SOIL PRODUCTIVITY RESEARCH PROGRAMME

IN

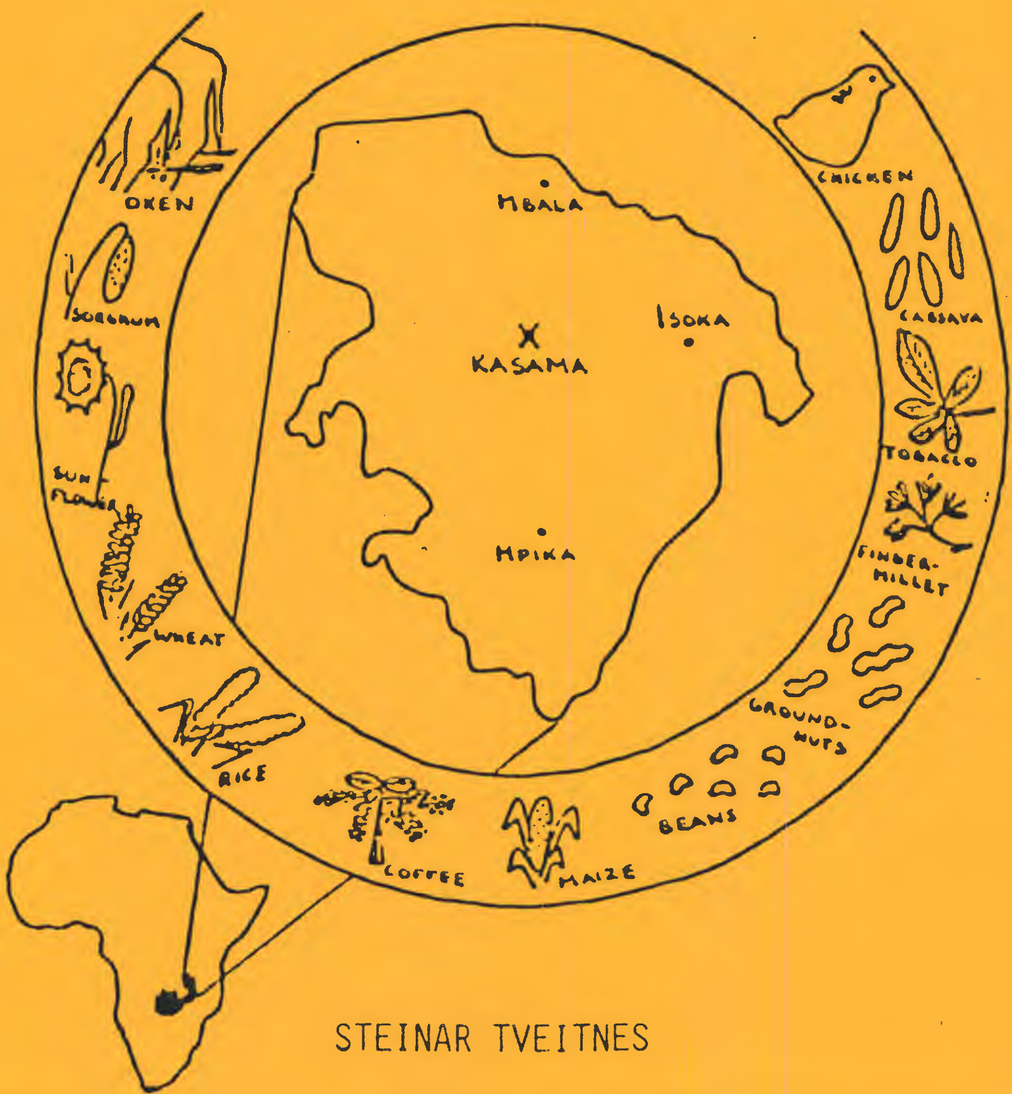
THE HIGH RAINFALL AREAS IN ZAMBIA

REPORT ON PHASE I

1981-1983

PART 1

AN OUTLINE OF SOILS AND SOIL FERTILITY RESEARCH IN THE HIGH RAINFALL AREAS OF ZAMBIA



STEINAR TVEITNES

NORWEGIAN CENTRE FOR INTERNATIONAL AGRICULTURAL DEVELOPMENT

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PUBLISHER'S PREFACE

The Soil Productivity Research Programme (SPRP) in the high rainfall areas of Zambia commmenced in April, 1981. The Programme was initiated on the basis of agreement between the Government of Zambia (GRZ), the Norwegian Agency for International Development (NORAD) and the Agricultural University of NORWAY (AUN).

The work is centered at Misamfu Regional Research Station, Kasama, and covers the Northern, Luapula, Copperbelt and North-Western Provinces in Zambia, approx. 370 000 km^2. The main investigations have been carried out in Northern Province.

The overall aim of the SPRP is to enable Zambian authorities to establish a long term soil productivity research programme which will produce more permanent farming systems in the high rainfall areas for farmers at different levels of technology.

The major target is the smallholders in the designated area.

For the initial period of the project (phase 1) which ends June 30th 1983, AUN has provided senior scientific personell totalling 59 man months plus 21 man months representing graduate students. Staff assigned to SPRP by GRZ has amounted to 2 junior technical officers. The project is expected to continue at an expanded scale.

The emphasis of the investigations in phase I has been to provide better understanding of soil condidtions, crop production and farm managemant systems and their interactions. Information sources have been Department of Agriculture; Research, Land Use and Extension branches, Parastatal agencies, local farmers and relevant literature. In addition, the SPRP's soils, agronomy and agricultural economy sections have carried out field investigations in different parts of the high rainfall areas.

Reports and papers of general interest emerging from this project will be presented in this series.

We gratefully acknowledge the cooperation of the GRS, especially the Research Branch of the Department of Agriculture. We also thank NORAD for its financial support of the SPRP project of which this publication is a part, and the NORAD representation in Zambia for its logistical support and assistance. Finally, we thank the people of the Northern Province for their cooperation and hope that this joint effort may serve their needs.

Halvor J. Kolshus
Ås, February 1986

Preface

The initial phase of the Soil Productivity Research Programme (phase 1) started in April 1981 and ended in June 1983.

Beeing in charge of the soil science part of the programme, I worked closely with my counterpart, H.C.Goma and other members of the SPRP staff. I would like to thank every individual for making a good effort and showing a positive will to cooperate.

H. Steinshamn from the Agricultural University of Norway (AUN) participated as a graduate student for about 3 months in 1983. His thesis was based on material collected during the field work.

H.P.Godfrey from the School of Agricultural Sciences, University of Zambia, made a collection and evaluation of information and structure while he was attached to the SPRP as a graduate student for 2 months in 1982.

These reports have been a useful contribution to the further studies in the soil fertility part of the SPRP.

I should like to express my sincere thanks to all officers and assistants in the Research Branch and the Extension Branch, Department of Agriculture in Zambia for valuable cooperation and assistance.

I should also like to thank the State Soil Investigation, Norway, especially prof. emeritus G.Semb for his contribution in the field of soil analysis, and for valuable advise.

CONTENTS

1. INTRODUCTION.

The high rainfall area of Zambia includes Northern, Luapula, Copperbelt and North-Western Province of Zambia, approximately 370 000 km^2. Most soils in the area are highly weathered and strongly leached ferralsols. Some of the major agricultural constraints are low levels of available plant nutrients, low cation exchange capasity and weak retention of bases applied as fertilizers. In this report, a compilation of existing information on soils and soil fertility in the high rainfall areas of Zambia has been made.

During the initial phase (phase I) of the Soil Productivity Research Programme, an investigation of the nutrient status of cultivated soils in the area has been carried out, and the results are presented.

Detailed experiments designs for field, frame and pot experiments were worked out, and a number of experiments were started during phase I concerning soil fertility problems.

A comparison of soil analysis results obtained in the Soil Survey Unit laboratory, Mt. Makulu Central Research Station, Zambia, and the State Soil Investigation, Aas-NLH, Norway is also included in this report.

2. GEOLOGY

2.1 The Prekibaran system

Much of the Northern and Luapula Provinces is Prekambrian in age, and more than 500 million years old. Grouping of rock types according to age (Reeve 1963) comprise the main groups Basement complex, Muva, Katanga, Karro Kalahari Alluvium and Igneous rocks.

Basement is precambrian in age and consists of granites, gneisses, schists, and limestone. Muva is also precambrian and comprise quartzites, schists, and conglomerates. Both Basements and Muva is metamorphic rock types. Drysdall et. al (1972) subdivided the Basement complex into Kibaran and Prekibaran elements. The Prekibaran element contains schists and gneisses while the Kibaran is far less metamorphosed. The areas with Prekibaran schists and gneisses are south of Mpika and in Isoka districts.

To the north west of the Great North Road in Mpika and Chinsali, mostly Katanga elements are found. The Katanga comprises shales, tillodial conglomerates, argillites, sand stones, grits and limestones.

East of Lake Bangweulu swamps, an area of alluvium is found. Also along the main rivers in Isoka and Chinsali there are areas of alluvium.

2.2 The Kibaran system.

The Kibaran System occupies a large area in the north west, it is called the Plateau Series and comprises most of the Mpika Isoka Ridge Land Region. It comprises also an area in the extreme south west.

The dominant rock types in the Kibaran system are quartzite, micacous flagstone and sandstone. Most outcrops consist of quartzite because of its resistance to weathering.

2.3 The Kundelungu System.

This system is found along the Luapula Valley - where it is called the Luapula Beds - and in the south eastern part of the Chambesi/Bangweulu Plain Land Region. This area is called the Lwitikila Beds.

The Luapula and Lwitikila Beds consist of shale, mudstone, siltstone and sandstone.

2.4 Intrusive rocks, (consolidated from magma).

Granite occupies a central NE to SW zone. It is also scattered throughout the Northern Province with the exception of the Mbala-Kawambwa Land Region. It is deeply, but irregularly weathered. The granites have a variable structure, and are pink to grey.

The Bangweulu craton is a primeval resistant block.

The most extensive faulting is found in the north. The faults are associated with the East Africa Rift Valley system. They form the sides of Lake Tanganyika.

The rocks in the area are mostly acidic, and the basic areas rarely attain diameter greater than about 50 m. The occurance of valuable minerals in limited. Manganese is probably the only mineral of any economic significance especially in the Mansa area (Thieme, 1970).

Limestone is found in the Luapula Beds and can possibly be used as a source of lime.

2.5 The Lufilian arch and the Katanga system.

The Lufilian arch and the Katanga system covers the North Western and Copperbelt Provinces. The Lufilian arch is an organic zone occupied by folded and thrushed geosynclinical rocks of the Katanga system (Drysdall et. al, 1972). It contains late Precambrian and possibly early Paleozoic geosynclinical sediments. The age is found to be 840 - 465 million years. The mineralization in the Copperbelt has taken place in stratiform bodies, usually 10 - 30 m and occasionally 40 m thick.

2.6 Topography and Drainage.

Most of the area lies between 1200 - 1700 m, and forms part of the Central African Plateau. The plateau extends from South Africa to the highlands of Ethiopia.

Slopes are usually very gentle. A very large part of the area having slopes of about 1%.

Soils on the very gentle slopes which occupy most of the area tend to have an intermediate texture. Areas of higher stream frequency and steeper slopes give rise to shallower soil.

The interfluve are at present mostly well protected from soil erosion by vegetation, as evidenced by many rivers which are clear even during the rainy season.

The geomorphic processes are operating very slowly, but this stable situation could easily be reversed by denudation which would lead to soil erosion.

The climate provides ideal conditions for chemical decomposition; i.e. high temperature and soils at field capacity during the rainy season. Deep weathering is prevalent.

2.7 Drainage

The area of Northern and Luapala Provinces are drained by three major river systems: The Chambeshi, the Luangwa and the Luapula. The Kafue, which is a sub drainage system of the Zambezi, is important in the North-Western and the Copperbelt Provinces.

3. CLIMATE

The climate of Zambia is characterized by two main seasons, the dry season and the rainy season.

The dry season starts in early April in the North-Western and Copperbelt Provinces and in May in the Luapula and Northern Provinces. Rain is sporadic and the mean monthly temperature is 15-22°C. Mean monthly temperatures rise to 24°C in September or October, with absolute maximum reaching 35°C. The dry season has a cool period in June/July with mean monthly temperatures of about 16°C. Although frost generally does not occur, a temperature just below zero was recorded in Northern Provinces in 1976. However, the average number of frost days is one per year and two per year for Copperbelt and North-Western Provinces respectively occuring in the month of July. Relative humidity is at its lowest in the hot season ranging from 40-65% while wind speed increases slightly as the wind backs.

The wet season usually starts around mid October and lasts till April in the North-Western and Copperbelt Provinces, while it starts in November over most of Luapula and Northern and lasts till May. Prolonged rain spells are uncommon, although storms become more frequent as the wet season develops. The mean annual rainfall is 1360 mm in this region, the wettest months usually being December of January with mean monthly rainfall maximum of about 280 mm. In southern Zambia the wet season often ends abruptly in mid-March, but in the north-east storm activity steadily decreases through mid or late April. During the wet season, mean monthly temperatures are about 21°C with mean maximum about 10°C higher. Mean relative humidity ranges from 75-85% for most of the year, but decreases towards April.

The annual rainfall in different areas is shown in figure 1. In table 1, the mean monthly rainfall for a number of stations in the high rainfall area is shown.

Table 1. Monthly rainfall distribution for eight selected stations in Northern Zambia (Source: Dept. of Meteorology, Lusaka)

Station		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	TOTAL
Mbala (1)	mm	0	1	5	20	110	220	210	210	230	110	20	1	1125
Mporokoso (82)	mm	0	1	8	55	160	230	220	200	250	120	20	1	1275
Kafulwe (75)	mm	0	3	7	30	120	260	220	210	250	130	12	0	1250
Isoka (13)	mm	0	0	1	11	80	210	230	230	230	65	12	0	1075
Kawambwa (93)	mm	0	1	11	65	170	250	210	190	240	140	16	1	1300
Mpika (164)	mm	0	1	0	7	110	230	300	240	190	25	3	0	1100
Twingulu (157)	mm	0	0	1	12	150	270	320	300	290	50	4	0	1400
Mansa (137)	mm	0	0	1	25	140	240	240	220	220	60	6	0	1150

In the southern part of northern Zambia (Mansa, Twingulu and Mpika), there is a one peak distribution of rainfall which becomes bimodal in the north. The difference is due to the influence of the intertropical convergance zone, and has the effect of lenghening the wet season by 40-50 days in the north west part of the central plateau compared with the south east.

The climatic data for Kasama is shown in table 2.

Table 2.Kasama Climatic data (Source: Dept of Meteorology, Lusaka)

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
Rainfall (mm).Mean Monthly	1	0	2	23	149	226	280	223	245	70	9	1	1360
Mean Temp °C	16.9	18.8	21.6	23.4	21.7	20.1	19.8	19.9	20.1	20.3	18.8	17.1	19.8
Mean Max. Temp. °C	24.7	26.8	29.4	31.1	28.7	26.5	26.0	26.1	26.3	25.6	24.6	24.6	26.9
Abs. Max Temp. °C	28.9	32.8	34.4	35.0	35.0	32.8	31.1	30.0	30.0	31.1	29.4	30.6	35.0
Mean of Abs. Max Temp.	27.2	29.7	32.3	33.3	32.6	29.6	28.9	28.7	28.5	28.3	28.2	27.2	29.5
Mean Min. Temp. °C	9.6	11.1	13.8	16.1	16.5	16.3	16.2	16.3	16.2	15.3	12.6	10.0	15.8
Abs. Min. Temp. °C	4.4	2.8	6.1	11.7	13.3	12.8	13.3	12.8	12.2	10.6	6.7	3.9	2.8
Mean of Abs. Mean Temp.	6.2	7.5	10.3	13.3	14.6	14.5	14.7	14.7	14.7	12.7	9.0	6.6	11.5
Relative Humidity %	55	49	45	43	63	77	82	82	81	75	65	59	60
Sunshine Hrs. per day	10	9.8	9.5	8.6	7.0	5.7	4.2	4.3	5.5	7.8	9.2	9.6	7.6
Rain days 1 mm	0	0	0	1	9	18	16	14	8	3	0	0	69
Rain days 10 mm	0	0	0	1	5	10	11	7	7	1	0	0	42
Frost days	0	0	0	0	0	0	0	0	0	0	0	0	0

The reliability of the rain each year is quite essential for cultivation of crops. Rainfall less than 6 mm in a day mainly adds to evaporation and contributes little to soil moisture.

