: Long gentle middle slope

PARENT MATERIAL: Gneiss/Schist

DRAINAGE: Moderately well drained

PERMEABILITY: Moderately rapid

VEGETATION/USE: Cleared Miombo woodland

SLOPE: 1-2%

SAMPLED: AUTHOR, 29/11/73

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0-23	Dark greyish brown (10YR 4/2) moist and greyish brown (10YR 5/2) dry, organic stained, loamy sand; single grain, becoming coherent below 10cm; non-sticky, non-plastic wet, loose, becoming extremely friable moist and slightly hard dry below 10 cm; many fine and very fine pores; many fine roots; abrupt, wavy boundary.
B1	23-48	Yellowish brown (10YR 5/6) moist and brownish yellow (10YR 6/6) dry, sandy loam; massive; slightly sticky, slightly plastic wet, extremely friable moist, hard dry; many very fine, few fine and medium, pores; common, fine grit; many fine, few medium and large, roots; gradual, smooth boundary.
B21	48-70	Brownish yellow to light yellowish brown (10YR 5.5/6) moist and yellow (10YR 7/6) dry, sandy clay loam; massive; slightly sticky, slightly plastic wet, extremely friable moist, hard dry; many very fine, common fine, and few medium, pores; common fine grit; many fine, few medium and large, roots; gradual smooth boundary.
B22	70-100/123	Yellowish brown (10YR 5/6) moist and yellow (10YR 7/6) dry, sandy clay loam; massive; sticky, plastic wet, extremely friable moist, slightly hard dry; many very fine, common fine, and few medium, pores; common fine grit; many fine and medium, few large, roots; abrupt, wavy boundary.
B3	100/123-137	Yellowish brown (10YR 5/6) moist and yellow (10YR 7/6) dry, sandy clay loam; massive; sticky, plastic wet, very friable moist, slightly hard dry; many fine and medium pores; many medium and coarse quartz gravel and ironstained stones; many fine roots; clear, wavy boundary.
C	137-167+	Brownish yellow and red (10YR 6/8 and 2.5YR 4/6) moist and yellow and red (10YR 7/8 and 2.5YR 4/6) dry, highly weathered rock; massive; sticky, plastic wet, extremely friable moist, very hard dry; many fine and medium pores; many fine and coarse gravel; many hard and soft lateritic and manganese concretions; many fine roots.

ANALYTICAL DATA

	International Classes				U.S.D.A. Classes			
Depth (cm)	C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0-23	40.6	50.8	1.2	7.4	7.7	44.3	33.6	7.0
23-48	36.4	44.0	2.2	17.4	8.8	37.4	31.2	5.2
48-70	41.4	36.0	0.2	22.4	6.3	29.9	31.8	9.6
70-100/123	34.6	38.8	2.2	24.4	8.8	32.2	26.3	8.3
100/123-137	44.0	34.4	1.2	20.4	9.6	26.0	30.4	13.6
137-167	44.7	35.7	4.2	15.4	12.4	27.5	27.0	17.7

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0-23	0.62	0.026	1.25	0.20	0.10	3.5	44.3	4.9	28.0	47.3
23-45	0.31	0.018	1.40	0.40	0.12	4.4	43.6	5.9	4.5	25.3
48-70	0.23	0.012	1.15	0.88	0.12	4.0	53.8	6.0	3.0	17.8
70-100/123	N.D.	N.D.	0.90	0.90	0.16	3.8	51.6	6.3	N.D.	15.6
100/123-137	N.D.	N.D.	1.00	0.73	0.24	4.4	44.8	6.2	N.D.	21.6
137-167	N.D.	N.D.	1.65	0.45	0.41	4.3	58.4	6.0	N.D.	27.9

