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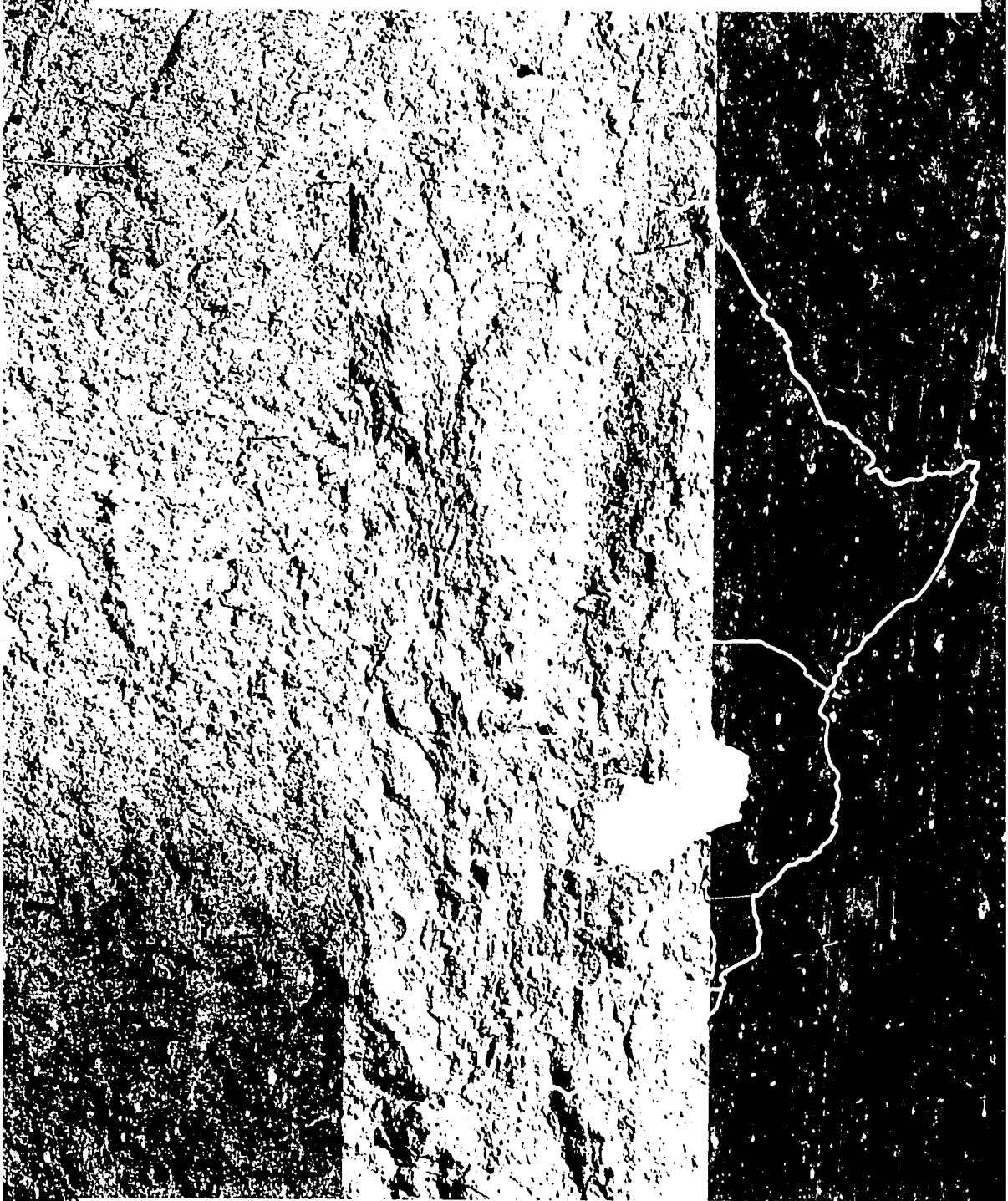
XI INTERNATIONAL FORUM ON SOIL TAXONOMY AND AGROTECHNOLOGY TRANSFER

Zambia, July 15-August 1, 1985



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PART 2. EXCURSION GUIDE AND APPENDICES