Table 3. Average number of dry speels per ten years (Dept. of Meteorology, Lusaka)

District	NOV	DEC	JAN	FEB	MAR	SEASON
Kasama						
5 days or more	14.8	9.6	10.0	8.8	13.0	56.2
10 days or more	5.2	3.9	1.3	0.4	3.5	14.3
15 days or more	1.7	1.7	0	0	1.3	4.7
20 days or more	0.4	0	0	0	0.4	0.8
Mansa						
5 days or more	15.8	12.9	11.3	12.1	15.4	67.5
10 days or more	5.4	3.3	2.1	1.2	3.8	15.8
15 days or more	1.6	1.6	0.8	0	1.2	5.2
20 days or more	0	0.4	0	0	0	0.4
Mwinilunga						
5 days or more	9.2	8.8	12.5	9.2	12.9	52.6
10 days or more	0.8	0.8	1.7	0.8	0	4.1
15 days or more	0	0	0.4	0.8	0	1.2
20 days or more	0	0	0	0.4	0	0.4
Mpika						
5 days or more	16.7	12.5	12.1	11.7	19.2	72.2
10 days or more	8.8	3.3	1.7	2.1	5.0	20.9
15 days or more	5.4	0.8	0	0	2.9	9.1
20 days or more	3.3	0	0	0	0.4	3.7
Ndola						
5 days or more	16.7	12.5	12.1	9.6	15.6	65.9
10 days or more	6.7	2.5	2.1	0.8	5.8	17.9
15 days or more	1.2	0.4	0.4	0	2.9	4.9
20 days or more	0.4	0	0.4	0	1.7	2.5
Mbala						
5 days or more	15.4	11.7	14.2	14.2	10.0	65.5
10 days or more	7.5	2.5	2.1	0.5	1.6	14.2
15 days or more	2.5	1.2	0	0	0.4	4.1
20 days or more	1.2	0.4	0	0	0.4	0

The average number of dry spells per ten years is given for a number of stations in the high rainfall area.

Dry spells are much more prevalent in the southern and south-western part of Zambia than in the north-western and northern parts. Rainfall less than 6 mm in a day mainly adds to evaporation and contributes little to soil moisture.

The mean annual rainfall and potential evaporation indicate a considerable rainfall deficit. During the rainy season, the excess of rainfall e.g. in Kasama is 480 mm. About 150 mm may be stored in the soil profile and utilized by plants, while the rest may be leached out.

Clayey and deep soils have better ability to store water than sandy and shallow soils. With an annual rainfall of 1000 mm and more, the excess rainfall may be 250-300 mm. Under these conditions all soils are liable to leaching.

This affects e.g. the soil nitrogen. During the dry season soil nitrogen is converted to nitrate, which is easily leached out during the rainy season.

4. VEGETATION

The main vegetation groups in the high rainfall areas are Miombo woodlands, and a mixture of Chipya and dry evergreen forest. Within the Chipya there are groups of dense ever-green forest called the Mateshi.

Characteristic vegetation groups are also the Itigi thicket and the Uapaka fringe woodland. In the damboes grassland dominates.

4.1 Miombo woodland

The Miombo woodland dominates the plateau areas of North Western, Copperbelt, and Luapula Provinces and also the Mpoka - Isoka ridge. This woodland consists of genera like Brachystegia, Julbernardia, Isoberlinia, Pterocarpus, Percopsis, and Erythrophleum, all of which belongs to the Leguminosae.

Some species are found to be indicators of definite habitats. Among the 16 species of Brachystegia, the B. floribunda and B. glaberrima are usually found on deep well drained soils that retain moisture during the latter half of the dry season.

Species like B. Bussei and B. Boehmii is indicators of shallow soils. Of the Julbernardia genus two species are common, namely the Julbernardia paniculata and the Julbernardia globiflora. The Julbernardia paniculata is found on deeper and more fertile soils than the J. globiflora.

Among the factors affecting vegetation, fires made by man have had the greatest effect.

Long term burning experiments in Miombo woodland have been conducted both near Ndola and Kasama in order to study the effects of fire. Late burning every year was found to destroy the Moumbo woodland and it can only be maintained or regenerated from coppice under a complete protection or and early burning regime.

4.2 <u>Chipya and dry ever-green forest.</u>

This vegetation type is common in the Chambeshi/Bangweulu plains. The Chipya vegetation varies in composition but all species are fire-hardy or fire tolerant. Common species are Pterocarpus angolensis, Erythropleum africanum, Parinaria curatellifolia. Marquesia marcoura dominates in the groups of dense ever-green forests, "Mateshi", which is found within the Chipya.

The open herb grass communites of the Chipya is Aframomum biauriculatum. Pteridum aqulinum, and grass of the genera Andropogon and Hyparrhenia.

4.3 "Itigi" thicket

In addition to the main vegetation types the Mweru Depression is covered by a dry deciduous thicket called the "Itigi"-thicket.

4.4 Uapaka fringe woodland

This vegetation type forms a fairly continous narrow fringe, usually not more than 30 cm broad, lying between the Miombo woodland and the upper grassland. The main grasses are Loudetia simplex and Trestachya rehmannii.

The main Uapaka group series, Uapaka benguelensis, U. berkiana, U. nitida and U. sansibarica forms a canopy of 4-12 m.

The sandy or sandy loamy soils are overlain by a thin dark humus layer 3.5 cm thick. The pH-range is high and the phosphate level good compared to other soils.

4.5 Grassland.

The grassland of the Miombo areas where sandy soils are common is dominated by Hyparrhenia dissoluta, Hyparrhenia filipendua, and Digitaria spp.

The damboes in the Miombo area are dominated by sandy soils and the most common plant assosciation is Loudetia simplex, but as the moisture increases the Monocymbium cerosiforum grassland replaces it. In the central swamp area of the upland dambo the tall grass Miscanthidium teratfolium dominates. In the different dambo types, specific grass communites are found.

The vegetation ecology of the damboes is described by Trapnell (1953) Astle (1969) Astle (1965) Verboom (1969) and Mansfield et.al (1976). Prior (1983) has made a compilation of information about soils and vegetation of the damboes in the high rainfall areas.

5. SOILS

The age of the land surface is the principal determining factor in soil formation. The soils are a product of previous erosion cycles, in which wetter and warmer climates brought about the intense weathering and leaching. North of the 1000 mm rainfall line most soils are strongly leached and chemically poor. The sub surface horizon boundaries are either gradual or diffuse. The sub soil structure is weak to massive. Kaolinite is the dominant clay numeral. The consistence is usually friable when moist, and of variable hardness when dry, depending on clay content. Very small tubular pores are abundant.

The maximum mean clay content is found in the lower subsoil (1-2 m depth) with small changes down to the regolith. In the Copperbelt there is an area of moderately leached red clays and clay loams in a transitional zone towards lower rainfall areas, some areas of "better" soils are also found in the North-Western Province. Some of these soils are characterized by a relatively high silt content (Wen, 1982).

In Northern and Luapula Provinces, three major soil groups may be extiguished, namely deep upland soils, shallow soils and poorly drained soils (Vikan, 1983).

From an agricultural part of view, the deep upland soils are most important. These soils occur on the very gently undulating plateau, and occupy about 1/2 of the total land as they vary in texture from coarse loamy to clayey soils and are reddish to brownish in colour. Most of the soils are derived from non basic parent material and are poor in nutrients. These soils are moderately to very strongly acid, and with low cation exchange capacity and base saturation. The acidity of the soils may also lead to aluminium toxicity and high phosphorus fixation.

In limited areas where the soils are derived from basic material, the nutrient status is slightly better. The majority of the deep upland soils are well drained.

The shallow soils are mainly found on hills, ridges and inselberg footslopes of hilly terrain, they are fine to coarse loamy textured, often with gravel in top and subsoil. The soil colours covers a wide range.

The poorly drained soils (alluvial soils) includes the soils of upland damboes, river valleys and floodplains. These soils are waterlogged for at least 4 months of more a year. The thickness of the A or H horizon is 20 cm or more. The chemical properties of the alluvial soils varies with the material from which they originate.

6. OUTLINE OF SOIL SURVEYS IN THE HIGH RAINFALL AREAS OF ZAMBIA.

6.1 Surveys 1930-1965.

In 1937-1940, C.G. Trapnell conducted an ecological survey in the Northern and Luapula areas. The survey was first published in map form under the title "The Vegetation and Soil Map of Northern Rhodesia". The survey noted the broad soil vegetation relationships within the area.

In 1951, samples from representative soil profiles from Luwingu, Mpika and Kasama were collected by Odell, during the course of the Central African Rail Line Development Survey. The results were published in 1952 together with a vegetation map of the Upper Chambeshi River area.

The soil profiles covered the most common groups found by Trapnell, namely Plateau and Lake Basin soils, fertile red earths and upper valley soils, dambo and swamp profiles.

In the 1950ies, a major reconnaissance survey of soils and land use in the Copperbelt was carried out by Ballantyne and Wilson. In 1965 Ballantyne and soil specialists at Mt. Makulu Central Research Station compiled all existing knowledge to produce the Soil Map of Zambia. The map was produced in scale 1:2,500 000.

6.2 An outline of the land classification system, the soil groups and soil series worked out by the Land Resources Study.

The Land Resources Division of the Ministry of Overseas Development, England (LRD) carried out the field work of a reconnaissance land and capability analysis with regard to the land resources of Northern and Luapula Provinces.

The objectives of the survey was to provide a reconnaissance soil and water map to provide a basis for further study in areas worthy of more detailed investigation. The findings of the LRD-team are presented in a report consisting of 6 volumes (Mansfield et. al, 1976).

In Volume I, an introduction to the reconnaissance study is given, together with conclusions and recommendations. Volume II gives an overview of the land use in the area, while Volume III deals with the land capability and potential land use. The first part of Volume III describes the land capability classification system which were designed from the project, and the land capability of the project area. In the second part the potential for agricultural development is outlined, based primarily on soils and crop suitability. In Volume IV, the climate, geology, soils and ecology of the area are described.

A description of social and economic factors like population distribution, rural land tenure, crop production costs and credit facilities is given in Volume V, The sixth and final volume describes and maps the land systems of the project area.

In order to examine the land capability, a specific method was developed. The system is based on soil and site characteristics which affect crop growth and on the conservation of land under cultivation. It is based on the concept that factors of the soil and environment limit the use of the land under a particular management system.

The team measured physical characteristics which are sufficiently and systematically variable throughout the project area were examined in detail for their effects under several management systems, and used as factors in the land capability classification.

The L.R.D. team limited their study of the soils to the upper 50 cm of the soils, since the majority of the roots are found in this layer. Furthermore, composition and characteristics of the lower subsoils of the freely drained soils are markedly less than of the upper subsoils.

They selected and used some of the most systematically variable factors of the soil which is measurable, and made them the subjects of indices.

The following soil factors are considered to affect land capability:

a. Available water capacity, a.w.c.
b. Subsoil physical status
c. Fertility
d. Erodibility
e. Depth of impervious horizon

Stone content and rock outcrop were not included.

The site factors affecting land capability which were used are:

a. Slope
b. Lift
c. General topography

6.2.1 Available water capacity indices.

Available water capacity (a.w.c.) is the water held at field capacity minus the water still held at wilting point. Field capacity is the moisture content reached 48 hours after a completely saturated soil is left to drain.

A regression analysis on 19 samples carried out by the LRD team showed that soil depth, organic carbon content of the soil and various particle size fractions correlated quite closely to the available water capacity. However, the simple relationship with coarse sand appeared to give the most satisfactory estimate.

Wn and Wt are the indices for the 0-50 cm and 0-150 soil layer respectively. In order to construct these indices, estimating equations were used. Each index is calculated by multiplying the depth of each layer (in cm) by the:

A. Factor appropriate for the texture of the topsoil, or the appropriate.

B. Factor for the surface to 50 cm depth for Wn and to 150 cm depth for Wt. The factors A and B were based on the mean particle size distribution of field determined texture classes, and estimated equations of the form:

$$Y = K + a\,Si + b\,CS + c\,FS + d\,OC + eD,$$

where y is numerically equal to the estimated a.w.c. in cm/dm, K, a,b,c,d and e are defined constants, and Si, CS, FS, OC and D are percentage contents of the respective constituents in the soil sample.

Wn is half the calculated value in mm of the a.w.c. of the 0-80 cm layer and is considered an index of the a.w.c. of the main feeding layer of annual plants like maize. The probable error in the estimate of Wn is not less than $\pm 20\%$.

Wt is half of the value in mm of the a.w.c. of the 0-150 cm layer. It is considered an indication of the maximum quantity of water available to the plant. The Wt index is of less certain significance, and probably less accurate.

6.2.2 Upper subsoil index.

Destruction of structure under cultivation is an important problem on the soils in the high rainfall areas of Zambia, and may lead to crop failure. Special attention was paid to the physical properties of the horizon immediately below the organic topsoil and down to 50 cm depth. The LRD team tried to combine several physical determinations in an index, but eventually they chose the despersion ratio as the sole index because it was most relevant to the main problem, relatively simply measured and reproducible.

The upper subsoil index (S) does not cover all aspects of subsoil aggregation status, but gives the weakness of aggregate development in the soils which is the most important aspect. Trapnell (1983) and Webster (1960) indicated that Upper Valley Soils with a distinctive vegetation type, had superior physical status, and that among the remaining soils, Chipya covered soil had better developed structure than Miombo covered soil.

The LRD-team examined the stability (as resistance to slaking in water of aggregates of 4-6 mm size), and the instability (as ease of disposal when shaken in water) of microaggregates of 2000-50 size, (dispersion ratio and aggregation index). In the latter case, the texture and time of the soils of group 2 were fairly closely correlated with relative instability. Silty soils and yellow soils were most instable, clayey or coarse sandy and red soils were least instable.

The physical status of the soil underlying Chipya was generally better than that of the soil below Miombo. According to the LRD team it was concluded that the soil hue was quite strongly correlated with subsoil instability, although their findings differ from those of Webster and Trapnell with regard to details.

6.2.3 Fertility Index.

The fertility index (F) estimates the mean exchange capacity through the uppermost 50 cm. It covers only the requirements of Ca, Mg and K. One of the chief problems of the most common soils in the survey area is that the exchange capacity of the clay is extremely low, and the top 50 cm of the soil may not be able to hold the nutrient requirements for a crop for one season.

As an index of the exchange capacity, the LRD team based an estimate of this capacity on a combination of data from analysis at Mount Makulu and the LRD unit at Reading, England. The cation exchange capability of the mineral clay of group 2 soils was estimated using the CEC of the lowest horizon from all the profiles within the station. Since the organic content was less than 0.1%, it was assumed that it did not contribute to the CEC.

For each field texture, a mean figure for clay content was determined graphically. The organic matter contribution to total CEC were estimated at 3 meg for 1 % of organic carbon.

Several approximations were made. Thus, generalisation were made of the clay exchange capacity figures, particle size analysis figures and the volume taken up by stones or concretions. Assumptions were made about the loss of organic carbon under cultivation.

CEC is determined at pH 7, while the natural pH in the soil is considerably less. The interpretation in terms of nutrient availability is therefore uncertain.

The main intention with the index F is to permit the differentiations of the very varied textural profiles which are often found within an area.

6.2.4 Index of erosion susceptibility

According to Hudson (1963) a rainfall rate of 12 mm per hour is the treshold value for raindrop splash erosion. In northern Zambia intensites of this order may occur on more than 20 occasions in each wet season.

Splash erosion of an erodible soil quickly induces sealing of the surface of the soil and reduces infiltration, permitting surface runoff. A heavy rainfall produces normally a surface cap, espicially if the surface is very silty or fine sandy.

For clean cultivated soils, the following three factors are considered most immediately important as regards erosion hazard:

a. Erodibility (E) of the soil, the inherent susceptibility of the soil peds to erosion.
b. Exceptional soil factors affecting runoff.
c. Slope angle (A) and length of slope.

Two factors, E_1 and E_2, for the basis of the erosion susceptibility index, E_1 is derived from the erodibility index proposed by Vosnesensky and Artsrui(1974), giving the following equation:

$$\text{Erodibility} = \frac{\text{dispersion index of cultivated soils.}}{\text{Aggregation index of cultivated soil x weighing factor.}}$$

The dispersion index is Middetons dispersion ratio, (Middeton 1930) and the aggregation index is the ratio:

$$\frac{\text{Coarse sand (200) without despersion.}}{\text{Coarse sand determined during normal particle size analysis.}}$$

The weighing factor is dependent on soil texture and stone content, which makes the denominator of the expression approximately equal to the weight percentage of water stable aggragates of 2,0 - 0.2 mm size together with stones.

The E_2 factor is an empirial adjustment for profile factors restricting water movement.

The index of erodibility is determined by multiplying E_1 and E_2.

Erosion susceptibility is then considered to be dependenton the factor final E and the angle of slope at the point site.

In considering overall capability, erosion susceptibility is an important limiting factor, and is quite heavily weighed in the classification.

The overall capability class which is determined through use of the indices is provinsial. It can be modified to take account of the wetness of the profile and rock outcrops and to eliminate all very shallow soils. (Lang, 1973).

The indices have been related to readily observed morphological features, especially colour and texture wherever possible.

There are five capability classes:

Class I No limitations
II Slight to moderate limitations
III Severe limitations
IV Very severe limitations
V Indicates a site virtually without value for the management systems of arable crops production, e.g. laterite pavements, bare rocks and slopes.

The LRD team recommended that attention should be focused on strata with at least 60 % class II land.

This land is mainly found between Kasama and Mbala with extensions into Luwingu and Mporokoso districts. Furthermore in Chiundaponde in Mpika district, and between Chisunka and Makasa in Luapula Province.

Nchelenge and Samfya in Luapula Province, and Kaputa and Chinsali in the Northern Province have nil or very small areas with 60% class II land.

6.2.5 Soil groups and soil series.

Major consideration was given to the deep, freely drained upland soils, while dambos and local riverine areas were excluded from the survey.

The soil groups and soil series within each group used by the LRD team are presented below. For each soil series the corresponding category in the USDA 7th Approximation (USDA) and in the FAO/UNESCO Soil Unit (FAO) are included.

Group I. Upland soils with moderate or well developed macrostructure.