PROFILE 11

SOIL NAME: Kalomo Series

LOCATION: Zamic Chisamba Farms

PHYSIOGRAPHY: Long gentle middle slope

PARENT MATERIAL: Gneiss/Schist

DRAINAGE: Well drained

PERMEABILITY: Rapid

VEGETATION/USE: Cleared Miombo woodland

SLOPE: 2%

SAMPLED: AUTHOR 29/11/73

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0–16	Dark greyish brown (10YR 4/2) moist and light brownish grey (10YR 6/2) dry, organic stained, loamy sand; massive; non-sticky, non-plastic wet, soft; many fine and very fine, common medium, pores; many fine roots; abrupt wavy boundary.
B11	16–33	Yellowish Brown (10YR 5/6) moist and dry, (with organic traces), loamy sand; massive; non-sticky, non-plastic, soft; many fine and very fine, common medium pores; many fine, common medium and large roots; gradual, smooth boundary.
B12	33–60	Strong brown (7.5YR 5/6) moist and reddish yellow (7.5YR 6/6) dry, loamy sand; massive; non sticky, non-plastic wet, soft; many fine and very fine pores; many fine, few medium and large roots; gradual, smooth boundary.
B13	60–71	Strong brown (7.5YR 5/6) moist and reddish yellow (7.5YR 6/6) dry, sandy loam; massive; very slightly sticky, very slightly plastic wet, soft; many fine and very fine roots; many fine, common medium and few large roots, clear, smooth boundary.
B21	71–80	Yellowish red (5YR 5/8) moist and reddish yellow (5YR 6/8) dry, sandy clay loam; massive; slightly sticky, slightly plastic wet, friable hard dry; many fine and very fine pores; many fine, common medium and few large, roots; clear smooth boundary.
B22	80–85	Yellowish red (5YR 5/8) moist and reddish yellow (5YR 6/8 dry, sandy clay loam; massive; sticky, plastic wet, friable moist, hard dry; many fine and very fine, common medium, pores; many fine, common medium and few large, roots; clear, smooth boundary.
B23	85–170+	Ditto; but few coarse pores above 120 cm.

ANALYTICAL DATA

Depth (cm)	International Classes: C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %	U.S.D.A. Classes: Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0–16	42.0	51.4	1.2	5.4	7.2	45.4	37.2	4.8
16–33	39.0	52.4	1.2	7.4	7.7	45.9	32.4	6.6
33–60	39.2	51.2	1.2	8.4	9.9	42.5	32.1	7.1
60–71	34.2	50.4	1.2	14.2	10.0	41.6	32.9	1.3
71–80	32.6	41.8	2.2	23.4	7.5	36.5	28.4	4.2
80–85	34.0	39.4	1.2	25.4	7.6	33.0	28.8	5.2
85–120	31.3	38.1	0.2	30.4	4.9	33.4	28.2	3.1
120–170	31.1	41.5	0.0	27.4	4.5	37.0	26.1	5.0

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K. m.c.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–16	0.74	0.34	1.65	0.30	0.11	4.1	50.3	4.8	33.0	29.6
16–33	0.35	0.018	0.80	0.28	0.08	1.8	64.5	5.0	2.0	24.3
33–60	N.D.	N.D.	0.65	0.30	0.10	1.5	70.0	5.4	N.D.	17.9
60–71	N.D.	N.D.	0.75	0.58	0.12	2.3	63.0	5.6	N.D.	16.2
71–80	N.D.	N.D.	1.00	1.00	0.24	4.4	51.0	5.5	N.D.	18.8
80–85	N.D.	N.D.	1.00	1.15	0.29	4.7	51.9	5.6	N.D.	18.5
85–120	N.D.	N.D.	1.15	1.08	0.46	5.4	49.8	5.6	N.D.	17.8
120–170	N.D.	N.D.	0.95	0.80	0.45	4.6	47.8	5.7	N.D.	16.8

N.D. = Not determined

PROFILE 12

SOIL NAME: Luano Series

LOCATION: Mukonchi East Block

PHYSIOGRAPHY: Dambo Head

PARENT MATERIAL: Granite

DRAINAGE: Imperfect to poor

PERMEABILITY: Rapid in upper horizons
Very slow in lower horizons

VEGETATION/USE: Miombo woodland fringe

SLOPE: 2%

SAMPLED: AUTHOR 14/8/74

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0–10	Brownish black (10YR 3/1) moist and brownish grey (10YR 6/1) dry, sand; single grain; non-sticky, non-plastic wet, loose; many fine and very fine pores, many fine roots; clear smooth boundary.
A21g	10–65	Dull yellow orange (10YR 6/3) becoming brownish yellow (2.5YR 6/3) moist, and dull orange (10YR 7/2) dry, sand; with common medium and distinct strong brown (7.5YR 5/8) moist, mottles from 30cm. Single grain; non-sticky, non-plastic wet, loose becoming extremely friable moist and very slightly hard dry with depth; many fine and very fine, few coarse pores; many fine, common medium and few coarse roots; clear smooth boundary.
A22g	65–77	Light brownish grey (2.5Y 6/2) moist and light grey to grey (2.5Y 6/1) dry, sandy loam, with many medium and and coarse distinct strong brown (7.5YR 5/8) moist mottles; massive; sticky, plastic wet, very friable moist, extremely hard dry; many fine, few medium and coarse pores; many fine, common medium and few coarse, roots; gradual smooth boundary.
B2g	77–125+	Light brownish grey (2.5Y 6/2) moist and dry, sandy clay loam; massive; very sticky, very plastic wet, very friable moist, extremely hard dry; many fine and medium, few coarse, pores; few fine and medium roots.
	Note	Iron rich quartz layer (5mm. thick) at 90cm.