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PROCEEDINGS OF THE

XI th INTERNATIONAL FORUM

ON

SOIL TAXONOMY AND AGROTECHNOLOGY TRANSFER

ZAMBIA, JULY 15th to AUGUST 1st, 1985

Sponsored by

International Benchmark Sites Network for Agrotechnology Transfer
(IBSNAT)
Belgian Administration for Development Cooperation, Belgium
(BADC)
Ministry of Agriculture and Water Development, Zambia
(MAWD)
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(NORAD)
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(SMSS)
University of Zambia
(UNZA)

Editor - P.R. WOODE

PART 1 - PAPERS

PART 2 - EXCURSION AND APPENDICES

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INTERNATIONAL FORUM ON SOIL TAXONOMY AND AGROTECHNOLOGY TRANSFER - ZAMBIA, JULY 15th - AUGUST 1, 1985.

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PREFACE

EDITOR'S NOTE

During many of the introductory sessions where the various epipedons, subsurface horizons, properties and orders of the system were being described, no papers were presented. In many of these sessions, copies of the relevant pages of "Soil Taxonomy" or descriptive lecture notes were distributed. These have not been reproduced in these proceedings.

During the first five sessions although no papers were presented, the editor took some brief notes, and these are reproduced under the heading "Introductory Sessions".

Where presented papers included a summary, the summary has been omited from these proceedings for the sake of brevity.

All figures have been re-drawn because most originals could not be found. Any errors that may have crept in during the re-drawing are regretted.

References originally listed with papers but not refered to in the text have been omited.

Where papers contained glossaries consisting of definitions available from standard textbooks, these glossaries have also been omited, and only definitions of terms of local origin retained.

Some papers were distributed during the forum, but were not presented formally as lectures. These are given in Volume 2 under "Miscellaneous handouts".

P.R. WOODE.

XI th INTERNATIONAL FORUM ON SOIL TAXONOMY AND AGROTECHNOLOGY TRANSFER - ZAMBIA, JULY 15th - AUGUST 1, 1985.

INTRODUCTION

The goal of every country in the region is to seek self-sufficiency in food and fibre production. The World-wide energy crisis of the last decade has had its impact in practically every country. For the small farmer the energy crisis translates and compounds itself in several forms in such a way that he is the hardest hit. Lacking the technology and the ability to respond to problems, he is faced with the hazards of drought, soil degradation and low productivity. Everybody concerned with improving the productivity of the small farmer is working to overcome these constraints.

The soil resource of a nation is one of its greatest assets. It has to be managed so that it is most productive and at the same time care has to be taken so that it is conserved and forms a resource base for generations to come. This calls for a discriminatory use of soils, requires a reliable resource inventory and good appreciation of its potentials and constraints. Soil surveys provide such an inventory and soil research provides the basis for its optimal use and management. All local, national and even regional agricultural planning should be based on soil resource inventories. Every country of the region has some kind of resource inventory, but these vary in scale, terminology, quality and methodology with which they were made. From the point of view of regional cooperation and collaboration it will be useful to rectify this situation and work towards standardizing techniques and approaches.

The theme of this forum is "Soil Taxonomy and Agrotechnology Transfer". Soil Taxonomy is a system of soil classification for making and interpreting soil surveys. It is used by more than 40 countries as the national system of soil classification and many others as an adjunct system. One of the reasons for its wide use is because of its use as a vehicle for agrotechnology transfer.

The need for agrotechnology transfer is apparent in many countries of the region. Research is expensive and most countries cannot afford the money, time or some do not even have the personnel to conduct the necessary research. A short term solution is to do adaptive research for validating technologies developed elsewhere and modifying the technologies for local use. These considerations form the rationale for this international forum.