Kaombe Series
USDA : Ustropept
FAO : Eutric Cambsol

Mululwe Series
USDA : Tropeptic Haplustox
FAO : Rhodic Ferralsols

Group II. Upland soils without macrostructure below the organic horizon.

Subgroup II. Sandy soils.

These soils lack a horizon containing more than 15 % clay through a depth greater than 30 cm.

Lungu Series.
USDA : Typic/Oxic Quartzipsamment
FAO : Ferralic Arenosol.

Twingi Series.
USDA : Typic/Oxic Quartzipsamment
FAO : Ferralic Arenosol.

The Lungu and Twingi series are the only series defined by colour and are 2.5 YR and 10 YR respectively.

Subgroup 2b. Soils with oxic horizon.

Division I. Duplex soils.

Chishwishi Series.
USDA : Psammentic/Typic Haplustox
FAO : Helvic and Ochric Ferralsol.

Mabumba Series.
USDA : Psammentic/Typic Haplustox
FAO : Rhodic, Helvic and Ochric Ferralsol.

Division 2. Gradational Soils.

Lunzuwa Series.
USDA : Typic Haplustox
FAO : Rhodic, Helvic and Ochric Ferralsol.

Nkolemfumu Series.
USDA : Typic Haplustox
FAO : Rhodic, Helvic and Ochric Ferralsol.

Milima Series.
USDA : Psammentic Haplustox
FAO : Acric, Rhodic, Helvic and Ochric Ferralsol.

The Kaombe and Mululwe series of group I have a very small total extent. They are found on baserich parent material. In the field these series can be recognized by their better structure. Only soils of group I have a well developed macro-structure with natural aggregates larger than 4 mm.

Soils of group II have a complete lack of macrostructure in the field. There are wide differences in this group regarding organic matter content texture textural profile and hue.

Within soil group II reduction of air and water permeability, surface capping and the transport of soil particles are more likely than in soil group I.

The red soils with high clay and silt content have the highest proportion with good structure.

The Kaombe + Mululwe series group I have high chemical fertility, due basically to the high CEC of the clay of the former, and the high clay % and high base saturation on the latter. They contain weatherable minerals - so that a nutrient reserve is present. The chemical fertility of remaining series are low, the mineral fraction having a low base saturation.

In the coarse textured soils there are high figures for the coarse textured soils, particularly for CEC. This is attributed to organic matter having been carried down the profile by the very rapid internal drainage. In the abscence of weatherable minerals the potential of this second group of series is measured in terms of their ability to retain fertilizers which is reflected in the percentage of clay, and reaches a maximum in the Lunzuwa series.

7. AN OUTLINE OF SOIL SURVEYS IN HIGH RAINFALL AREAS OF ZAMBIA CARRIED OUT BY THE SOIL SURVEY UNIT.

In 1969, a Soil Survey Unit was created, operating from 1974 within the land Use Branch of the Department of Agriculture. As from 1973, the Soil Survey Unit has been funded by NORAD (Norwegian Agency for International Development).

Among the objectives of the Soil Survey Unit were to carry out a systematic soil and land capability survey so as to allow a more comprehensive assessment of Zambia's soil resources to be made use of as a basis for national, provincial and economic planning. The areas surveyed by the unit in the high rainfall areas of Zambia until 1980 was approximately 10 ha at a very detailed level, 150 000 ha at detailed level, 161 000 ha at semidetailed level, and 193 000 ha at reconnaissance level. An outline of soil survey reports produced dealing with the high rainfall area until March, 1980 is given in appendix 2. A land use classification system is worked out by the Soil Survey Unit and is presented in a guide to Agricultural planning by the Land Use Branch, Department of Agriculture (Land Use Planning Guide, 1977).

Very detailed surveys. The very detailed surveys which are called "Intensive Survey", are produced in the same manner as detailed surveys, and are mapped at scales larger than 1 : 10,000. They are used for irrigation schemes and research plots. This particular kind of survey covers only about 10 ha of land in the area.

Detailed surveys. Produced mainly by field survey. Map scales range from 1 : 20,000. They are used for irrigation schemes and other high cost projects. Thid kind of survey covers approximately 150,000 ha in this region.

Semi-detailed surveys. These covers the whole area by air photograph interpretation combined with a substantial amount of field survey. Map scales range from 1 : 60,000 to 1 : 20,000. They are used for farm plans and catchment conservation plans.

The area covered by this kind of survey amounts to 161,000 ha of the entire high rainfall area.

Reconnaissance surveys. These are the smallest scale of survey to achieve coverage of the whole survey area. The usual map scales are from 1 : 250,000 to 1 : 100,000, but maps from 1 : 500,000 (rapid Reconnaissance) to 1 : 50,000 (detailed Reconnaissance) are included. They are used for National and Provincial Development planning, of the total area surveyed in the region, these covers about 193,000 ha.

Exploratory surveys. These are rapid road traverses made to provide a minimum of information about otherwise unknown regions. Map scales vary from 1 : 2,000,000 to 1 : 2,250,000.

They are used for feasibility studies in order to determine areas for further studies.

General characteristics of the main soil series are described in the soil survey reports.

7.1 Very detailed survey.

7.1.1 Chinsali farms training centre.

The Chinsali F.T.C. area is located in Northern Province, Chinsali district on a piedmont slope below a steep quartzitic ridge. The alluvio-colluvial red sandy or coarse loamy parent materials on which the soils are developed have been derived from ferrogenous sandstones. They are mostly drained towards the lower plain in the north and finally to the Chambeshi swamps which are to the west and north west of the area of the total of approximately 7.6 ha area surveyed, only 1.5 ha consist of moderately good arable land of the remaining area, 5.8 ha consist of poor arable land while 0.3 ha are unsuitable land due to rockiness.

Tentative soil classification of the most important soil series of the Chinsali F.T.C. area and its surroundings.

SOIL RESULTS	USDA-SOIL TAXONOMY SYSTEM
Lubwa	Typic (or Oxic) Quartzipsamments.
Chinsali	Coarse Loamy Typic Haplustoxs
Nsato	Psammentic-Lithic Haplustoxs
Konkola	Clayey (fine) Typic Haplustoxs
Mulanga	Clayey (fine) Typic Eutrustoxs
Misamfu	Fine loamy Typic Haplustoxs

All the soils of the F.T.C. area are chemically poor with the totals of exchangeable Ca, Mg and K mostly below 1%. They are strongly to very strongly acid, and the need for lime is urgent. The soils have low cation exchange capacity and base saturation percentage. They are poorly provided with organic matter, and available phosphorus is usually acutely deficient. Physically the soils may suffer from droughtiness due to its coarse textures.

7.2 Detailed surveys

7.2.1 Nondo settlement scheme.

The survey area is located in Mbala district, 80 km south of Mbala along the Mbala Kasama road, on a very gentle convex interfluve, which is well drained to the east west of the area (Van Sleen 1976).

The survey area covers approximately 1880 ha of which about 63 % has been classified as good arable land and 10% as moderately good arable land. Marginal arable land constitutes about 15%, while non arable land makes up the remaining 12%. This land is suitable for winter grazing.

The most common soil series in the area are Mufulira, Konkola, Kasama and Mwambwa. The Mufulira series is characterized by pH 4.1 in the topsoil, increasing to 4.4 on 1 m depth. CEC and base saturation are low. Organic carbon is 1.2 % in the upper 12 cm topsoil decreasing downwards. The Kasama series has a high pH especially in the top soil, and CEC in clay is between 50 and 60 m.e./100g. Also the base saturation percentage of Kasama soil is higher than in the other series in the area.

7.2.2 Misamfu Regional Research Station

The Misamfu Regional Research Station is located in Kasama district, about 7 km north of Kasama on the Mbala road. The area which comprises 4.26 ha is situated on a plateau and is drained to the north east (Van Sleen, 1976).

About 52 % of the total area consists of good arable land. About 10 % has been downgraded due to some rock outcrops, slight wetness or sandy textures into moderately good arable land. Marginal arable land constitutes about 15 %, while nonarable land makes up the remaining 23 % consisting of rock-land, shallow soils or poorly drained dambos.

The good arable land soils represent soil types which are typical for Northern Zambia. They are deep, strongly leached acid soils and generally occur on the very convex to nearly level plateau interfluves and lower piedmont slopes. They consist of the Misamfu series (139 ha), the Kasama series (39 ha) and the Mufulire series (21 ha). The Misamfu and Kasama series are fine loamy soils and the Mufulira series are clayey soils. They are all tentatively classified according to the USDA - Soil taxonomy system as Typic Haplustox, provided that the micromorphological studies of thin-sections do not reveal an alluvial clay horizon, which is quite possible since clay skins have been recorded in several profile descriptions.

Unfortunately, the Mufulira series - which is the most wide spread soil type of Northern Province - is not wellrepresented here and its red "variant", the Konkola series, does not occur at all on this research stations.

Typical representatives of upper piedmont slope soils of the Northern Province are also found on this station. They occupy rather small and narrow units below hilly ridges, plateau, escarpments etc. They comprise the sandy Lubwa series as well as the coarse loamy Chinsali and Milima series. The Lubwa series have been classified according to the USDA - Soil Taxonomy system as Typic (occasionally oxic), quartzipsamments, the Chinsali and Milima series. The Lubwa series as Psammentic Haplustoxs and the Milima series as Thapto Haplustoxic Quartsipsamments.

These upper piedmont soils are generally downgraded for agricultural use because of their coarser textures and gentle slopes.

7.2.3 Kateshi rucom coffee estate.

The area is situated in Kasama district, about 20 km north of Kasama, on a plateau which is flat to gently sloping convex interfluve. (Slørdal, 1973).

The Kateshi Rucom Estate includes an area of approximately 1440 ha, of which about 2062 ha (85 %) is moderately good arable land. Because of moderate fertility limitation no land has been rated better.

About 1716 ha is regarded well suited and 293 ha moderately well suited to coffee under irrigation. 172 ha of the area is classified as marginal arable land of which 62 ha is considered as poorly suited to irrigated coffee. The non-arable land makes up 206 ha.

Main soil series are Kasama, Mufulira and Konkola. In all series the clay content increases with depth. The subsoil pH is 4.4-4.5 in all series, topsoil pH 4.9-5.1 in Konkola and Mufulira, and 4.7 in Kasama series. Differences in CEC, org. C, avail P and base saturation are also small in the subsoil.

7.2.4 Chifwesa groundnut scheme.

The area is located on an interfluve in the Chinsali district, about 6 km south east from Mafumbo Village, south of the road to Mulanga Mission. (Van Sleen, 1976)

The soils surveyed in detail cover an area of approximately 800 ha. About 25 % of the total area is considered suitable for groundnuts and about 48 % has been considered as moderately suitable because of 3-5 % slopes, imperfect drainage or a rather heavy topsoil texture (loam or clay loam) which may dry hard.

Five per cent are regarded poorly suited for groundnuts because of shallowness or very sandy texture throughout the soil profile.

The remaining 22 % are regarded unsuitable for groundnuts due to wetness, shallowness or rock outcrops.

For small scale cultivation the imperfectly drained soils can be upgraded by one class, provided that the crop is grown on high ridges or raised beds.

As the topsoil pH of this area range from 5.1 to 5.5 the application of lime or gypsum is recommended to improve yields.

Considering the overall capability of this area, it was found that about 32 % of total area consists of good arable land and 27% of moderately good arable land.

Marginal arable land contributes 24 %, while non-arable land makes up the remaining 18 % half of which are suitable for winter grazing.

All the soils are chemically poor, with a C.E.C. of 3-12 m.e./100 g, clay with a pH ranging from 4.3-5.5. The content of exchange-able cations are low, totally less than 2.5 %, while organic carbon is less than 1.5 %. Nitrogen is also low, while the phosphorus content varies. Physically the soils are good. The downgrading is mostly due to rock outcrops, shallow depths and rather poor drainage conditions.

Among the soil series described are Chibesakunda, Chifwesa, Milima and Mulanga series.

7.2.5 Lubu dairy settlement scheme.

This survey area is located in Chinsali district, about 10 km south from Chinsali township. It consists of a broad valley on shales, argillites, siltstones and sandstones. Two terraces with very slight difference in elevation have been recognized and delineated within this valley, one with predominantly clayey soils, and the other one with predominantly fine loamy soils, both with laterilic gravels "at their toes". The valley bottom is a very wet alluvial overflow plain. It is partly overburdened by sandy alluvial wash material from the side slope. (Van Sleen, 1976)

Soil samples from profile on Mufulira sandy loam indicate very low CEC, org. C, in the subsoil, while BSP is above 50 down to 45 cm. In the upper 11 cm, pH is 5.2. Available P and CEC m.e./100 g clay are high.

7.2.6 Mpika dairy settlement scheme.

The scheme is located in Mpika district, about 3-4 km from the town along the Great North Road. The Malashi Agriculture sub-station falls within the survey area. The land is flat to gently moderating between 1400 - 1500 in altitude.

The land surveyed covers 1002 ha of which 69 % is good arable land. The rest of the land in downgraded due to wetness, depth or slope limitations. Poor arable land covers 10 %.

The soils are leached red clays, leached red sandy soils and red clays over ultra basic rocks.

7.2.7 Uningi seed potato area.

The Uningi seed potato area is situated at Mbala State Ranch, about 10 km south of Mbala township. The area covers about 285 ha, and is very gently undulating interfluves. (Van Sleen, 1978)

About 75 % of the land has been rated as moderately suited for potatoes. This area comprises mostly deep, clayey soils. Shallow soils comprises 13 % of the area and is downgraded into poorly suited for seed potatoes because of very shallow soils or poor drainage conditions.

Clayey soils are dominating, representing Mufulira, Konkola and Mbala series. CEC and pH is high, while the organic C % is less than 0.5 % in the Mbala series. Available P is very high in the upper 0.12 cm, but very small in the 12-30 cm horizon.

7.2.8 Proposed rice schemes.

A survey of 9 proposed rice schemes. The areas are situated on the Chambeshi - Bangweulu plain. The land suitability is shown in table 5. (Slørdal, 1978)

Table 4. Land suitability of 8 proposed rice schemes in Northern (N) and Luapula (L) Provinces.

Area		Well suited		Moderately suited		Poorly suited		Not suited		Total
		ha	%	ha	%	ha	%	ha	%	
1. Kalasa Mukoso	L	1177	59	298	15	257	13	248	12	1980
2. Kasongo	L	250	71	24	7	78	22	2	0.5	354
3. Chama-Lufimba	L	1217	73	198	12	183	11	78	5	1676
4. Chakaba	N	226	50	101	22	89	20	39	9	455
5. Mutondo	N	972	80	16	1	8	0.7	215	18	1211
6. Mulema	N	119	14	372	45	334	40	-	-	825
7. Chifulo	N	199	17	416	36	438	38	103	9	1156
8. Nashinga	N	776	61	207	16	220	17	79	6	1282
Total		4936		1632		1607		764		8939
Mean			55		18		18		9	

7.2.9 Luapula Regional Research Station

The Luapula Regional Research Station which covers 881 ha is located approximately 7 km east of Mansa on the southern side of the Kawambwa road. (Yager et. al, 1968).

The station occurs on landscape typical of the area. There is a rather wide upland drainageway or dambo along the eastern side of the farm with a small lateral inside the south eastern farm boundary and another which bisects the north central part of the farm.

The highest point on the farm lies in the south western corner. Although appearing nearly level, much of the land has slopes ranging from one to two percent which increase near the dambos to over three percent.

Clayey soils are common, both the red ferralilic Konkola series, and the yellowish brown Mufulira. Of sandy soil, Nsato series is found. Analysis of Kafulafuta loamy sand shows a high pH value, around 6.0 in both topsoil and subsoil, a high base saturation percentage but moderate to low content of org. carbon.

7.2.10 Copperbelt Regional Research Station.

The Station covers 1705 ha and is situated some 13 km west of Mufulira on the western side of the Kafue River. General elevation of the Station ranges from 1245 in the western part, to 1170 m on the Kafue flood plain in the south east. (Yager et. al, 1968).

62 % of the total area consists of the shallow Nsato Soils. The Mufulira and Misamfu series covers about one third of the area. Small amounts of alluvial land, Chambeshi and Kafulafuta soils occur on the remainder. These are soils typical of the Western, North-Western and the Northern Provinces.

C.E.C. and organic matter are fairly high in the topsoil of a Misamfu loamy sand. pH is 4.7 in the topsoil decreasing downwards in the profile to 4.1.

7.3 Semi-detailed reports

7.3.1 Mbala State Ranch, northern part.

It is situated in Mbala district about 11 km south east of Mbala township. The altitudes of the area range between 1620 - 1820 m. (Slørdal, 1978).

10,890 ha is surveyed on a semi-detailed level 5,674 ha 52 % of the total area has been classified as good arable land. Marginable arable land covers about 1059 ha of the total area. These soils are downgraded because of moderate slopes, rock outcrops or imperfect drainage.

Non-arable land makes the remaining area. This is unsuitable for agricultural cultivation because of poor drainage steep slopes, shallow soils or many rock outcrops.

Chemical analysis of samples from a Mufulira sandy clay loam indicate a low CEC, but fairly high content of available phosphorus in the topsoil.

7.3.2 Katito wheat scheme.

The area is situated in Mbala district, Northern Province, with its centre about 22 km south of Mbala township. The surveyed area covers 3905 ha of which 59 % is classified as good arable land, 32 % moderately good arable land, and 9 % poor arable land and grazing land. Most of the area is very gently convex interfluve with slopes less than 3 %. The approximate altitude ranges from 1600 - 1700 m. Konkola sandy clay soil is dominating. (Slørdal and Nyendwa, 1978).