ANALYTICAL DATA

U.S.D.A. Classes

Depth (cm)	Clay < 0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0–10	3	6	50	34	7
10–20	4	5	44	36	11
20–30	4	5	45	36	10
30–65	5	6	49	32	8
65–77	17	6	44	27	6
77–90	26	6	44	19	5
90–125	30	5	37	22	6
125+	30	7	35	21	7

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–10	0.82	0.042	2.30	2.00	0.15	6.0	74.2	5.1	1	106
10–20	0.27*	0.028	1.10	0.55	0.11	3.4	51.8	5.1	1	63
20–30	0.31	0.020	0.70	0.55	0.11	2.4	56.7	5.5	1	33
30–65	N.D.	N.D.	0.60	0.60	0.22	2.1	67.6	5.9	N.D.	42
65–77	N.D.	N.D.	1.20	0.82	0.65	5.0	53.4	4.7	N.D.	29
77–90	N.D.	N.D.	1.95	1.25	0.90	7.6	53.9	4.7	N.D.	29
90–125	N.D.	N.D.	1.30	1.05	0.67	9.2	32.8	4.6	N.D.	31
125+	N.D.	N.D.	2.00	1.15	0.56	8.0	46.4	4.9	N.D.	27

N.D. = Not determined

* Eroneous figure. Too low in relation to N. and CEC.

PROFILE 13

SOIL NAME: Muchanga Series

LOCATION: Mukonchi East Block

PHYSIOGRAPHY: Dambo Head

PARENT MATERIAL: Granite

DRAINAGE: Imperfect to poor

PERMEABILITY: Very rapid

VEGETATION/USE: Miombo woodland fringe

SLOPE: 1%

SAMPLED: AUTHOR 14/8/72

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
	+1-0	Recent wash cover of whitish coarse sand.
A1	0-10	Black (10YR 2/1) moist and brownish grey (10YR 6/1) dry, sand; single grain; non-sticky, non-plastic wet, loose; many fine pores; many fine, common medium, few coarse, roots; clear smooth boundary.
E1	10-20	Ditto but greyish yellow brown (10YR 4/2 + 6/2) moist and dry, respectively.
E2	20-30	Ditto but dull yellow orange (10YR 6/3) moist and light grey (10YR 7/1) dry.
E3	30-50	Ditto but dull yellow orange (10YR 7/2) moist and light grey (10YR 8/1) dry; many fine, few medium roots.
E4	50-70	Ditto
E5	70-90	Ditto but with common coarse distinct yellow brown (10YR 7/6) moist, indurated mottles:
B1	90-110	Ditto but loamy sand; massive; slightly sticky, slightly plastic wet, extremely friable moist, soft dry.
B	110+	Ditto but sandy loam.

ANALYTICAL DATA

Depth (cm)	Clay < 0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
			U.S.D.A. Classes		
+1-0	0	1	89	9	1
0-10	1	8	57	26	8
10-20	1	8	58	26	7
20-30	1	7	57	26	9
30-50	3	6	48	28	15
50-70	2	8	51	28	11
70-90	3	8	55	25	9
90-110	11	6	56	20	7
110+	16	8	46	22	8

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
+1-0	0.58	0.024	1.70	0.95	0.11	3.7	74.6	5.1	N.D.	-
0-10	0.09	0.048	3.70	1.08	0.20	8.2	60.7	5.0	1	-
10-20	0.43	0.020	1.55	0.82	0.18	2.6	98.1	5.9	2	-
20-30	0.23	0.012	1.25	0.72	0.15	2.5	84.8	6.2	1	-
30-50	N.D.	N.D.	1.00	0.65	0.14	1.1	100.0	6.4	N.D.	37
50-70	N.D.	N.D.	1.25	0.48	0.17	1.0	100.0	6.5	N.D.	50
70-90	N.D.	N.D.	1.50	1.12	0.21	1.5	100.0	6.5	N.D.	50
90-110	N.D.	N.D.	1.30	1.45	0.63	4.4	76.8	5.7	N.D.	40
100+	N.D.	N.D.	2.90	1.48	0.74	5.4	94.8	4.5	N.D.	34

N.D. = Not determined

PROFILE 14

SOIL NAME: Unclassified Pediment soil

LOCATION: Zamic Chisamba Farms

PHYSIOGRAPHY: Gentle Pediment slope

PARENT MATERIAL: Quartzite + Gneiss/Schist

DRAINAGE: Very well drained

PERMEABILITY: Moderately rapid

VEGETATION/USE: Cleared Miombo woodland

SLOPE: 3%

SAMPLED: AUTHOR 30/11/73

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0–18	Dark reddish brown (5YR 3/4) moist and brown (7.5YR 5/4) dry, loamy sand; massive; non-sticky, non-plastic wet, extremely friable moist, slightly hard dry; many very fine pores; many fine roots; clear smooth boundary.
B1	18–37	Reddish brown (5YR 4/4) moist and dry, sandy loam; massive; very slightly sticky, very slightly plastic wet, extremely friable moist, slightly hard dry; many very fine, common fine, pores; many fine roots; gradual, smooth boundary.
B21	37–49	Red (2.5YR 4/6) moist and dry, sandy clay loam; massive; slightly sticky. slightly plastic wet, extremely friable moist, slightly hard dry; many fine and very fine, few medium, pores; many fine, few medium, roots; gradual, smooth boundary.
B22	49–115	Red (2.5YR 4/6) moist and (2.5YR 5/6) dry, sandy clay loam; massive; sticky, plastic wet, extremely friable moist, slightly hard dry; many fine and very fine, common medium, pores; many fine, few medium, roots; gradual, smooth boundary.
B23	115–150	Ditto; but many fine and very fine, common medium, pores; many fine, common medium, roots.
B24	150–190	Ditto, but many fine and very fine, common medium, pores; many fine, common medium, roots.

ANALYTICAL DATA

Depth (cm)	International Classes: C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %	U.S.D.A. Classes: Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm %	C.Sand 0.5/2.0 mm. %
0–18	36.0	53.0	2.4	8.6	9.2	46.2	30.5	5.5
18–37	38.0	46.0	2.4	13.6	9.5	38.9	32.4	5.6
37–49	36.4	40.6	2.4	20.6	7.9	35.1	30.2	6.2
49–78	40.3	34.7	1.4	23.6	5.8	30.3	33.0	7.3
78–115	35.6	35.4	2.4	26.6	6.3	31.5	31.5	4.1
115–150	31.8	38.2	2.4	27.6	6.4	34.2	24.0	7.8
150–190	27.4	42.6	2.4	27.6	9.8	35.2	21.5	5.9

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–18	0.66	0.032	2.20	0.30	0.24	4.7	58.3	N.D.	70	54.6
18–37	0.51	0.030	1.10	0.32	0.22	4.4	37.3	4.4	64	32.4
37–49	0.31	0.022	1.50	0.40	0.27	5.0	43.4	5.0	34	24.3
49–78	N.D.	N.D.	1.50	0.75	0.26	4.2	59.8	5.6	N.D.	17.8
78–115	N.D.	N.D.	1.10	0.78	0.18	7.4	27.8	6.0	N.D.	27.8
115–150	N.D.	N.D.	1.20	0.85	0.32	4.3	55.1	5.9	N.D.	15.6
150–190	N.D.	N.D.	0.40	0.40	0.17	4.3	22.6	5.3	N.D.	15.6

N.D. = Not determined

PROFILE 15

SOIL NAME: Kabwe Series

LOCATION: Kabwe Research Station

PHYSIOGRAPHY: Level upland

PARENT MATERIAL: ?

DRAINAGE: Moderately well drained

PERMEABILITY: Rapid in topsoil and upper subsoil. Moderate in lower subsoil.

VEGETATION/USE: Cleared Miombo woodland

SLOPE: < 1%

SAMPLED: O. HAUGBOTN. AUG 1973

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0–7	Very dark grey (10YR 3/1) loamy sand; massive; slightly hard dry; many fine pores; penetrated by roots.
B21	7–18	Brown (10YR 5/3) loamy sand, massive; slightly hard dry; many fine pores; penetrated by roots.
B22	18–34	Brown (10YR 5/3) loamy sand; massive; slightly hard dry; many fine pores; penetrated by roots.
B23	34–54	Yellowish brown (10YR 5/4) loamy sand; massive; hard dry; many fine pores; penetrated by roots.
B24	54–63	Brownish yellow (10YR 6/6) sandy loam; very weak subangular blocky; hard dry; common fine pores; penetrated by roots.
B31	63–80	Brownish yellow (10YR 6/6) sandy clay loam with common fine distinct yellowish red mottles; weak subangular blocky; hard dry; common fine pores; penetrated by roots.
B32	80–100	Ditto but massive; gravelly; penetrated by a few small roots.
?	100+	Impenetrable quartz gravel/laterite layer.

ANALYTICAL DATA

U.S.D.A. Classes

Depth (cm)	Clay <0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0–7	4	8	48	38	2
7–18	4	8	34	50	4
18–34	4	8	54	31	3
34–54	2	12	48	34	4
54–63	13	11	34	37	5
63–80	28	18	26	25	3
80–100	26	11	24	31	8

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–7	1.11	0.048	2.5	0.6	0.1	5.9	54.4	5.4	20	52.5
7–18	0.26	0.018	0.8	0.4	0.03	1.8	65.6	5.6	14	45.0
18–34	0.15	0.010	0.6	0.4	0.05	1.2	77.5	5.8	18	30.0
34–54	N.D.	N.D.	0.6	0.4	0.06	1.6	60.0	5.6	N.D.	80.0
54–63	N.D.	N.D.	1.3	0.8	0.2	3.1	70.9	5.6	N.D.	23.8
63–80	N.D.	N.D.	1.7	1.1	0.3	6.8	46.2	5.6	N.D.	24.3
80–100	N.D.	N.D.	1.5	1.1	0.3	6.0	46.5	5.5	N.D.	23.1

N.D. = Not determined

PROFILE 16

SOIL NAME: Kabuyu Series

LOCATION: Pit to west of Kabuyu railroad Siding, 31 miles N. of Livingstone

PHYSIOGRAPHY: Level upland

PARENT MATERIAL: ?