7.3.3 Mr. Musakanya's estate

The estate is located in Northern Province Kasama district, Chief Munkonge area with its centre 37 km west of Kasama township. The altitude ranges between 1200 - 1300. (Slørdal, 1978).

The estate covers approximately 56,000 ha 53 % is good arable land, 16% moderately arable land, 11 % marginal arable land and 9 % non arable land, due to poorly drained damboes and shallow soils with rock outcrops.

7.3.4 Lukulu North proposed stateland block.

The area is located in Kasama district, Northern Province, 35 km west of Kasama township along the Kasama - Mporokoso road. The area is dominated by a relatively uniform and flat plateau, broken by some rock outcrops and the drainage line. (Kalima, 1980).

The general pattern of the soils in the area is characterized by deep strongly weathered clay soils on the plateau and upper slopes. In the river valleys the soils are variable due to the alluvial process. They range from sandy to clayey.

7.3.5 Proposed second sugar estate. Luena area.

The area is located in Luapula Province with the major part in Kawambwa district and the area south of the Luonga river in Mwense district. (Commisaris, 1977).

The Luena survey area consists os 62,440 ha. The upland soils are deeply weathered and leached. Almost half of the area consists of soils without any physical limitation including the red frable clay soils (Konkola series), the brown clayey soils (Mufulira series), and the red and brown fine loamy soils (Kasama and Misamfu series). A reconnaissance survey was carried out by Van Sleen (1976)

7.3.6 Nyangombi settlement scheme

This scheme is situated in Mwinilunga district, Nort-Western Province, about 25 km. East of Mwinilunga Boma and south of the Mwinilunga - Solwezi road between the Kanyama turn off and Samuteba School. (Heilmann, 1978).

The Solwezi - Mwinilunga road form the boundary of the scheme in the north, the Kampemba Stream in the west, the Nyangombi river in the south and the Lwamitova Stream in the East.

The total area surveyed amounts to 4518 ha.

The area consists of two plateau areas separated by a small subsidiary stream of the Nyangombi river and an extensive dambo area on the watershed. In the N.W. part a small tributory of the Kampemba stream is deeply incised in the western plateau. Generally the area is sloping towards the south. Especially in the southern half of the area the plateau has rather steep slopes towards the dambo (over 5%). The altitude of the highest upland parts is about 1400 m in the western part and 1450 m in the eastern part; this is about 50 - 75 m above the level of the surrounding streams and rivers.

The altitude of the vast dambo area in the centre of the scheme is approximately 1380 m.

7.3.7 Jivundu settlement scheme.

This scheme is situated in Solwezi district, North-Western Province about 112 km west of Solwezi, on a flat to very gentle sloping plateau with very gentle slopes towards the dambo (Heilmann, 1978).

The survey area is approximately 4518 ha, 86 % of which consists of good arable land while 4 % is regarded as modarately good to poor arable land. About 6 % has been considered as grazing land while 4 % is unsuitable land.

7.3.8 Mpongwe block I & II : G.R.Z./E.E.C. Irrigated wheat scheme.

The area is situated in Ndola rural east district, Copperbelt Province approximately 60-80 km S.W. of Luanshya on a relatively flat area between the Kafue and the Lukanga rivers which consists of flat to very gently undulating plateaux surrounded by large depressions in the south, the west and the north. (Heilmann, 1978).

The survey area is approximately 35,225 ha. More than half of this is good arable land, 18 % constitute moderately good arable land while 7 % is poor arable land. Grazing and unsuitable land covers about 10 % of the total area.

There are no permanent streams in the area. A number of streams originates at the margines of the plateau and drain towards the north, north-west, south west and west.

7.3.9 Munkumpu proposed irrigation scheme.

The survey area is located in Ndola rural east district, Copperbelt Province along Mpongwe-Machiya road at some 80 - 90 km from Luanshya, on almost level to very gently undulating upland plain with slopes between 1 - 3 %. (Hennemann, 1980).

Semi-detailed survey cover approximately 22,000 ha and detailed soil survey covers approximately 2600 ha.

Most common soil series in the area are Munkumpu II, Kawambwa II and Mbereshi II. Munkumpu II is characterized by pH about 4.7 - 5.1 while C.E.C. and base saturation are low. Organic carbon is about 0.65 % in the upper 5 cm topsoil decreasing downwards to about 0.25 % in the range of 5 - 10 cm depth. The Kawambwa and Mbereshi series also have pH within the same range as Munkumpu series, low C.E.C., base saturation percentage and organic content.

7.3.10 Ipafu development area.

The area is situated in Chingola district of Copperbelt Province at about 12 km north west of Chingola town along the Chilonga-Solwesi road. The survey area is incised by the Kafue river, which rises from the north west and runs east. At this stage the Kafue river is characterised by meanders in broad flood plain and appears to be in the mature stage.

Soil drainage varies greatly, being free to moderate on the interfluves and becoming poorer as the riparian areas are approached down the slopes.

7.4 Reconnaissance Reports.

7.4.1 Munkungule/Katibunga area.

The area is located some 35 km north-east of Mpika township, Soil Survey Unit, in the broken, hilly country near the top of the Muchinga escarpment. (Wood, 1981).

The survey area covers approximately 55-66 ha of which about 52 % has been classified as good arable land for both commercial and small scale farming.

7.4.2 Mambwe I.D.Z. area

The survey area is located in Northern Province, Mbala district at about 25 km. South east of the Mbala township, on a mostly rather open grassland interspersed with clumps of trees and valleys between the ridges farming grassy plains (dambos) which mormally are water-logged during the rainy season. (Van Sleen, 1977).

Over 95.000 ha have been surveyed in the Mambwe area on a reconnaissance level of detail and of which the I.R.D.P. comprises about 66.250 ha. The breakdown of the I.R.D.P. area shows that approximately 37.7% consists of non-arable land of which about 10.175 ha are dambo and marshes and about 14.750 ha rocky mountains or hills.

The residual area consequently covers approximately 41.325 ha (62.3%) out of which 32.2% consists of good arable land and about 24.7% of moderately good arable land. Marginal arable land constitutes 5.4%.

The major soil series in the area is Misamfu which is characterised by high pH, C.E.C. m.e./100 g in clay and base saturation percentage in the upper and sub-upper layers of the profile i.e. 0.20 cm and 20-53 cm.

7.4.3 Mwinuna proposed state farm.

The area is located in Copperbelt Province, Ndola rural district, ablout 40 km due south of Mpongwe sub-centre. (Commisaris, 1976).

The survey area includes an area of approximately 30.140 ha. About 66% consists of moderately good arable land, and 18% of marginal arable land. The remaining area comprises poor and very poor arable soil and non arable soils.

7.5 General characteristics of major soil series.

The main soils in the high rainfall belt of Zambia represent soil types which are typical for the region. Generally the soils are deep, strongly leached, strongly to very strongly acid, they have a low ability to provide nutrients for plant growth and special care is required to fertilizing and liming.

The most important soil series in this region include the Konkola, Mufulira, Kasama and Misamfu series.

7.5.1 Konkola series

Konkola series is a deep well drained sandy clay to clay soil with a sandy loam surface soil and a sandy clay loam upper subsoil. It is typic haplustox.

Table 5. Konkola sandy clay loam.

Depth (cm)	Clay %	C.E.C. m.e./ 100 g clay	Org.C %	Avail P ppm	pH	Base Sat. %	Text. U.S. D.A.
0-5	25	25.6	1.21	6.	4.6	30.8	SCL
5-28	40	14.5	0.62	4	4.4	17.9	SL
28-47	55	11.3	0.51	2	4.2	17.3	C
47-90	65	10.2	0.31	N.D.	4.3	14.6	C
90-120	65	10.2	N.D.	N.D.	4.3	12.4	C

Table 6. Konkola clay

Depth (cm)	Clay %	C.E.C. m.e./ 100 g clay	Org.C %	Avail P ppm	pH	Base Sat. %	Text. U.S. D.A.
0-10	52	17.1	-	-	4.5	-	Clay
10-28	54	14.3	0.90	1.7	4.2	-	"
28-53	52	12.3	N.D.	N.D.	4.3	8	"
53-90	62	9.7	N.D.	N.D.	4.3	9	"
90-130	64	8.1	N.D.	N.D.	4.4	10	"
130-150	65	8.6	N.D.	N.D.	4.4	7	"

Soil reaction, pH($CaCl_2$), of Konkola series is very strongly acid in the subsoil and medium acid in the top soil. This soil has a moderate fertility limitation. it is well to moderately well suited to most crops common in the area.

7.5.2 Mufulira series.

Mufulira series is a deep, well drained, sandy clay to clay soil with a sandy clay loam to sandy clay top soil. (Typic haplustox).

Table 7. Mufulira sandy clay loam

Depth (cm)	Clay 0.002 %	C.E.C. m.e./ 100 g clay	Org.C %	Avail P ppm	pH	Base Sat. %	Text. U.S. D.A.
0-12	24	34.2	1.21	9	4.1	22.0	SCL
12-33	40	15.0	0.58	4	4.1	16.3	SC
33-60	55	11.5	0.47	3	4.3	10.8	C
60-84	54	12.6	N.D.	N.D.	4.3	12.8	C
84-105	57	11.2	N.D.	N.D.	4.4	17.8	C

Table 8. Mufulira sandy clay.

Depth cm	Clay 0.002 %	C.E.C. m.e/ 100 g clay	Org.C %	Avail P %	pH	Base Sat. %	Text.
0-13	39	18.0	1.56	18.2	4.8	53	SC
13-40	49	9.4	0.16	6.0	4.3	19	SC
40-70	57	8.4	N.D.	N.D.	4.3	12	C
70-110	49	9.0	N.D.	N.D.	4.4	13	SC
110-150	58	6.9	N.D.	N.D.	4.5	11	C

The reaction of the soil is very strongly acid throughout the profile except, in some cases, for the topsoil that may be strongly acid. The soil has a moderate fertility limitation. When cultivated this soil is expected to be well to moderately well suited to most crops common in the region.

7.5.3 Kasama Series.

This is a deep, well drained sandy clay loam to sandy clay soil. (Typic haplustox.)

Table 9. Kasama sandy clay loam

Depth cm	C.E.C. m.e./ 100 g	C.E.C m.e./ 100 g clay	Org.C %	Avail P %	pH	Base Sat. %	Text.
0-6	6.3	22.5	1.09	8.9	3.8	8.4	SCL
6-30	5.3	23.0	0.47	2.2	4.1	9.4	SCL
30-60	5.6	20.0	N.D.	N.D.	4.2	5.0	SCL
60-95	5.4	15.9	N.D.	N.D.	4.3	9.1	SCL
95-130	4.8	11.4	N.D.	N.D.	4.5	14.8	SCL

The soils have a weak subangular blocky structure and are friable. The soils reaction is strongly acid. Inherited fertility is low. These soils have a moderate fertility limitation. They are well to moderately well suited to most crops.

7.5.4 Misamfu series.

The Misamfu series is a deep, well drained sandy clay loam with a sandy loam top soil, typic haplustox.

Table 10. Misamfu sandy loam

Depth (cm)	Clay 0.002 %	C.E.C. m.e./ 100 g	C.E.C. m.e./ 100 g clay	Org.C %	Avail P ppm	pH	Base Sat. %	Text. U.S. D.A.
0-9	16	8.1	50.6	2.2	-	5.0	-	SL
9-30	24	3.8	15.8	0.86	-	4.3	-	SCL
30-60	26	3.0	11.5	N.D.	N.D.	4.3	9	SCL
60-100	24	2.6	10.8	N.D.	N.D.	4.4	12	SCL
100-130	40	3.2	8.0	N.D.	N.D.	4.4	9	SC
130-150	32	3.6	11.3	N.D.	N.D.	4.4	9	SCL

8. LIME DEPOSITS IN NORTHERN AND LUAPULA PROVINCES.

Investigations on geological and geochemical characteristics of calcareous at Isoka and Mpika in Northern Province, and at Chambe and Matanda in Luapula Province suggest that the rocks at Isoka and at Matanda have a composition which make them suitable as agricultural lime, and that they occur in sufficient quantity to warrant exploitation. (Anderson 1981).

The chemical analysis of rocks from Nkombwa Hill at Isoka contain about 45 % $CaCO_3$, 30 - 35 % Mg CO_3, and have typical neutralising values of 85 - 100 % with a mean of 88 %. The corresponding values for Matanda are 50 - 55 % $CaCO_3$, about 40 % Mg and neutralising values within a narrow range of 96 - 100 %.

At Matanda the resources above the water table have been estimated at 5 million tons, whereas they exceed 500 million tons at Isoka.

A production of 5000 ton/year can be obtained during 143 days in a one shift operation, which makes it possible to work during the dry season only. However, the recommended mining method and the equipment both allow for an increase of production to 10,000 or 20,000 ton/year.

Small scale mining requires a minimum investment of K500,000 for any production below 20,000 ton/year. Based on an initial production of 5000 ton/year the price of agricultural lime collected at the quaries will be about K22/ton (1981) compared to a price of K45.20/ton (1982) from Crushed Stones Ltd., Lusaka.

On the basis of reports from Provincial Agricultural Officers of these provinces on current land use, the initial requirement of agricultural lime in Northern Province has been estimated at 5000 ton/year, whereas it is 2000 ton/year for Luapula Province.

9. SURVEY OF THE NUTRIENT STATUS OF CULTIVATED SOILS IN HIGH RAINFALL AREAS OF ZAMBIA CARRIED OUT BY THE SPRP.

During 1981 and 1982, soil samples were collected from farmers fields in different districts and from different soils throughout the high rainfall area, in order to assess the soil nutrient status of cultivated soils. Soil samples were collected from the 0-15 cm and 20-40 cm horizons from 222 sites, and represent various soil types, climatic conditions, farm management systems, crops and crop yield levels. A preliminary report have been prepared in connection with the SPRP-seminar held in Lusaka in February, 1983 (Tveitnes, 1983).

Since then, a more comprehensive statistical analysis of variance (one way classification) and correlation tests of the material have been carried out.

9.1 Soil series.

The soils from where the samples were collected were classified tentatively according to the method used by the Soil Survey Unit. The material was subdivided in 10 soil series. An additional group consists of samples where the classification into soil series became too uncertain.

Significiant differences between the soil series were found with regard to pH, texture, cation exchange capacity, and base saturation as shown in tables 12-16.

Table 18 indicates that the calsium content is highest in the soil series Chibesakunda, Kalomo, Chansonge and Twingi, while in Mufulira and Misamfu series the calsium content is rather low.

Chibesakunda is also high in magnesium, while the Lunzuwa, Konkola and Kasama series (red soils) are low.

The subsoil content of aluminium differs significantly with soil series. The highest aluminium content is found in Mufulira, Konkola, Mulobola and Twingi series with 11 - 13 ppm Al. A substantial variation within series is demonstrated, and in the topsoil no significant differences in Al content was found.

Table 11. The content of clay and fine sand of different soil series, per cent.

Soil series	No. of samples	Clay 0-15 cm Mean	Clay 0-15 cm S.D.	Clay 20-40 cm Mean	Clay 20-40 cm S.D.	Fine sand 0-19 cm Mean	Fine sand 0-19 cm S.D.	Fine sand 20-40 cm Mean	Fine sand 20-40 cm S.D.
Not identified	65	24	13.3	28	14.7	37	12.8	34	13.5
Mufulira	26	27	6.3	40	5.9	37	10.3	31	6.9
Chibesakunda	6	33	3.8	48	5.7	33	3.9	24	7.9
Lunzuwa	9	53	9.7	53	8.7	20	7.7	21	6.6
Konkola	3	29	8.3	41	5.0	40	11.0	29	11.2
Misamfu	34	21	7.0	26	5.4	40	11.5	35	10.9
Mulobolo	24	23	5.5	27	5.0	37	10.9	33	10.5
Kasama	4	24	2.1	29	4.2	44	14.3	43	15.5
Kalomo	5	14	1.5	18	1.5	45	11.3	44	11.6
Chansonge	6	12	3.2	13	3.8	38	11.7	41	9.6
Twingi	4	14	3.5	15	1.0	49	9.1	47	12.4
Total	186								
Mean		25	11.9	30	13.1	37	12.1	34	12.0

	F	S.E.Total
Clay % 0-15 cm	11.30 ***	0.87
Clay % 20-40 cm	14.9 ***	0.96
Fine sand 0-15 cm	3.13 ***	0.89
Fine sand 20-40 cm	3.41 ***	0.88

Table 12. The content of medium and coarse sand in various soil series, per cent.