DRAINAGE: Excessive

PERMEABILITY: Rapid

VEGETATION/USE: Miombo woodland

SLOPE: < 3%

SAMPLED: T.U. YAGER

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0–25	Brown (7.5YR 5/4–4/4) sand; structureless; loose when moist; clear boundary.
B1	25–60	Brown (7.5YR 4/4) sand; structureless; loose to very friable when moist; gradual boundary.
B21	60–100	Strong brown (7.5YR 5/6) loamy sand; structureless; loose to very friable when moist; diffuse boundary.
B22	100–195	Similar to B21
B23	195–330	Strong brown (7.5YR 5/6) loamy sand; loose to very friable when moist.

ANALYTICAL DATA

Depth (cm)	International Classes: C.Sand 2.0/0.2 mm. %	F.Sand 0.2/0.02 mm. %	Silt 0.02/0.002 mm. %	Clay <0.002 mm. %
0–25	56	38	1	5
25–60	60	32	1	7
60–100	57	32	2	9
125–150	52	38	2	8
315–330	51	39	1	9

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–25	0.35	0.026	1.0	0.1	0.1	1.4	84	6.3	N.D.	-
25–60	0.12	0.022	0.5	0.1	0.1	1.2	57	6.3	N.D.	17
60–100	0.08	0.016	0.3	traces	0.2	1.2	43	5.6	N.D.	13
125–150	0.12	0.014	0.5	9.1	0.1	0.8	76	5.8	N.D.	10
315–330	0.04	0.008	0.4	0.3	0.1	0.8	91	6.2	N.D.	9

N.D. = Not determined

Note: Texture classes for this profile are those of the 'International' system

PROFILE 17

SOIL NAME: Chapya Series

LOCATION: Kabwe Res. Station

PHYSIOGRAPHY: Level upland

PARENT MATERIAL: ?

DRAINAGE: Moderately well

PERMEABILITY: Moderately rapid

VEGETATION/USE: Miombo woodland

SLOPE: < 1%

SAMPLED: O. HAUGBOTN. AUG 1973

PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	
A1	0–20	Yellowish brown (10YR 4/2) loamy sand; massive; slightly hard dry; many fine pores; penetrated by roots.
B21	20–38	Ditto, but yellowish brown (10YR 5/4) pores
B22	38–55	Ditto, but hard dry.
B23	55–75	Ditto, but with wavy horizontal cracks; many roots.
B24	75–94	Light yellowish brown (2.5Y 6/4) sandy loam with common fine faint yellowish red mottles; very weak subangular blocky; hard dry; many fine pores; many roots.
B25	94–138	Ditto, but many fine distinct yellowish red mottles; common fine pores; few roots.
B26	138–180	Light grey (10YR 7/2) sandy loam with many fine and medium, distinct yellowish brown mottles; massive; hard dry; common fine pores; no roots.
B3	180–250	Ditto, but light grey (10YR 6/1); mottles prominent.

ANALYTICAL DATA

U.S.D.A. Classes

Depth (cm)	Clay < 0.002 mm. %	Silt 0.002/0.05 mm. %	F.Sand 0.05/0.2 mm. %	M.Sand 0.2/0.5 mm. %	C.Sand 0.5/2.0 mm. %
0–20	4	11	54	26	5
20–38	4	11	54	26	5
38–55	4	11	54	26	5
55–75	6	12	47	31	4
75–94	17	11	43	26	3
94–138	17	11	43	26	3
138–180	12	8	43	28	9
180–250	15	16	41	19	9

Depth(cm)	Org.C %	Total N %	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.K m.e.%	CEC m.e.%	BSP	pH	Av.P ppm	CEC/Clay m.e.%
0–20	0.41	0.024	1.0	0.3	0.1	2.2	60.4	5.4	12	55.0
20–38	0.18	0.016	0.6	0.3	0.1	1.6	61.2	5.4	10	40.0
38–55	N.D.	N.D.	0.7	0.4	0.1	1.6	70.6	5.1	N.D.	40.0
55–75	N.D.	N.D.	0.5	0.3	0.1	1.8	49.4	4.9	N.D.	30.0
75–94	N.D.	N.D.	1.3	0.7	0.2	3.8	56.0	4.8	N.D.	22.4
94–138	N.D.	N.D.	1.2	0.7	0.1	3.6	56.7	4.9	N.D.	21.2
138–180	N.D.	N.D.	0.9	0.6	0.1	2.4	60.8	4.8	N.D.	20.0
180–250	N.D.	N.D.	1.2	1.0	0.1	3.8	59.7	4.8	N.D.	25.3

N.D. = Not determined

APPENDIX 2

EROSION CLASSIFICATION

Visible evidence of soil erosion at or in the vicinity of a sampling point, or within a mapping unit, is classified as follows:

1. No apparent erosion:
2. Slight erosion: Slight loss of topsoil by sheet erosion.
3. Moderate erosion: Loss of topsoil by sheet erosion or slight gullying by small run-off channels (rills); or presence of a few large gullies at very wide intervals not sufficient to interfere with cultivation on a normal field scale.
4. Severe erosion: Severe or very severe loss of topsoil by sheet erosion, exposing the subsoil; or presence of many small and/or large gullies sufficient to hinder or prevent normal cultivation.

APPENDIX 3

WETNESS CLASSIFICATION

No Wetness Apparent. The soil is well to excessively drained. Water is removed sufficiently quickly from the soil surface and rooting zone that plant growth is not restricted by waterlogging. Well drained soils are usually strong brown to red in colour but may be yellower or paler in sands.

Slight Wetness. The soil is moderately well drained. It is wet for short periods following heavy rainfall or the water-table rises to between 60-90cm from the ground surface during the rainy season. Drainage is sufficiently impeded to prevent the cultivation of deeprooting crops or crops particularly sensitive to wetness (e.g. cotton, Virginia tobacco, some vegetables). Moderately well drained soils generally have some grey mottles present between 60-90cm (as well as yellow, brown or red mottles); or, if grey mottles are absent from this layer, the soils have yellow-brown or pale brown colours dominant between 30-90cm in loamy or clayey soils (Munsell colour hues 10YR or 2.5Y and chromas of 4 or higher).

Moderate Wetness. The soil is imperfectly drained. It is wet for considerable periods during the growing season. Conditions are too wet for normal dry-land crops unless these are cultivated on high ridges or beds, or unless artificial drainage is provided. Imperfectly drained soils are generally predominantly grey or dark grey throughout the subsoil or have grey mottles (together with yellow, brown or red mottles) starting at between 30-60cm from the ground surface. Rusty root channels are usually absent from the topsoil, but may be present where water has stood on the soil surface in cultivated fields. Chromas of the matrix colour are generally below 4.

Severe Wetness. The soil is poorly or very poorly drained: i.e. it is wet for most or all the growing season, preventing the cultivation of dry-land crops (without artificial drainage).

Cultivation of rice and dry-season grazing may be possible. The soils are usually grey or dary grey throughout the subsoil and may be black or peaty in the topsoil. Rusty root channels are visible in the topsoil within 30cm from the ground surface.

APPENDIX 4

SUCCESSIVE HOURLY WATER INFILTRATION RATES (cm/hr) FOR MUSHEMI AND CHOMA SERIES

(Data from investigations carried out at Chisamba Farms).

PIT No.	SOIL SERIES	HOUR	INFILTROMETER SITES					MEAN	STANDARD ERROR	CO-EFFICIENT OF VARIATION
			1	2	3	4	5			
2	MUSHEMI	1	12.3	10.5	12.0	15.7	11.8	12.5	0.9	16.0
		2	3.5	3.6	4.5	4.3	5.3	4.2	0.3	17.2
		3	2.5	2.7	2.7	3.6	3.1	2.9	0.2	15.1
10	MUSHEMI	1	12.4	17.3	18.1	10.6	10.8	13.8	1.6	26.0
		2	5.2	6.1	5.9	4.8	4.2	5.2	0.4	14.9
		3	4.8	6.1	5.2	5.6	5.8	5.5	0.2	9.3
12	MUSHEMI	1	14.5	14.3	15.5	15.6	22.2	16.4	1.5	20.0
		2	8.0	12.8	12.6	15.6	10.7	11.9	1.3	23.5
		3	5.7	9.8	9.6	9.4	9.3	8.8	0.8	19.6
1	CHOMA	1	2.8	2.8	7.7	2.3	2.1	3.5	1.0	66.0
		2	1.5	4.1	3.1	1.7	1.1	2.3	0.6	54.4
		3	1.1	1.7	2.1	0.8	0.9	1.3	0.3	42.4
9	CHOMA	1	27.6	11.6	19.2	25.9	17.5	20.4	2.9	32.0
		2	13.4	9.2	15.0	16.4	10.9	13.0	1.3	22.7
		3	10.8	7.6	11.0	11.2	8.3	9.2	1.0	17.3
3	CHOMA	1	2.8	4.7	3.4	5.5	3.6	4.0	0.5	27.0
		2	1.6	1.4	2.0	1.8	1.5	1.7	0.1	14.5
		3	1.6	1.5	1.6	1.7	1.3	1.5	0.1	9.7
11	CHOMA	1	24.5	25.0	39.0	22.3	42.8	30.7	4.2	31.0
		2	10.9	9.7	16.5	10.3	16.0	12.7	1.5	26.0
		3	7.7	7.6	11.1	7.4	12.5	9.3	1.1	25.6