Soil series	No. of samples	Medium sand 0-15 cm Mean	Medium sand 0-15 cm S.D.	Medium sand 20-40 cm Mean	Medium sand 20-40 cm S.D.	Coarse sand 0-15 cm Mean	Coarse sand 0-15 cm S.D.	Coarse sand 20-40 cm Mean	Coarse sand 20-40 cm S.D.
Not identified	65	15	9.2	15	9.1	7	11.3	7	8.9
Mufulira	26	16	8.0	12	6.1	6	3.7	5	2.8
Chibesakunda	6	16	4.5	10	1.9	6	1.4	5	1.7
Lunzuwa	9	6	3.4	5	2.6	2	1.2	3	1.3
Konkola	3	12	4.0	7	3.5	2	1.5	3	2.0
Misamfu	34	16	8.7	17	10.3	7	4.9	6	4.6
Mulobolo	24	18	6.4	19	5.9	7	5.3	8	5.2
Kasama	4	13	10.5	12	11.1	4	3.9	4	4.1
Kalomo	5	17	8.9	17	4.6	10	5.5	11	6.2
Chansonge	6	25	5.8	23	5.9	14	11.6	13	9.9
Twingi	4	19	11.0	20	10.9	7	9.5	8	8.4
Total	186								
Mean		16	8.6	15	8.7	7	8.0	7	6.7

	F	S.E.Total
Medium sand 0-15 cm	2.56 ***	0.63
Medium sand 20-40 cm	3.58 ***	0.64
Coarse sand 0-15 cm	1.01 NS	0.58
Coarse sand 20-40 cm	1.61 NS	0.49

Table 13. pH($CaCl_2$) and pH(H_2O) of various soil series

Soil series	No. of samples	pH ($CaCl_2$) 0-20 cm Mean	S.D.	20-40 cm Mean	S.D.	pH (H_2O) 0-20 cm Mean	S.D.	20-40 cm Mean	S.D.
Not identified	65	4.9	70	4.8	0.61	5.6	0.77	5.5	0.69
Mufulira	26	4.4	28	4.2	0.32	5.2	0.27	4.9	0.45
Chibesakunda	6	5.2	33	4.9	0.37	6.0	0.26	5.8	0.43
Lunzuwa	9	4.5	39	4.4	0.22	5.2	0.45	5.1	0.30
Konkola	3	4.8	55	4.3	0.06	5.5	0.64	5.0	0.17
Misamfu	34	4.5	49	4.3	0.33	5.2	0.50	5.1	0.43
Mulobolo	24	4.4	44	4.2	0.25	5.1	0.51	4.9	0.37
Kasama	4	4.6	22	4.4	0.15	5.3	0.41	5.3	0.21
Kalomo	5	5.4	21	5.3	0.23	6.3	0.22	6.3	0.14
Chansonge	6	5.2	66	5.0	0.64	5.9	0.60	5.8	0.50
Twingi	4	5.0	85	4.9	0.83	5.7	1.05	5.6	1.10
Total	186								
Mean		4.7	61	4.5	5.52	5.4	0.65	5.3	0.63

	F	S.E.Total
pH $CaCl_2$ 0-15 cm	5.15 ***	0.045
pH $CaCl_2$ 20-40 cm	9.43 ***	0.041
pH H_2O 0-15 cm	4.10 ***	0.048
pH H_2O 20-40 cm	6.99 ***	0.46

Table 14. The cation capacity of different soils series, m.e./100 g soil, and m.e./100 g clay.

Soil series	No. of samp-les.	CEC, m.e./100 g soil				CEC, m.e./100 g clay			
		0 - 15 cm		20 - 40 cm		0 - 15 cm		20 - 40 cm	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Not identified	64	7.76	5.96	7.12	6.00	38	26.4	27	17.8
Mufulira	26	6.62	2.36	5.63	1.78	25	9.9	15	5.0
Chibesakunda	6	6.08	1.20	5.83	0.56	19	4.4	12	1.9
Lunzuwu	9	7.98	1.20	7.30	1.70	16	4.3	14	5.0
Konkola	3	6.62	2.08	5.70	1.86	23	7.6	14	5.3
Misamfu	34	4.89	1.89	3.97	0.98	26	11.4	16	5.7
Mulobolo	24	5.36	1.75	4.47	1.10	25	10.3	17	3.7
Kasama	4	5.65	1.06	4.31	0.41	23	2.9	15	4.0
Kalomo	5	3.80	0.48	3.21	0.61	27	2.8	18	3.1
Chansonge	6	3.70	1.59	2.51	0.86	33	13.2	20	4.5
Twingi	4	3.20	0.44	2.89	0.37	24	5.4	17	2.7
Total	185								
Mean	6.31	4.02	5.51	3.95	29	18.6	20	12.3	

	F	S.E.Total
CEC, m.e./100 g soil 0-15 cm	2.43 **	0.30
CEC, m.e./100 g soil 20-40 cm	3.02 **	0.29
CEC, m.e./100 g clay 0-15 cm	2.88 **	1.37
CEC, m.e./100 g clay 20-40 cm	4.41 **	0.91

Table 15. The base saturation percentage of various soil series.

Soil series	No. of samples	base saturation percentage 0 - 15 cm Mean	S.D.	20 - 40 cm Mean	S.D.
Not identified	64	44	27	35	26
Mufulira	26	26	11	20	12
Chibesakunda	6	53	15	44	5
Lunzuwu	9	23	16	17	11
Konkola	3	27	16	14	6
Misamfu	34	31	17	29	20
Mulobolo	24	33	18	21	15
Kasama	4	32	7	19	8
Kalomo	5	73	19	57	13
Chansonge	6	59	27	46	23
Twingi	4	61	35	43	27
Total	185				
Mean		38	23	30	22

	F	S.E.Total
Base saturation percentage 0-15 cm	5.25 ***	1.72
Base saturation percentage 0-15 cm	3.89 ***	1.59

Table 16. The organic carbon content (%), and the content of aluminium (ppm) of various soil series.

		Org C %				Al ppm	
		0-15 cm		20-40 cm		20-40 cm	
Soil series	No.of samp-les.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Not identified	65	1.29	0.80	0.86	0.65	6.9	10.8
Mufulira	26	0.94	0.36	0.71	0.43	13.1	9.2
Chibesakunda	6	0.84	0.30	0.60	0.30	1.4	1.7
Lunzuwu	9	1.10	0.19	0.84	0.29	8.1	11.0
Konkola	3	1.02	0.31	0.54	0.24	13.2	10.3
Misamfu	34	0.80	0.30	0.56	0.24	8.9	1.4
Mulobolo	24	1.06	0.68	0.66	0.32	12.4	12.8
Kasama	4	1.04	0.07	0.32	0.12	6.3	5.6
Kalomo	5	0.63	0.17	0.42	0.18	1.2	0.2
Chansonge	6	1.10	1.08	0.41	0.19	2.2	3.1
Twingi	4	0.67	0.04	0.33	0.10	11.3	20.5
Total	186						
Mean		1.05	0.63	0.69	0.48	8.6	10.7

	F	S.E.Total
Organic C% 0 - 15 cm	2.18 *	0.05
Organic C% 20 - 40 cm	2.24 *	0.04
Al ppm 20 - 40 cm	1.92 *	0.79

Table 17. The content of exchangeable calcium and magnesium in different soil series.

Soil series	No. of samples.	Ca, m.e./100 g 0 - 20 cm Mean	S.D.	Ca 20 - 40 cm Mean	S.D.	Mg m.e./100 g 0 - 20 cm Mean	S.D.	Mg 20 - 40 cm Mean	S.D.
Not identified	64	2.73	3.92	1.69	2.43	0.65	0.58	0.51	0.46
Mufulira	26	1.01	0.76	0.51	0.48	0.43	0.18	0.40	0.27
Chibesakunda	6	1.93	0.66	1.24	0.28	0.88	0.32	0.85	0.36
Lunzuwu	9	1.26	0.99	0.82	0.64	0.30	0.22	0.30	0.21
Konkola	3	0.80	0.51	0.24	0.21	0.62	0.40	0.27	0.13
Misamfu	34	0.83	0.80	0.57	0.74	0.40	0.19	0.36	0.19
Mulobolo	24	1.11	0.99	0.53	0.46	0.38	0.24	0.25	0.20
Kasama	4	0.85	0.58	0.36	0.33	0.70	0.19	0.31	0.05
Kalomo	5	1.89	0.73	0.96	0.46	0.70	0.28	0.63	0.30
Chansonge	6	1.72	1.57	0.76	0.60	0.42	0.35	0.27	0.25
Twingi	4	1.50	1.01	0.58	0.44	0.39	0.25	0.33	0.26
Total	185								
Mean		1.68	2.54	0.98	1.58	0.52	0.41	0.42	0.35

	F	S.E.Total
Ca, m.e./100 g 0-15 cm	2.00 *	0.19
Ca, m.e./100 g 20-40 cm	2.27 *	0.12
Mg, m.e./100 g 0-15 cm	2.51 **	0.03
Mg, m.e./100 g 20-40 cm	2.80 **	0.03

Table 18. The content of Cu and B of different soil series, ppm.

	Cu, ppm			B, ppm		
	No. of samples	0 - 15 cm Mean	0 - 15 cm S.D.	No. of samples	0 - 15 cm Mean	0 - 15 cm S.D.
Not identified	33	1.25	2.07	33	0.13	0.08
Mufulira	22	0.34	0.22	23	0.11	0.03
Chibesakunda	4	0.42	0.10	5	0.15	0.03
Lunzuwu	6	1.19	0.97	6	0.20	0.07
Konkola	3	3.97	3.76	3	0.19	0.12
Misamfu	24	0.34	0.21	25	0.11	0.03
Mulobolo	8	0.45	0.41	10	0.15	0.09
Kasama	3	0.30	0.20	3	0.12	0.01
Kalomo	4	0.43	0.26	4	0.10	0.05
Chansonge	4	0.30	0.23	4	0.08	0.05
Twingi	2	0.35	0.07	2	0.11	0.01
Total	113			118		
Mean		0.76	0.14		0.13	0.06

	F	S.E.Total
Cu ppm	3.02 *	0.01
B ppm	2.02 *	0.005

9.2 Soil Texture.

pH was significantly different in the various texture classes (Table 18). The coarse loamy soils were highest in pH and clayey soils lowest.

Table 19. pH, carbon and exchangeable potassium in different texture classes (20-40 cm).

		pH				C%		Exch. K mg/100 g	
	No. of	0 - 15 cm		20 - 40 cm		20-40 cm		0 - 15 cm	
Texture	samples.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Sandy	32	4.8	0.63	4.7	0.68	0.53	0.42	0.12	0.05
Coarse loamy	12	5.2	0.70	5.10	0.53	0.54	0-14	0.21	0.08
Fine loamy	69	4.7	0.69	4.4	0.51	0.66	0.45	0.26	0.29
Silty	8	4.7	0.53	4.5	0.43	0.92	0.64	0.26	0.13
Clayey	65	4.6	0.46	4.4	0.49	0.81	0.51	0.20	0.09
Total	186								
Mean		4.7	0.61	0.45	0.55	0.69	0.48	0.21	0.19

		F	S.E.Total
pH $CaCl_2$	0-15 cm	2.90 *	0.05
pH $CaCl_2$	20-40 cm	4.25 *	0.04
C%	20-40 cm	2.89 *	0.04
K	0-20 cm	3.25 *	0.01

The cation exchange capacity was significantly higher in the silty and clayey soils. The CEC per 100 g clay,however, was lowest in the fine textured soils as was also the base saturation percentage (Table 19).

The carbon percentage was highest in the silty and clayey soils.

Table 20. The cation exchange capacity and base saturation of various texture classes.

	No. of samples	CEC, m.e./100 g soil 0 - 20 cm Mean	CEC, m.e./100 g soil 0 - 20 cm S.D.	CEC, m.e./100 g soil 0 - 20 cm Mean	CEC, m.e./100 g soil 0 - 20 cm S.D.	Base saturation % 0 - 15 cm Mean	Base saturation % 0 - 15 cm S.D.	Base saturation % 20 - 40 cm Mean	Base saturation % 20 - 40 cm S.D.
Sandy	31	4.89	3.65	43	29	47	31	36	25
Coarse loamy	12	4.47	1.01	33	17	57	25	45	21
Fine loamy	69	5.88	3.58	27	15	39	21	31	24
Silty	8	10.13	11.31	37	30	37	15	29	17
Clayey	65	7.34	2.80	23	10	30	18	22	15
Total	185								
Mean		6.32	4.02	29	19	38	23	30	22

	F	S.E.Total
CEC, m.e./100 g 0-20 cm	5.07 ***	0.30
CEC, m.e./100 g clay 0-20 cm	7.57 ***	0.19
B S P, % 0-20 cm	5.60 ***	1.72
B S P,% 20-40 cm	4.53 ***	1.59

The available phosphorous content (Bray 2) was highest in the medium and coarse textured soils. The highest values of both Cu and B in the topsoil was found in the silty and coarse sandy soils, while clayey soils were poor in these micronutrients.

The content of exchangeable potassium was lowest in the sandy soils and highest in the loamy soils (Table 19). The other exchangeable cations did not show any significant difference between texture groups.

Table 21. The content of available P (Bray 2), Cu and B in different texture classes.

	No. of samples	P (Bray 2) ppm 0 - 15 cm Mean	P (Bray 2) ppm 0 - 15 cm S.D.	Cu, ppm 0 - 15 cm Mean	Cu, ppm 0 - 15 cm S.D.	Cu, ppm 20 - 40 cm Mean	Cu, ppm 20 - 40 cm S.D.	B, ppm 0 - 15 cm Mean	B, ppm 0 - 15 cm S.D.
Sandy	25	3.05	1.73	0.30	0.20	0.29	0.19	0.10	0.04
Coarse loamy	8	4.34	4.11	0.44	0.27	1.04	2.47	0.12	0.08
Fine loamy	37	3.74	5.92	0.72	1.34	0.56	0.84	0.13	0.05
Silty	6	13.77	19.03	0.33	0.15	0.43	0.23	0.11	0.04
Clayey	40	2.75	4.63	1.81	2.42	1.63	2.05	0.18	0.08
Total	116								
Mean		3.81	6.43	0.76	1.42	0.71	1.37	0.13	0.06

		F	S.E.Total
P Bray 2	0-15 cm	4.44 ***	0.60
Cu ppm	0-15 cm	3.98 **	0.13
Cu ppm	20-40 cm	3.27 *	0.13
B ppm	0-15 cm	6.88 ***	0.01

9.3 Soil colour.

As shown in table 22 the redness of the soil increases with increasing clay and silt percentage, while the medium coarse and coarse sandy soils tend to be more yellowish in time.

Table 22. Textural distribution of various soil colours (hue).

	No. of samples	Clay % 20-40 cm Mean	Clay % 20-40 cm S.D.	Silt % 20-40 cm Mean	Silt % 20-40 cm S.D.	Fine sand % 20-40 cm Mean	Fine sand % 20-40 cm S.D.	Medium sand % 20-40 cm Mean	Medium sand % 20-40 cm S.D.	Coarse sand % 20-40 cm Mean	Coarse sand % 20-40 cm S.D.
10 YR	63	25	11	13	6.2	35	11.4	19	6.3	8.5	8.4
7.5 YR	61	27	11	14	8.0	35	12.1	16	9.1	7.5	6.5
5 YR	34	34	12	16	7.3	32	9.6	13	9.2	4.7	3.2
2.5 YR	28	43	13	19	7.4	29	14.6	7	5.8	2.8	1.9
Total	126										
Mean		30	13	15	7.5	34	12.0	15	8.7	6.6	6.7

	F	S.E.Total
Clay %	18.3***	0.96
Silt %	5.46 **	0.55
F. sand %	NS	0.88
M. sand %	16.1 ***	0.64
Coarse sand %	6.70 ***	0.49

The red soils (2.5 YR) are significantly higher in exchangeable Ca and Mg, and also in organic carbon than the more yellowish brownish soils, while the MN content was highest in the soils with 5 YR.

Table 23. The content of exchangeable Ca and Mg, Mn and Organic Carbon in soils of various colours (hue).

HUE	No. of samples	Ca, m.e./100 g 0 - 15 cm Mean	Ca S.D.	Mg, m.e./100 g 0 - 15 cm Mean	Mg S.D.	Mn, ppm 0 - 15 cm Mean	Mn S.D.	Org C, % 0 - 15 cm Mean	Org C S.D.
10YR	63	1.44	1.49	0.43	0.30	7.73	6.74	1.18	0.72
7.5YR	61	1.35	1.12	0.47	0.28	9.10	6.92	0.84	0.39
5 YR	33	1.25	0.88	0.55	0.27	13.5	8.11	0.90	0.36
2.5 YR	28	3.45	5.58	0.79	0.76	6.96	8.39	1.40	0.86
Total	185								
Mean		1.68	2.53	0.52	0.41	9.12	7.60	1.05	0.62

	F	S.E.Total
Ca m.e./100 g 0-15 cm	5.82 **	0.19
Mg m.e./100 g 0-15 cm	5.90 **	0.03
Mn ppm 0-15 cm	5.62 **	0.56
Org C 0-15 cm	7.21 ***	0.05

The cation exchange capacity was highest in the red soils in both horizons. The red soils are also highest in clay, having a higher exchange capacity than coarser textured soils.

Table 24. The cation exchange capacity in soils of different colour.

	No. of samples	C.E.C. m.e./100 g 0 - 15 cm Mean	0 - 15 cm S.D.	20 - 40 cm Mean	20 - 40 cm S.D.	C.E.C. m.e./100g clay 0 - 15 cm Mean	0 - 15 cm S.D.	20 - 40 cm Mean	20 - 40 cm S.D.
10 YR	63	5.73	2.63	5.46	4.16	32	20	23	15
7.5 YR	60	5.50	2.61	4.49	2.10	28	12	18	9
5 YR	34	6.13	3.54	5.01	1.99	26	20	15	5
2.5 YR	28	9.59	7.13	8.45	6.34	28	23	21	17
Total	185								
Mean		6.31	4.02	5.51	3.95	29	19	30	12

	F	S.E.Total
CEC, m.e./100 g 0-15 cm	8,36 ***	0.30
CEC, m.e./100 g 20-40 cm	7.42 ***	0.29
CEC, m.e./100 g clay 0-15 cm	NS	1.37
CEC, m.e./100 g clay 20-40 cm	3.14 *	0.91

CEC, m.e./100 g clay showed less clear relation to colour. The relation between hue and micronutrients was not significant. The content of both Cu and B seemed to decrease with increasing value of hue both in top soil and upper subsoil.