APPENDIX 5

PHYSICAL CHARACTERISTICS OF MUSHEMI AND CHOMA SERIES

Symbols

R = Infiltrometer site at selected pit.

B.D. = Bulk Density g/cc.

P.D. = Particle Density g/cc

$\frac{1}{3}$M, 15M = Moisture content at $\frac{1}{3}$ & 15 bars(%).

A.M. = Available Moisture

C.S. = Clay and Sand percentages

T. = Texture

Texture Symbols

S = Sand

LS = Loamy sand

SL = Sandy loam

SCL = Sandy clay loam

SC = Sandy clay

Pit No	R	Soil Series	Depth cm	B.D.	P.D.	T.D.	$\frac{1}{3}$M	15M	A.M.	C.	S.	T.
2		Mushemi	0–12	1.47	2.72	46.0	13.1	6.5	6.6	15.0	10.9	SL
			20–28	1.42	2.50	43.2	17.0	7.9	9.1	30.0	10.3	SCL
			40–48	1.44	2.70	46.7	18.3	8.1	10.2	34.0	10.2	SCL
			66–72	1.39	2.60	46.5	18.2	10.9	7.3	37.0	11.3	SC
			104–112	1.33	2.63	49.5	16.6	8.1	8.5	38.0	12.0	SC
2	1	Mushemi	0–12	1.58	2.80	43.6	14.9	6.7	8.2	17.0	12.4	SL
	2		0–12	1.58	2.61	39.5	14.0	6.0	8.0	16.0	8.8	SL
	3		0–12	1.46	2.40	39.2	14.0	7.5	6.5	19.0	12.4	SL
	4		0–12	1.51	2.54	40.6	13.2	7.2	6.0	15.2	10.6	SL
	5		0–12	1.53	2.60	41.3	14.5	6.5	8.0	12.2	9.0	SL
10		Mushemi	0–12	1.52	2.51	39.4	13.9	6.4	7.5	19.2	10.7	SL
			26–34	1.45	2.60	44.2	14.9	7.9	7.0	25.2	10.0	SCL
			60–68	1.42	2.50	43.2	16.6	9.1	7.5	31.2	9.7	SCL
			78–86	1.39	2.60	46.5	17.3	7.2	10.1	33.2	11.0	SCL
			110–118	1.32	2.82	53.2	18.1	9.2	8.9	33.2	12.5	SCL
10	1	Mushemi	0–12	1.46	2.71	46.1	16.2	5.9	10.3	16.4	15.8	SL
	2		0–12	1.45	2.82	48.6	17.2	5.6	11.6	16.6	14.3	SL
	3		0–12	1.50	2.62	42.7	14.0	5.4	8.6	15.4	12.8	SL
	4		0–12	1.47	2.50	41.1	14.1	6.4	7.7	6.7	13.4	LS
	5		0–12	1.65	2.61	36.8	15.5	6.6	8.9	10.4	16.4	SL
12		Mushemi	0–12	1.48	2.61	43.3	15.1	4.8	10.3	20.2	10.2	SCL
			22–30	1.50	2.30	34.8	18.3	7.4	10.9	20.0	14.0	SL/SCL
12	1	Mushemi	0–12	1.54	2.80	45.0	15.9	5.7	10.2	13.2	10.4	SL
	2		0–12	1.61	2.63	38.8	13.7	4.4	9.3	13.2	9.2	SL
	3		0–12	1.57	2.43	35.4	13.7	4.3	9.4	11.2	10.3	SL
	4		0–12	1.69	2.90	41.7	13.1	4.5	8.6	12.7	10.6	SL
	5		0–12	1.60	2.85	43.9	10.2	4.2	6.0	11.2	9.3	SL

APPENDIX 5 (CONTD.)

Pit No.	R	Soil Series	Depth cm	B.D.	P.D.	T.D.	$\frac{1}{3}$M	15M	A.M.	C.	S.	T.
			0–12	1.57	2.66	41.0	13.0	3.4	9.6	10.0	8.1	LS
			30–38	1.55	2.51	38.2	19.9	7.2	12.7	24.0	7.8	SCL
1		Choma	54–62	1.39	2.48	43.5	18.2	8.8	9.4	29.0	9.4	SCL
			84–92	1.33	2.45	45.7	17.2	8.6	10.6	29.0	9.4	SCL
	1		0–12	1.46	2.58	43.4	12.3	4.7	7.6	10.0	10.3	LS/SL
	2		0–12	1.52	2.68	43.2	13.5	4.3	9.2	11.5	13.9	SL
1	3	Choma	0–12	1.48	2.55	42.0	15.4	4.5	10.9	9.0	14.1	SL
	4		0–12	1.56	2.54	38.5	15.9	4.7	11.2	8.0	11.1	LS
	5		0–12	1.60	2.74	41.6	15.3	5.3	10.0	11.0	17.9	SL
			0–12	1.59	2.60	38.8	15.1	5.1	10.0	12.4	8.2	SL
			28–36	1.50	2.60	42.3	18.1	1.9	10.2	24.4	5.8	SCL
9		Choma	60–68	1.40	2.60	46.1	17.2	8.2	9.0	34.4	6.9	SCL
			130–138	1.31	2.65	50.6	19.2	10.4	8.8	35.4	9.8	SC
	1		0–12	1.35	2.60	48.1	11.4	5.8	5.6	6.4	8.8	LS
	2		0–12	1.49	2.55	41.6	13.3	5.9	7.4	7.4	10.0	LS
9	3	Choma	0–12	1.32	2.50	47.2	12.0	4.7	7.3	8.4	9.8	LS
	4		0–12	1.56	2.50	37.6	11.9	4.9	7.0	7.4	9.6	LS
	5		0–12	1.38	2.40	42.5	12.8	5.7	7.1	7.4	9.5	LS
			0–12	1.60	2.60	38.5	13.5	7.0	6.5	10.0	13.8	SL
			32–40	1.46	2.51	41.8	14.0	7.3	6.7	14.0	14.4	SL
3		Choma	60–68	1.51	2.90	47.9	16.0	9.4	6.6	23.0	11.9	SCL
			80–88	1.61	2.70	40.4	17.3	8.3	9.0	25.0	13.3	SCL
	1		0–12	1.64	2.60	36.9	8.2	3.9	4.3	9.0	13.4	SL
	2		0–12	1.45	2.43	40.3	7.3	3.7	3.6	8.0	14.3	SL
3	3	Choma	0–12	1.64	2.64	37.9	8.4	3.6	4.7	8.0	12.0	LS
	4		0–12	1.51	2.51	39.9	7.1	3.9	3.2	8.0	11.1	LS
	5		0–12	1.61	2.72	40.8	8.5	3.8	4.7	8.0	14.2	LS
			0–12	1.36	2.61	47.9	13.0	4.4	8.6	9.4	8.2	LS
11		Choma	30–38	1.49	2.70	44.8	11.6	5.4	6.1	15.4	8.6	SL
			60–68	1.49	2.74	45.6	20.5	8.6	11.9	24.9	8.0	SCL
	1		0–12	1.55	2.31	32.6	12.7	6.0	6.7	10.9	10.8	SL
	2		0–12	1.48	2.65	44.2	13.6	5.9	7.7	10.4	12.0	SL
11	3	Choma	0–12	1.47	2.63	44.1	11.9	4.2	7.7	9.4	10.9	LS/SL
	4		0–12	1.47	2.50	41.2	13.3	5.0	8.3	10.9	11.1	SL
	5		0–12	1.43	2.70	47.0	14.5	7.6	6.9	10.4	12.4	SL

APPENDIX 6

DEFINITIONS FOR SELECTED SOIL TEMPERATURE AND MOISTURE REGIMES

A. TEMPERATURE REGIMES

1. Isomesic: The mean annual soil temperature is 8°C or higher but lower than 15°C.

2. Thermic: Mean annual soil temperature between 15–22°C with more than 5°C difference between summer and winter temperature at 50cm (or at the base of the soil in shallow profiles).

3. Hyperthermic: Mean annual soil temperature higher than 22° with more than 5° difference between summer and winter temperature at 50cm (or the base of the soil in the shallow profiles).

4. Isothermic/Isohyperthermic: Mean annual soil temperatures as above, respectively, but less than 5°C difference between summer and winter temperatures at 50cm.

B. MOISTURE REGIMES

1. Ustic: In 7 or more years out of 10, the moisture control section is dry in some or all parts for more than 90 days (cumulative), but is not dry in all parts for more than half the year.

2. Udic: The soil is not dry in any part of the moisture control section for as long as 90 days (cumulative).

3. Aquic: The moisture control section is saturated with water long enough for reducing conditions to obtain (probably more than two weeks).

4. Perudic: The moisture control section is continuously, or almost continuously, saturated.