9.4 Farm management and fertilizer use.

In order to investigate whether there were any differences in soil nutrient level among different farm management systems, 8 groups were made as shown below.

1. Virgin land, no fertilizer use.
2. New chitemene, no fertilizer use.
3. New chitemene, slight use of fertilizer.
4. Old chitemene and fallow land, no fertilizer use
5. Other traditional systems, no use of fertilizer.
6. Other traditional systems, slight use of fertilizer.
7. Other traditional systems, moderate use of fertilizer.
8. Emergent and commercial farming, heavy use of fertilizer.

The highest soil pH was found on the new chitemene sites, and the lowest on virgin land and on emergent and commercial farms with heavy use of fertilizer.

The differences were significant also in the 20-40 cm horizon.

Table 25. pH ($CaCl_2$) and Al ppm in soils from various farm management groups.

Farm management and fertilizer use	(pH, $CaCl_2$) No. of samples	0 - 15 cm Mean	0 - 15 cm S.D.	20 - 40 cm Mean	20 - 40 cm S.D.	Al, ppm No. of samples	0 - 15 cm Mean	0 - 15 cm S.D.
1.	31	4.4	0.3	4.3	0.3	30	8.8	6.9
2.	9	5.4	1.1	4.8	0.5	9	3.7	6.6
3.	3	4.8	0.8	4.2	0.6	3	1.7	2.7
4.	28	4.9	0.5	4.7	0.6	28	1.9	2.7
5.	43	4.9	0	4.7	0.6	42	6.3	10.9
6.	15	4.6	0.4	4.4	0.4	15	2.0	3.1
7.	25	4.7	0.5	4.6	0.7	25	3.6	5.5
8.	32	4.5	0.5	4.4	0.5	31	4.9	7.1
Total	185					183		
Mean		4.7	0.6	4.5	0.6		4.9	7.4

	F	S.E. Total
pH $CaCl_2$ 0-15 cm	4.93 ***	0.45
pH $CaCl_2$ 20-40 cm	2.83 **	0.41
Al, ppm 0-15 cm	2.69 *	0.6

The Al-content was highest in the virgin soils but the variation was considerable. The organic carbon percentage varied both between and within the different groups, specially in the top soil. The virgin soils were lowest in carbon, an no particular farm and soil management affected the carbon percentage significantly even if the soils samples from sites with heavy use of fertilizers had the highest carbon content, 1.33% in the 0-15 cm horizon.

Table 26. Total N and organic carbon percentage in soils from various farm management groups

Farm management and fertilizer use	No. of samples	Total N, % 0 - 15 cm Mean	Total N, % 0 - 15 cm S.D.	Total N, % 20 - 40 cm Mean	Total N, % 20 - 40 cm S.D.	Organic C% No of samples	Organic C% 20 - 40 cm Mean	Organic C% 20 - 40 cm S.D.
1.	8	0.05	0.01	0.35	0.02	31	0.50	0.31
2.	4	0.08	0.02	0.053	0.01	9	0.57	0.81
3.						3	0.83	0.43
4.	11	0.07	0.02	0.042	0.01	28	0.60	0.37
5.						42	0.78	0.54
6.	2	0.09	0.02	0.065	0.01	15	0.84	0.46
7.						25	0.63	0.32
8.						32	0.86	0.54
Total	25							
Mean		0.06	0.02	0.043	0.02	185	0.69	0.48

	F	S.E. Total
Total N % 0-15 cm	4.93 **	0.39
Total N% 20-40 cm	3.07 *	0.31
Organic C % 20-40 cm	2.12 *	0.04

The nitrogen percentage was very low in all groups, 0.06% in the top soil and 0.02% in the subsoil silty.

The cation exchange capacity was highest in soils where fertilizer are organic material were added.

Table 27. Cation exchange capacity and base saturation percentage in soils from various farm management groups.

		CEC, m.e./100 g				BSP			
Farm management and fertilizer use.	No. of samples.	0 - 15 cm		20 - 40 cm		0 - 15 cm		20 - 40 cm	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.	30	5.17	2.37	4.29	1.74	24	13	17	11
2.	9	4.54	1.57	4.75	2.97	54	19	35	19
3.	3	4.33	0.50	3.37	1.28	67	32	67	25
4.	28	5.11	2.56	4.53	1.89	47	24	37	19
5.	43	7.03	4.24	5.51	3.08	43	27	33	24
6.	15	7.69	4.70	5.89	1.86	35	18	30	22
7.	25	5.69	2.81	4.88	2.64	36	25	36	26
8.	32	8.03	5.94	8.33	7.28	32	18	24	18
Total	185								
Mean		6.32	4.02	5.51	3.95	38	23	30	22

		F	S.E. Total
CEC, m.e./100 g	0-15 cm	2.56 *	0.30
CEC, m.e./100 g	20-40 cm	3.63 **	0.29
B S P	0-15 cm	4.55 **	1.72
B S P	20-40 cm	4.17 ***	1.59

The base saturation percentage was highest in new chitemene soils.

The exchangeable cations, Ca was significantly highest in new chitemene soil and in heavy fertilized soils. The Al-saturation (Al in percent of Ca + Mg + K + Na + Al) was 21 % in virgin soil, and significantly less in cultivated soils.

The Cu and B content were found to be higher in soils from emergent and commercial farms, most likely due to use of fertilizers and spray agents. Otherwise, no clear differences could be seen in the level of micronutrients in the various farm management groups.

9.5 Crop yield.

The material was grouped in four groups by yield, such that

0 = no yield
1 = poor yield
2 = medium yield
3 = good to very good yield.

The cation exchange capacity and base saturation percentage was higher in soils with poor and medium yields. The nitrogen content was least in virgin soils. Otherwise no significant differences were found in the soil data between the yield groups.

Table 28. CEC, BSP and total N % in soils grouped by yield.

		CEC		BSP					Total N %	
	No.of samp-les.	0 - 20 cm		0 - 15 cm		20 - 40 cm		no.of samp-les	0 - 15 cm	
		Mean	S.D.	Mean	S.D.	Mean	S.D.		Mean	S.D.
0.	45	5.34	2.60	30	18	23	16	13	0.05	0.01
1.	32	7.85	6.94	39	23	34	24	2	0.08	0.03
2.	75	6.07	3.23	44	26	34	24	8	0.08	0.02
3.	33	6.71	3.01	34	20	27	18	2	0.08	0.01
Total	185							25		
Mean		6.31	4.02	38	23	30	22		0.06	0.02

		F	S.E. Total
CEC, m.e./100 g	0-15 cm	2.72 *	0.29
B S P	0-15 cm	4.24 **	1.72
B S P	20-40 cm	3.19 *	1.59
Total N%	0-15 cm	3.92 *	0.004

Table 29. Calcium, content and the Ca/Mg and the Al/(Ca + Mg + K + Na + Al) ratio in soil from various farm management groups.

		Ca, m.e./100 g					Ca/Mg			Al/(Ca +Mg + K + Na + Al)	
Farm m. & fert use	No. of samples	0 - 15 cm		20 - 40 cm		No. of samples	20 - 40 cm		No. of samples	20 - 40 cm	
		Mean	S.D.	Mean	S.D.		Mean	S.D.		Mean	S.D.
0	31	0.60	0.47	0.26	0.21	31	1.31	1.33	34	0.208	0.175
1	9	2.94	4.75	0.81	1.03	9	1.56	1.10	9	0.075	0.120
2	3	9.44	13.62	5.48	7.40	3	20.2	29.2	3	0.009	0.008
3	28	1.41	0.99	0.86	0.68	28	1.97	1.29	28	0.073	0.114
6	43	2.00	1.63	1.12	1.26	40	3.32	2.11	41	0.146	0.225
7	15	1.39	0.89	0.94	1.04	15	2.40	3.00	15	0.097	0.167
8	24	1.02	0.81	0.84	0.80	24	1.94	1.81	24	0.093	0.149
9	32	2.06	2.58	1.38	2.16	31	3.79	3.27	51	0.103	0.159
Total	185										
Mean		1.68	2.54	0.98	1.58	181	2.78	4.46	205	0.120	0.174

		F	S.E. Total
Ca, m.e./100 g	0-15 cm	6.90 ***	0.19
Ca, m.e./100 g	20-40 cm	5.68 ***	0.12
Ca/Mg	20-40 cm	10.47***	0.33
Al/(Ca + Mg + K + Na)	20-40 cm	2.18 *	0.012

9.6 Land, slope percentage.

A grouping by slope of the land where the soil samples were taken shows that the soil pH are low where the land is approximately flat, and increasing with increasing slope percentage up to 4 %. The base saturation and the content of copper also increased with increasing slope percentage up to 5 % while the content of Al was highest in soils with little slope percentage, as was also the aluminium saturation.

Only few soil samples were taken from land with a slope percent of more than 5.

Table 30. Cation exchange capability, base saturation percentage, pH ($CaCl_2$) and Al ppm, in soils grouped by slope %.

Slope	No. of samples	CEC, g/100 g clay 20 - 40 cm Mean	S.D.	BSP 20 - 40 cm Mean	S.D.	pH ($CaCl_2$) 20 - 40 cm Mean	S.D.	Al. ppm 20 - 40 cm Mean	S.D.
0.	16	15	4.1	17	17.4	4.4	0.48	12.9	9.41
1.	44	18	8.4	28	19.1	4.4	0.50	10.1	12.9
2.	77	19	9.4	29	21.8	4.4	0.52	10.1	11.0
3.	15	21	11.1	29	15.5	4.6	0.49	3.3	4.87
4.	24	29	23.0	39	23.6	4.9	0.63	2.9	5.95
5.	5	21	5.5	51	35.2	4.7	0.68	4.7	8.74
6.	2	20	2.8	37	24.7	4.7	0.85	6.8	9.62
7.	1	57	-	16	-	4.2	-	6.8	-
Total	184								
Mean		20	12.4	30	21.7	4.5	0.55	8.67	10.7

		F	S.E. Total
CEC, m.e./100 g clay	20-40 cm	4.16 ***	0.91
BSP	20-40 cm	2.42 *	1.60
pH ($CaCl_2$)	20-40 cm	3.02 **	0.04
Al ppm	20-40 cm	2.36 *	0.79

Table 31. Organic carbon, aluminium saturation, available phosphorous and copper in soils grouped by slope percentage.

Slope	No. of samples	Organic C% 0 - 15 cm Mean	Organic C% 0 - 15 cm S.D.	Al/(Ca+Mg+K+Na+Al) 0 - 15 cm Mean	Al/(Ca+Mg+K+Na+Al) 0 - 15 cm S.D.	Available P 0 - 15 cm Mean	Available P 0 - 15 cm S.D.	No of samples	Cu, ppm 20-40 cm Mean	Cu, ppm 20-40 cm S.D.
0.	16	1.14	0.66	0.27	0.20	26.6	26.5	6	0.40	0.23
1.	44	0.91	0.46	0.13	0.18	14.2	21.8	34	0.42	0.69
2.	77	0.94	0.39	0.15	0.18	17.2	16.4	42	0.42	0.34
3.	16	1.34	0.92	0.04	0.07	25.7	21.9	10	1.94	2.91
4.	24	1.32	1.07	0.05	0.16	33.2	37.3	13	1.43	2.22
5.	5	0.96	0.34	0.13	0.27	9.6	4.4	5	0.24	0.11
6.	2	1.63	0.01	0.07	0.09	9.8	2.9	2	2.90	3.82
7.	1	1.75	-	0.06	-	10.5	-	1	1.10	-
Total	185									
Mean		1.05	0.63	0.13	0.18	19.7	23.1	113	0.71	1.37

		F	S.E. Total
Organic C, %	0-15 cm	2.32 *	0.04
Al/(Ca+Mg+K+Na+Al)	0-15 cm	2.53 *	0.01
Available P, ppm	0-15 cm	2.33 *	1.7
Cu ppm	20-40 cm	3.51 **	0.13

9.7 Soil wetness class.

The material was grouped by the following wetness classes:

0 = no wetness apparent
W1 = mottles starting between 60-90 cm depth
w2 = mottles starting between 30-60 cm depth
w3 = mottles and rusty root channels within 30 cm from surface.

The CEC appeared to increase with increasing degree of wetness as did also exchangeable Ca and Mg in the 20-40 cm layer. The organic carbon content and thereby the content of organic material was also highest in soils in wetness groups 1 and 2.

Table 32. Exchangeable Ca and Mg, Organic C %, Available P, ppm and Mn ppm in soils grouped by wetness classes.

		Ca, m.e./100 g		Mg, m.e./100 g		Organic C%		Available P ppm		Mn ppm	
Wetness class	No. of samples	20 - 40 cm		20 - 40 cm		0 - 15 cm		20 - 40 cm		20-40 cm	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
0	136	0.88	1.49	0.41	0.31	0.91	0.42	22.3	70.0	7.0	6.3
W1	32	0.87	1.01	0.37	0.34	1.25	0.67	15.5	25.6	5.0	3.5
W2	14	1.92	2.69	0.45	0.50	1.57	1.05	28.2	27.0	3.6	3.3
W3	3	2.42	2.29	0.96	0.65	2.92	1.07	339	566	2.6	1.4
Total	185										
Mean		0.98	1.57	0.42	0.35	1.05	0.63	26.7	94.4	6.3	5.8

		F	S.E. Total
Exch. Ca, m.e./100 g	20-40 cm	2.80 *	0.12
Exch. Mg, m.e./100 g	20-40 cm	2.74 *	0.03
Organic C%	0-15 cm	20.5 ***	0.05
Available P ppm	20-40 cm	13.46***	6.9
Ma ppm	20-40 cm	2.72 *	0.43

Available phosphorous was higher in soils with no apparent wetness than in the wetness groups W_1 and W_2.

The Manganese content decreased with increasing wetness. The content of boron in the dry soil was less than in wetter soils.

Table 33. The cation exchange capacity in soils grouped by wetness classes.

Wetness class	No. of samples.	CEC, m.e./100 g soil 0 - 15 cm Mean	S.D.	20 - 40 cm Mean	S.D.	CEC, m.e./100 g clay 0 - 15 cm Mean	S.D.	20 - 40 cm Mean	S.D.
0	137	5.58	2.62	4.83	2.46	27	15	17	7.0
W1	32	7.53	3.52	6.34	3.10	27	14	19	8.2
W2	13	9.49	8.71	7.82	8.88	49	36	34	23
W3	3	13.15	13.34	17.15	8.89	53	43	69	26
Total	185								
Mean		6.31	4.02	5.51	3.95	29	19	20	12

	F	S.E. Total
CEC, m.e./100 g soil 0-15 cm	9.15 ***	0.30
CEC, m.e./100 g soil 20-40 cm	14.86 ***	0.29
CEC, m.e./100 g clay 0-15 cm	7.90 ***	1.37
CEC, m.e./100 g clay 20-40 cm	39.58 ***	0.91

9.8 Crops nutrient consumption.

A grouping of the material was done according to the nutrient consumption of different crops grown on the soil sampling sites.

0 = No crops.
1 = Heavy nutrient consuming crops (maize, vegetables, sunflower, potatoes).
2 = Medium nutrient consumption (Bananas, pineapples, coffee, rice, wheat, groundnuts).
3 = Low nutrient consumption (cassava).

This grouping was done in order to see whether the degree of nutrient consumption of the plants affect the nutrient level in the soil.

Table 34. Calcium content and the ratio´s Ca/Mg and Al/(Ca+Mg+K+Na+Al) in soil grouped by crop nutrient consumption.

Crops grouped after nutrient consumption	No. of samples.	Ca, m.e./100 g 0 - 15 cm Mean	S.D.	Ca/Mg 20 - 40 cm Mean	S.D.	Ca+Mg+K+Na m.e./100 g 20 - 40 cm Mean	S.D.	Al/(Ca+Mg+K+Al) 20 - 40 cm Mean	S.D.
0.	48	0.52	0.61	1.64	1.47	1.05	0.98	0.17	0.17
1.	66	0.96	1.25	2.66	2.31	1.55	1.49	0.11	0.18
2.	47	1.68	2.50	4.25	8.06	2.41	2.69	0.09	0.17
3.	23	0.61	0.72	2.52	1.71	1.14	1.05	0.19	0.21
Total	184								
Mean		0.98	1.58	2.77	4.47	1.59	1.80	0.13	0.18

		F	S.E. Total
Ca, m.e./100 g	0-15 cm	5.22 ***	0.12
Ca/Mg	20-40 cm	2.83 *	0.33
Ca+Mg+K+Na, m.e./100 g	20-40 cm	5.61 ***	0.13
Al/(Ca+Mg+K+Al)	20-40 cm	2.70 *	0.14

Significant differences in the content of exchangeable calcium and also sum if exchangeable cations were shown. Soils with medium nutrient consuming plants turned out have the highest content, while the soils without crops were poorest.

The aluminium saturation was significantly higher on soils with low nutrient consuming plants, than on noncultivated soils.

Table 35. Organic carbon, base saturation and total nitrogen percentage in soils grouped by crops nutrient consumption

Crops grouped by nutrient consumption	No. of samples	Org. C % 20 - 40 cm Mean	Org. C % 20 - 40 cm S.D.	Base saturation 20 - 40 cm Mean	Base saturation 20 - 40 cm S.D.	No. of samples	N % 0 - 20 cm Mean	N % 0 - 20 cm S.D.
0.	48	0.59	0.45	25	18	15	0.056	0.16
1.	67	0.71	0.40	29	21	3	0.090	0.10
2.	47	0.84	0.63	38	25	5	0.076	0.20
3.	23	0.57	0.28	26	19	2	0.056	0.07
Total	185							
Mean		0.69	0.48	30	22	25	0.064	0.20

	F	S.E. Total
Organic C % 20-40 cm	2.75 *	0.04
Base saturation % 20-40 cm	3.74 *	4.25
Total n % 0-20 cm	5.15 **	0.004

The organic carbon and nitrogen content were highest in soils where medium and heavy nutrient consuming crops were grown.

9.9 Crops drought resistance

The material was also grouped by the cultivated plants drought resistance as shown below:

0 = No crops
1 = Drought resistant crops (cassava, fingermillet, sorghum).
2 = Drought tolerant crops (Beans, groundnuts, pineapples, sunflower, potatoes).
3 = None drought tolerant crops (Maize, bananas, coffee, rice, wheat vegetables).

The cation exchange capacity and the organic carbon content were highest in soils where crops with little or no drought tolerance were grown.

Table 36. CEC, BSP and organic carbon content in soils grouped by crops drought resistance

Crops drought resistance	No. of samples.	CEC, m.e./100 g 0 - 15 cm Mean	S.D.	20 - 40 cm Mean	S.D.	BSP 0 - 20 cm Mean	S.D.	Organic C 20 - 40 cm Mean	S.D.
0	44	5.30	2.61	4.43	1.79	30	18	0.55	0.34
1	35	5.30	1.91	4.64	1.90	45	28	0.59	0.47
2	28	7.56	4.73	6.20	3.00	35	23	0.85	0.49
3	78	6.90	4.84	6.27	5.37	40	23	0.76	0.52
Total	183								
Mean		6.32	4.02	5.51	3.95	38	23	0.69	0.48

		F	S.E. Total
CEC, m.e./100 g clay	0 - 15 cm	3.24 *	0.30
CEC, m.e./100 g clay	20 - 40 cm	3.02 *	0.44
BSP	0 - 20 cm	3.39 *	1.72
Organic C, %	20 - 40 cm	3.54 *	0.04

The Calcium content of the 0-15 cm soil layer was highest in the groups with drought resistant and drought tolerant crops. In the subsoil, the content of both calcium potassium and boron were higher in cultivated soils than where no crops were grown.

Table 37. The content of exchangeable calcium and potassium and of boron in soils grouped by crops drought resistance.

Crops drought resist-ance	No.of samp-les.	Ca, m.e./100 g 0 - 15 cm Mean	S.D.	Ca, m.e./100 g 20 - 40 cm Mean	S.D.	K m.e./100g 20 - 40 cm Mean	S.D.	Boron, ppm No.of samp-les	0 - 15 cm Mean	S.D.
0.	45	0.84	0.72	0.44	0.44	0.12	0.08	30	0.11	0.05
1.	35	2.50	4.76	1.14	2.42	0.20	0.17	20	0.12	0.04
2.	28	1.86	.202	1.36	1.93	0.21	0.22	18	0.16	0.08
3.	77	1.74	1.72	1.09	1.33	0.16	0.09	50	0.13	0.07
Total	185									
Mean		1.68	2.54	0.98	1.58	0.16	0.13	118	0.13	0.06

		F	S.E. Total
Ca, m.e./100 g	0-15 cm	3.00 *	0.19
Ca, m.e./100 g	20-40 cm	2.65 *	0.12
K m.e./100 g	20-40 cm	3.77 *	0.01
B ppm	0-15 cm	3.20 *	0.01

9.10 Correlation.

In table 38 correlations between different soil variables are shown. There is a significant negative correlation between Al ppm in the soil and pH, and in both topsoil and subsoil.

A weaker, but still significant correlation was found between P ppm and pH ($CaCl_2$) but only in the 0-15 cm layer.

A significant correlation between the organic C-content and content of available P in the soil was shown, as is also a correlation between organic C % and total N % ($P < 0.001$). A correlation between organic C and CEC, m.e./100 g ($P < 0.001$) was also demonstrated.

A significant correlation between the horizons 0-15 cm and 20-40 cm was found for exchangeable cations, CEC, Al, Org C, N, pH, base saturation and Mn was significant ($P < 0.001$).

Correlations were also found between clay % in the 0-15 cm horizon and CEC, Al and P respectively.

Table 38. Correlations between soil variables.

x	y	r	Depth	$\bar{x}$	$\bar{y}$	r	t	P%
Al ppm	pH($CaCl_2$)	185	0-15 cm	4.9	4.7	-0.58	9.63	0
Al ppm	pH($CaCl_2$)	185	20-40 cm	8.6	4.5	-0.65	11.6	0
Avail P	pH($CaCl_2$)	185	0-15 cm	1.97	4.7	0.18	2.44	1.47
Avail P	pH($CaCl_2$)	185	20-40 cm	2.67	4.5	0.09	1.19	23.3
Org C, %	Avail Pppm	183	0-15 cm	1.05	19.7	0.40	5.89	0
Org C, %	Tot N	25	0-15 cm	0.70	0.06	0.76	5.64	0.01
Org C	C.E.C., m.e./100g	185	0-15 cm	1.05	6.32		0.59	9.970

Table 39. Correlations between soil variables. (Analysis carried out at the State Soil Investigation, Norway.)

x		y	n	$\bar{x}$	$\bar{y}$	r	t	P%
pH	0-15 cm	pH 20-40 cm	147	4.8	4.5	0.77	14.6	0
P Bray 2	0-15 cm	P Bray 2 20-40cm	115	3.82	1.94	0.81	14.7	0
Cu	0-15 cm	Cu 20-40 cm	108	7.81	7.31	0.68	9.61	0
B	0-15 cm	B 20-40 cm	112	12.91	9.29	0.55	6.83	0

Correlation between the variables pH ($CaCl_2$), P (Bray 2), Cu and B in soil samples analysed in Norway are shown in table 39. The analyses indicate a clear correlation between these variates in the top soil horizon and in the upper subsoil horizon.

The cation exchange capacity, pH, the content of organic carbon, total nitrogen, exchangeable magnesium in the soils were significantly higher in the eastern than in the western part of the high rainfall areas of Zambia. The base saturation was highest in the north, while the aluminium content decreases towards east and south.

Some of the variations are probably caused by differences in the rainfall pattern. Thus, pH, base saturation, the content of total nitrogen, exchangeable magnesium, potassium and manganese, decrease with increasing rainfall, while the clay content, cation exchange capacity, organic carbon content and aluminium content increase.

Significant differences in the content of various macro- and

micronutrients were found between soil series, soil texture classes and soil colour.
Farm management including use of fertilizer affects the content of nutrients. Mostly the nutrient content was found to be higher in cultivated soils than in virgin or fallow soil. The first two years after burning of chitemenes, the soil is less acid and often richer in various nutrients.

The physiographic position also affect the nutrient status, as the soil on the crests are more acid and contains less nutrients than further down the interfluves, due to leaching of nutrients downwards.

The nutrient content was not significantly correlated to the yield level. Soils where medium nutrient consuming crops were grown were richest in nutrients.

A comparison of soil analysis results at the Soil Survey Unit Laboratory, Mt. Makulu Central Research Station, and the State Soil Investigation, Agricultural University of Norway, shows that in a number of analysis carried out there are a considerable variation. This espicially refers to analysis of magnesium.

It is therefore recommended that more effort should be done in order to minimize the variation.

As shown in Table 17 the percentage of organic carbon varies significantly between series, the Kalomo and Twingi series having the lowest carbon content.

Significant differences between soil series were also found with regard to manganese. The higher Mn-levels were found in Chibesakunda, Misamfu and Kalomo, and the lower levels in Konkola and Twingi.

The copper and boron content was highest in the Konkola and Lunzuwa series.

10. COMPARISON OF SOIL ANALYSIS RESULTS OBTAINED AT THE SOIL SURVEY UNIT LABORATORY, MT. MAKULU CENTRAL RESEARCH STATION, ZAMBIA AND THE STATE SOIL INVESTIGATION, AGRICULTURAL UNIVERSITY OF NORWAY.

Soil testing in conjunction with fertilizer trials is an important task in order to diagnose the nutrient status of the soil and to improve fertilizer recommendations. There is little relation between total content of nutrients in the soil and availability to plants. Testing of soils therefore aims at giving an index of the amount of nutrients that may become available during the season.

A problem in soil testing has been the reproducibility of results in different laboratories. Reproducibility is essential for calibration against field tests, and many soil laboratories are cooperating with each other by frequent analysis of standard samples.

In connection with the soil sampling programme of Soil Productivity Research Programme, directed by the Agricultural University of Norway in cooperation with the Department of Agriculture, Research Branch, Zambia, soil analyses have been carried out both at the Soil Survey Unit Laboratory, Mt. Makulu Central Research Station, Chilanga, Zambia, and at the State Soil Investigation, Ås-NLH, Norway. The laboratories have cooperated in comparing soil analysis results from samples of which equal portions were analysed at the two laboratories. The soil samples were collected from the high rainfall areas of Zambia, i.e. Northern, Luapula and North-Western Provinces, where ferralitic soils dominates. These soils are mostly acidic sandy and clayey soils poor in nutrients and organic material.

10.1 Methods of soils analysis at the State Soil Investigation, AUN.

pH determinations.
10 ml soil (<2 mm) is added 25 ml H_2O or 0.01 M $CaCl_2$, were shaken for 1/2 hour and stay until the next day. pH is measured in the suspension with separate glass and referance electrodes in a Radiometer apparatus. Before use the apparatus is adjusted with buffer solutions.

Exchangeable cations.
20 g of soil (2 mm) was filled into an Erlenmeyer flask and added 100 ml of 0.1 N neutral ammoniumacetate, stoppered and shaken several times and was standing overnight. The next day the soil was transferred on filter and washed with small amounts of the extracting solution until 500 ml. The content of Na, K, Mg and Ca was determined by atomic absorption and expressed as m.e./100 g soil.

Al-soluble P, K, Mg and Ca.
5 g soil was added 100 ml Al solution (0.1 M NH_4 lactate in

0.4 M CH3COOH with pH 3,75), shaken 1 1/2 hour and filtered. In an aliquot of the filtrate P was determined by the ammonium-molybdate method with ascorbic acid and antimony potassium-tartrate as reducing agent. The content is expressed as P = mg P/100 g.

In the filtrate the content of K, Mg and Ca were determined by atomic absorption. The content is expressed as K-Al. Mg-Al and Ca-Al = mg/100 g or as m.e./100 g.

P HCl
2 g soil was transferred into a 300 ml Erlenmeyer flask and added 50 ml 2 N HCL. The flask provided with a finger condenser was placed into a boiling water bath for 2 hours. The flasks were shaken each half hour. After cooling and filtering the phosphorous content was determined colorimetrically as for P-Al.

NH_4F soluble P (Bray´s method no. 2).
10 g soil and 100 ml extracting solution (0.3 N NH_4F and 0.1 N HCl) were shaken for 10 minutes and filtered. In the filtrate the phosphorous content was determined colorimetrically with ammoniummolybdate and ascorbic acid and antimony potassium tartrate as reducing agents. The method intends to determine the content of acid soluble and adsorbed soil phosphorous.

NAHCO3 soluble P (Olsen´s method).
5 g soil and 100 ml extracting solution (0.5 N $NaHCO_3$ with pH 8.5) was shaken for 1 hour and filtered. In the filtrate the content of phosphorous was determined.

Al and Mn in 0.02 M $CaCl_2$.
10 g of soil and 20 ml 0.02 M $CaCl_2$ solution was shaken for 1 hour, centrifuged at 3000 rpm and filtered. In the filtrate the content of Al and Mn was determined by atomic absorption. The figures are given in mg/kg.

10.2 Methods of soil analysis at the Soil Survey Unit Laboratory, Mt. Makulu C.R.S.

pH.
Soil reaction is measured by glass electrode in a 0.01 M $CaCl_2$ solution, using a soil/$CaCl_2$ ratio of 1:5.

NH_4 F soluble P (Bray´s method no 1).
Extracting solution 0,03 N NH_4F + 0.1 HCl.

Exchangeable cations.
Determined as described for the Norwegian laboratory.

10.3 Comparison of K, Ca and Mg analysis.

Statistical analysis of the data was carried out using the SAS computer programme for analysis of variance and correlation. In table 42 the analysis results with regard to K, Ca and Mg at the two laboratories are shown. In table 42 the analysis results with regard to K, Ca and Mg at the two laboratories are shown.

Table 40. Comparison of soil analysis results obtained at the Soil Survey Unit Laboratory, Mt. Makulu, Zambia (Z) and State Soil Investigation, Ås-NLH, Norway (N). m.e./100 g.

	No of samples	Potassium Mean	Potassium Min. value	Potassium Max. value	Calcium Mean	Calcium Min. value	Calcium Max. value	Magnesium Mean	Magnesium Min. value	Magnesium Max. value
Z	50	0.15	0.04	0.26	0.87	0.07	2.39	0.63	0.24	0.89
N	50	0.16	0.05	0.28	0.85	0.03	3.22	0.33	0.06	0.89
LSD5%			NS			NS			0.04***	

Potassium. Both laboratories obtained about the same mean and variation in the analysis of exchangeable potassium, and the results were significantly correlated (r=0.82***).

Calcium. The mean calcium values obtained at the two laboratories were found to be on the same level. The results were significantly correlated (r=0.91***)

Magnesium. The analytical values for exchangeable magnesium obtained at the Zambian laboratories were almost twice as high as those obtained at the Norwegian laboratory. The analysis variance shows that the results are not comparable although they are correlated.

10.4 Comparision of the acetate method and the AL-method for determining exchangeable cations.

At the Norwegian laboratory, a comparison of the AL-method and the acetate method for determining the cations K, Ca and Mg was carried out.

Table 41. Comparison of the acetate method and the Al-method for determination of exchangeable cations. m.e./100 g.

	No of samples	Potassium Mean	Potassium Min. value	Potassium Max. value	Calcium Mean	Calcium Min. value	Calcium Max. value	Magnesium Mean	Magnesium Min. value	Magnesium Max. value
Acetate method	50	0.17	0.06	0.28	0.85	0.05	3.34	0.33	0.05	0.90
AL method	50	0.16	0.05	0.28	0.83	0.01	3.22	0.33	0.06	0.89
LSD5%			NS			NS			NS	

Determination of exchangeable cations by the two methods tried gave analytical values that are very comparable, as shown in table 41. This is interesting since the AL method is the least demanding of these two methods. The correlation coefficient is is 0.97***

10.5 Phosphorous determinations.

The methods for determination of phosphorous in soil were different in the two laboratories. In Zambia, Bray´s method no 1 was used, while in Norway, phosphorous was determined according to Bray´s method no 2, the AL-method, Olsen´s method and the HCl-method. The mean and variation of the results obtained by the different methods are shown in table 42.

Table 42. Mean values and variation of phosphorous determinations obtained by different analytical methods. 50 soil samples. g/100 g.

Method	Mean	S.dev.	Min. value	Max. value
Z Bray no 1	0.21	0.16	0	0.95
N Bray no 2	1.41	1.06	0.3	4.7
N AL	0.41	0.56	0	2.50
N Olsen	0.81	0.31	0.40	1.75
N HCl	9.28	3.60	2.30	20.0

The amount of phosphorous extracted from the soil differs widely with the various methods. In some cases numerical values for the samples were not given. Correlation coefficients are therefore not calculated.

10.6 pH, Al and Mn determinations.

A number of analysis were carried out in order to compare pH, aluminium and manganese determinations obtained at the two laboratories.

Table 43. Mean, variation and correlation coefficients for values of pH, Al and Mn obtained at Soil Survey Unit Laboratory, Mount Makulu, Zambia (Z), and State Soil Investigation, Norway (N).

	No of samples	Mean	Min value	Max value	r
Z pH (in $CaCl_2$)	444 147	4.41	3.7	7.9	0.90***
N PH (in $CaCl_2$)	442 147	4.37	3.8	7.4	
Z pH (in H_2O)	126	4.78	4.0	6.1	0.86***
N pH (in H_2O)	126	4.88	4.0	6.20	
Z Al, ppm	150	6.90	0	50.4	0.78***
N Al, ppm	150	7.72	0	33.0	
Z Mn, ppm	91	8.17	0.20	45.0	0.87***
N Mn, ppm	91	8.31	0.20	60.0	

As shown in table 43, the pH values obtained at Mount Makulu are concordant with those obtained in the laboratory in Norway. The difference is only 0.04 pH unit when pH is measured in a calcium chloride solution, and the correlation is significant (r=0.90***).

The pH measurement in water was also quite satisfactory, with 0,1 pH unit difference of the mean and with a significant correlation.

With regard to aluminium, the mean values obtained in the Norwegian laboratory tended to be higher than those found in the Zambian laboratory. The correlation is clear even if the maximum values are rather different.

The mean values obtained for manganese are more consistent with each other and the correlation very clear. However, also for manganese the maximum values obtained are quite different.

10.7 Concluding remarks

During the years 1981-83, the Soil Survey Laboratory, Mt.

Makulu Central Research Station, Chilanga, Zambia and the State Soil Investigation, Norway, cooperated in comparing soil analysis results from samples of which equal portions were analysed at the two laboratories.

The analysis results of phosphorous and exchangeable cations differed considerably. The lack of conformity in the analysis of magnesium was particularly pronounced.

It is therefore recommended that further efforts are made in order to reduce the difference of the analysis results.

The soil pH analysis carried out in $CaCl_2$ solution and in water at the two laboratories was concordant. The mean difference between pH measured in the $CaCl_2$ solution and in water was about 0,5 pH units. Determination of potassium, calcium and magnesium by the lactat method at the State Soil Investigation gave analytical values that are well correlated with results obtained by the acetate method for determining exchangeable cations.

11. AN OUTLINE OF SOIL FERTILITY RESEARCH CARRIED OUT IN THE HIGH RAINFALL AREAS OF ZAMBIA.

The findings in the field of agronomic research in the high rainfall areas of Zambia was summarized by Mansfield (1973).

11.1 Chitemene experiments.

Included in this summary is an overview of research into the chitemene system carried out at Lunzuwa Regional Research Station 1928-1958, based on Lunzuwa´s work by Boyd (1959). This research included a comparison of chitemene versus hoe cultivation, use of fertilizers, value of ash, leaching of nutrients and the effect of heat and ash. A comparison of the chitemene system and the Mambwe mound system was also carried out.

The first year after burning the chitemene plots outyielded hoed plots. Sulphate of ammonia, single superphosphate and to a lesser extent potassium chloride gave a marked yield response on hoed plots.

Ash is rich in Ca as calcium carbonate and the soil became saturated with calcium which notably improved soil condition. The experiments demonstrated that the beneficial effect of burnt in ash was more significant in relation to soil structure and weed elimination than in its fertilizer effect.

Phosphate and potash status of the soil following wood burning was enhanced, but there was a tremendous drop in available and total phosphate and potash in the soil after 1 year.

The nitrogen content of ash is poor, however the growth and yield of crops on ash burnt plots without additional ferilizer were equal to that obtained from crops grown on unburnt plots using nitrogen.

An investigation into the effect of leaching under chitemene in 1957 showed that in the interval between an ash burned in October and late December, after 279 mm of rain had fallen, the nitrogen potassium and magnesium status had returned to level of the control. The organic carbon percentage, calcium and available phosphate, were still twice as high, and the pH 6.8 compared with 5.4 for the control at a depth of 30-61 cm.

Experiments investigating the effect of heat and ash was conducted in 1931 and onwards. It was considered that the possible effect which both ash and burn have in common might have been: 1. Raising the pH, 2. Production of a very porous fine seed bed 3. Soil sterilisation, 4. Increase of mineral carbon and 5. Increase of available nutrients.

Burning did not appear to affect either nitrogen fixers of denitrifiers. The effect of burning on the nitrification process appeared to delay the oxidation of ammonia to nitrite by approximately 4 weeks. The conversion from nitrite to nitrate was delayed to a lesser extent. The burning reduces the nitrification rate resulting in a concentration of ammonium nitrogen in the soil. This is less liable to be leached out than is nitrate.

Chitemene was also compared to the Mambwe mound system (Trapnell´s Northern Grassland system). This is basically a green manure system, which incorporates grass and leaves in the centre of earth mounds, where they rot down. The mounds are then spread to form a seed bed for millet.

The results of the experiment indicated that the Mambwe system could not replace chitemene either in respect of production of length of garden life, as long as adequate timber was available.

No method tried seemed to prevent a decline of production. It was obvious that a rest was required, but for how long and between what cropping period was not clear.

In 1943 experiments were started involving rest periods of up to 18 years. Further experiments were laid down to assess the benefit of differing ground covers, together with pilot trials to test one 5 to 6, and one 7 year rotations.

Boyd (1959) drew the following general conclusions:

1. Irrespective of treatment the yields of all fields continued to show a tendency to decline to uneconomic lecels. Manure only temporarily restored fertility.

2. Over nearly all cereal, non-cereal rotations the drop in yield from one cereal to the next was approximately one third of that for cereal monoculture.

3. Continous cultivation with or without nutrient assistance is not compatible with the prevailing soil conditions. Length of cropping and length of type of fallow were still as much a problem as in 1943.

Boyd (1959) considered that it was doubtful if Chitemene would ever be stopped until all trees had disappeared, or until the Mambwe system could be improved. Both systems need the land to be rested for 15-20 years, to restore the original fertility.

11.2 Experiments with chemical fertilizes.

In 1957 research swiched to Misamfu and initially a large proportion of the work concentrated on testing the value of chemical fertilizer and farmyard manure as both were considered essential (either separately or in combination) for any system of permanent agriculture.

Sulphur deficiency was noticed in 1958-59 in observation plots, which compared calcium ammonium nitrate and sulphate of ammonia. Between 1960-62 a number of experiments compared the application of nitrogen with and without the addition of sulphur. It was established that:

a. Sulphur was a limiting factor if below 11 kg/ha.

b. Sulphate of ammonia was more effective than either calcium ammonium nitrate or urea plus the addition of 56 kg/ha of sulphur.

c. Single superphosphate was more effective in combination with urea than double superphosphate, due to the greater amount of sulphur contained in single superphosphate.

d. Sulphur deficiencies was found in sites at Mpika, Isoka and Samfya, as well as Misamfu.

In the period 1959-62 residual responses to various fertilizers were measured using the site of a soya bean and groundnut fertilizer trial. Only superphosphate and sulphate of ammonia had a significant residual effect.

A long term fertility rotation trial was initiated in 1960-61, but was discontinued after 3 years and no conclusions could be drawn.

Trials with farmyard manure demonstrated its value compared with relatively high fertilizer application. The results indicated that there was no residual effect of farmyard manure. At present there are very few cattle in the area, and thus farmyard manure is unlikely to be available.

The monoculture of maize with the application of fertilizer only was investigated further, initially to assess the effects of continued and high applications of sulphate of ammonia on soil pH. Experiments started in 1962-63 indicated that successive high application of sulphate of ammonia resulted in reduction of yield. Although pH fell, increasing acidity could not be definitely correlated with low yield. With the fall of pH, the soil aluminium reached toxic levels and leaf analysis showed zinc deficiency.

In 1964-65 long term observation plots were laid down to assess the effect of incorporating maize stover when maize is grown continuously with the addition of fertilizer. The yields were reduced dramatically the third year, by the incorporation of stover reduced the decline in yield.

Fertilizer trials on red soils at Mbala indicated a significant effect from application of nitrogen and phosphorus in the 1st year. The second year there were no significant differences between treatments, and yield decreased on all plots.

As a part of the student participation in SPRP, Godfrey (1982) made a collection of information on soil fertility and structure in high rainfall areas of Zambia.

He has included results from field trials concerning soil physical characteristics, agronomical practices and changes in physical properties of soils. Changes of soil structure with cultivation and leaching losses. In his report he has also included closely related literature and references.

11.3 The long term fertilizer trial with continuous maize at Misamfu R.R.S.

The long term fertilizer trial with continuous maize, Master Number 1074 was initiated at Misamfu Regional Research Station in the Northern Province in 1964. The trial was set up to discover the long term effects of the then existing fertilizer recommendations, and also to obtain correlations between soil and leaf analysis and yields to assist in making future recommendations.

The site of the experiment is near the crest of a very gently sloping ridge, adjacent to an area of shallow, gravelly soils. The surrounding area is almost flat, and the landscape is typical of Northern, Zambia, having wide flat ridges between shallow dambos. Slopes on the interfluves rarely exceed 5 % and the trial site has a slope of 1 %.

Although the original soil descriptions of the site were identical yield responses and more recent investigation of the soils have shown that two different soil series occur within the trial site. Plot Numbers 1 - 48 occur on a lighter textured soil than plots 49-96. The establishment of the trial on a site with such a soil variation was unintentional.

Block I (Plot Numbers 1 - 48) is situated on soil of the Chinsali sandy loam series (Van Sleen 1976). This is a red soil with a texture of sandy loam throughout the profile. It has a weak structure with moderate to rapid permeability. It is strongly acid with a low cation exchange capacity, and a low base saturation percentage.

Block II (Plots 49 - 96) is situated on soil of the Kasama sandy loam series. It is similar to the Chinsali series, but has a subsoil texture of sandy clay loam.

Both soil series are classified as Typic haplustox under the USDA system and Rhodic Ferralsols according to the FAO system.

All plots receive an annual basal dressing of nitrogen fertilizer, regardless of treatment. Treatment levels of nitrogen are applied as varying levels of top dressing. Phosphorus, potassium and zinc treatment levels are applied as basal dressing. The zinc treatment was not introduced until 1971.

Sulphate of ammonia was proposed for the basal dressing to ensure that adequate sulphur was applied to all plots. Calcium ammonia nitrate was initially used as a top dressing in an attempt to avoid soil acidity problems. The phosphorus and potassium levels were chosen low because at the time of the initiation of the experiment they had not been shown to be dificient in the area. It was expected that deficiencies would show up after a few years. In 1981-82 season it was observed that where both phosphorus and potassium were applied the crop stand was reasonably better than in the plots where nitrogen was applied together with either phosphorus or potassium and the plots which did not receive phosphorus and potassium were below poor.

The two lime applications were attempts to receive the yields, though it was not intended originally that the trial should receive lime. In 1972 potassium level was drastically increased on the basis of the leaf analysis. The use of C.A.N. was discontinued in 1973 due to non-availability of the fertilizer in the country. The levels of phosphorus and potassium were raised from 1977 onwards to bring them in line with more recent recommendations.

Soil analysis included exchangeable calcium, exchangeable magnesium, exchangeable potassium, pH and available phosphorus in most years, and for organic carbon, total nitrogen and cation exchange capacity in some years. Soil physical data was also recorded for one year.

The trial clearly show that continous maize production under the management applied cannot be expected to produce sustained high yields of maize on similar leached sandveld soils.

The lowest economically acceptable mean yield for commercial maize production in Zambia is estimated to be 4t/ha This yield was achieved for only the first two years on the Kasama series. Neither the use of C.A.N. top dressing nor the two lime applications, nor the highest levels of fertilizer application halted the decline in mean yields.

11.4 Experiments with lime. The National lime Trial at Misamfu R.R.S.

This trial was initiated at Misamfu Regional Research Station in the Northern Province in 1971/1972. The intention of this trial is to determine the effect of lime on acid soils (pH approx. 4.6) on both maize and groundnuts and to determine the optium tate of application. The trial has six treatments, viz: Nil lime, 500 kg lime185, 1000 kg lime/ha, 500 + kg lime/ha, 2000 kg lime/ha and

4000 kg lime/ha Except 500 + kg lime per ha is applied every year, all the other treatments were applied only at the start of the trial in 1972. Hitherto, 500 + kg lime per ha and 4000 kg lome per ha give very good yield, in fact better than the other treatments.

Relatively little amounts of lime are required to neutralize soil acidity in tropical soils rather than the large amounts required in temperate regions. This is supported by the results of trials carried out in the country by the Research Branch on Acid trials, lime trials, and National lime trials and is reflected in the recommendation rates for lime on different soil types and for different crops.

Crop	Texture	Critical pH	Lime rate
Potatoes	Sands	4.3	500 - 1000
	sandy loam	4.5	1000 - 1500
	sandy clay	4.6	1000 - 2000
Maize	Sands	4.4	500 - 1000
Sunflower	Sandy loam	4.6	1000 - 1500
Rhodes grass	Sandy clay	4.8	1500 - 2000
Stargrass			
Wheat	Sands	4.6	500 - 1000
Soyabean	Sandy loam	4.8	1000 - 1500
Groundnuts	Sandy loam		
Cotton	Sandy clay	5.0	1500 - 2000
Beans			
Lucerne	Sands	4.7	1000 - 1500
	Sandy loam	4.8	1500 - 2000
	Sandy clay	5.0	1500 - 2000

After the application of large doses of Ammonia Sulphate the pH became very low in this trial field and the yield response to lime was marked. Maize yields gradually returned to normal after lime application.

The low levels of lime applied seem to provide adequate calcium to meet the crop needs, where favourable yield responses lime do not occur even at pH values below 4.5 Aluminium saturation is probably too low to retard growth.

11.5 Lime trials in North Western Province.

In the North Western Province, a number of investigations as to the effects of lime were carried out in 1970-71 at the Mwinilunga Farmers Training Institute.

De Boer (Agricultural Research North Western Province 1970-77, Results and Recommendations) has presented results from a series of experiments with lime carried out in a period of 5 years.

It was concluded that without lime, the yield of both maize and groundnuts would be reduced to practically nothing after 3 years of cultivation. This was also confirmed by experience from the previous observation.. From the results of the experiments, it was recommended to use 1000 kg of lime per ha every fourth year where soil pH($CaCl_2$) was less than 4.5

An experiment carried out at Mwinilunga in 1977/78 indicated a clear response to fertilizers together with lime, while the responses was insignificant where no lime was applied.

Acidity and lime trials conducted by the Research Branch have suggested that pH and aluminium concentration for optium yields did not show any consistency but varies from trial to trial and from year to year (Munyinda 1983). This however, might help to explain why reasonably good yields can be obtained on soils where the pH has dropped to below 4.5 and is still dropping where as, it is often reported that liming has no effect on yields even though the pH is raised. There appears to be a time lag between changes in pH and subsequent changes in the concentration of aluminium. aluminium values are higher for lime trials than acidity trials at the same pH value. This indicates that on liming the aluminium poly complexes are not instanteneously reduced to chemical inert forms but slowly reduced over several years inversely on acidiying a soil there is a time lag between the build up of aluminium and the drop in pH.

Plants differ in their tolerance to toxic substances and soils too differ as to the element most toxic and the level at which the toxicity is eliminated.

According to some results, maize responded to liming on mineral soils even where more than 70% aluminium saturation existed in the soils, except for soils where some other factors limit growth. In case of the National Lime Trial 1944 at Misamfu a yield response to maize was also obtained where aluminium saturation was 61% (Munyinda 1983).

By and large the use of lime is essential both to provide for the lack of Ca and Mg, as nutrients, to increase the pH to a level appropriate for the growth of plants and to reduce the toxic concentration of Al and Mn - ions in the soil solution. However, lime has little fertilizer effect in the soils since Ca and Mg which it provides as plant nutrients is little but has greater liming effect.

12. PROPOSALS FOR SOIL FERTILITY RESEARCH.

The existing knowledge about soils and soil fertility in the high rainfall area, which has been dealt with in this report, is the basis for future research in this field.

Organic material.

The management of crop residues and other organic material is of great importance for the nitrogen status of the soils, as well as for soil physical conditions. The effects of mulches, green manure and compost, especially of legumes, as nutrient supply and soil amendment should be further investigated in experiments. Recycling of nutrients and organic matters in traditional systems e.g. the Mambwe system, and how to improve the systems should be paid attention. Changes which takes place in the soil during the cultivation period and the fallow period in a chitemene station should be examined and experiments with alternative method to natural fallow should be carried out, e.g. by use of rapid growing forest trees and shrubs, green manuring, mulches and improved crop rotation systems.

Soil acidity.

Aluminium toxicity is considered to be one of the major cimitations to the growth of agricultural crops in the high rainfall areas. It is important to evaluate the effect of different types of land, the effect of deep placement and movement of Ca within the soil profile, as well as interactions between lime add phosphate fertilizers.

Soil fertility.

Phosphorus is probably the main limiting plant nutrient in the area. Methods of P-application, amounts and types of P-fertilizers. Phosphorus adsorption experiments should be carried out in order to assess the amounts of phosphorus fertilizers needed. Rock phosphate from local deposits may be an important source of phosphorus, and should be further investigated.

Nitrogen.

The variation in nitrogen content of different soil layers during the rainy season should be studied. There is a need for data on the nitrogen fixing potential of different legumes, and the residual effects of legumes. Magnesium and sulphur are other macronutrients which would require research.

Micronutrients.

Deficiencies and toxicities of micronutrients is a field of study which requires considerable attention.

Many reports indicate that a deficiency of one of several microelements is the reason for insatisfactory growth, e.g. Zn, Mo and B. Experiments with micronutrients should also be seen in association with liming, since liming may induce Zn and Mn deficiencies.

Microelement toxicity, especially manganese toxicity in different soils within the high rainfall area should also be investigated.

Soil erosion and soil water.

Soil erosion is regarded a major problem connected with intesive farming, and experiments should be carried out in order to find acceptable ways of minimizing soil erosion by water and wind, e.g. by use of no tillage, cover crops, mulches and alley cropping. The water infiltrability is often reduced with the introduction of arable cropping, espicially through intesitive tillage and soil composition. Erosion, moisture storage capacity and root distribution is regarded an important field of study.

Weed control and methods of cultivation.

Weeds are generally difficult to control in the rainy season. It shold be of great value to investigate methods of weed control in different crops.

Different means of controlling weeds, e.g. mechanically, by mulching and by dense crop stands should be studied. Time of tillage and planting should also be included in these studies.

Field experiments sites should be established on benchmark soils for the major soil series.

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