This forum is the eleventh in the series organized internationally by the Soil Management Support Services (SMSS), a project of international technical assistance in soil survey and soil management. of the U.S. Agency for International Development implemented by the Soil Conservation Service of the U.S. Department of Agriculture. The previous and future forums are:

No.	Year	Country/Region	
I	1980	Fiji	: S. Pacific
II	1981	Morocco	: N. Africa
III	1982	Cameroon	: W. Africa
IV	1983	Thailand	: S.E. Asia
V	1983	Papua New Guinea	: S. Pacific
VI	1983	Costa Rica	: C. America
VII	1984	Philippines	: S.E. Asia
VIII	1984	Jordan	: Middle East
IX	1984	Guam	: S. Pacific
X	1985	Rwanda/Burundi	: C. Africa
XI	1985	Zambia	: S. Africa
XII	1985	Pakistan	: Asia
XIII	1985	Panama	: C. America

The forums are organized in collaboration with several national and international organizations who provide financial and logistical support.

The Soil Survey Unit in Zambia forms part of the Land Use Branch of The Department of Agriculture. It deals with nation-wide soil survey and interpretation at scales varying from 1:5,000 to 1:1,000,000. Up to now about 25% of the country has been surveyed.

Soil surveyors are stationed at the provincial agricultural headquarters and a central unit, comprising the Senior Soil Surveyor, Soil Correlator, Land Evaluator, Soil Information System Specialist, Provincial Soil Surveyor, and the National Soil Surveyor, together with a soil analytical laboratory headed by the soil chemist, operates from Mount Makulu Central Research Station.

The survey findings are published in soil survey reports, of which so far 125 have been issued. Other publications are soil bulletins, dealing with special soil studies, and technical guides, containing technical aspects of soil survey and interpretation.

Since 1977 the Soil Survey Unit has been technically and financially supported by the Norwegian Agency for International Development (NORAD).

The School of Agricultural sciences is one of the eleven faculties of the University of Zambia (UNZA). It has five departments, Animal Science, Agricultural Engineering, Crop Science, Rural Economy and Extension Education, and Soil Science. One of the major research activities of the Department of Soil Science is its involvement as a collaborator in the International Benchmark Site Network for Agrotechnology Transfer (IBSNAT). In this endeavour the department is carrying out research on a number of crops. The data generated will be used to validate

crop simulation models for application in Zambia. Once validated, these models will be used for agrotechnology transfer within Zambia.

The Department of Soil Science is in part technically and financially supported by the Belgian Administration for Development Cooperation (ABOS).

The objectives of the forum are as follows:

1. To inform soil scientists in the region about Soil Taxonomy and to enable them to correctly use the system for making and interpreting soil surveys.

2. To enable soil scientists and others interested in the use and management of soils to meet and exchange information.

3. To assist in the standardisation of techniques in the making and utilisation of soil resource inventories to foster agrotechnology transfer in the region.

4. As a result of objectives 1,2 and 3, to strengthen national institutions in achieving the common goal of self-sufficiency in food and fibre production.

OPENING SPEECH

Hon. R.C. Kamanga, MCC
(Chairman of Rural Development Sub-Committee)

Comrade Chairman

Comrade Minister for Agriculture and Water development

Comrade Permanent Secretary of the Ministry of Agriculture and Water Development

Conference Participants

Ladies and Gentlemen

Zambia is greatly honoured and privileged to host the 11th International Forum on Soil Taxonomy and Agrotechnology Transfer.

I am informed that this forum is the 11th in the series organised internationally by the Soil Management Support Services (SMSS), a project of international technical support of the United States Agency for International Development.

The tremendous importance attached to this forum is expressed by the presence of a considerable number of international participants from neighbouring SADCC countries, Europe, and America, and the large participation of Zambia's soil scientists.

I wish to take this opportunity to thank most sincerely the local and foreign institutions that contributed both financial and technical assistance to make this forum a reality and for the honour bestowed upon Zambia as the host country. I wish to acknowledge the following institutions:

- The Soil Management Support Services (SMSS)
- The Norwegian Agency for International Development (NORAD)
- The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT)
- The United States Agency for International Development (USAID)
- The University of Zambia (UNZA)
- The Ministry of Agriculture and Water Development

Comrade Chairman, a lot of time and effort has been put into organising this event, it is therefore my sincere hope that all participants will greatly benefit from the exchange and interaction of ideas.

The need to increase and improve food production has been Zambia's pre-occupation for a long time now. There is great urgency to seek self-sufficiency in food production in order to

forestall possible hunger. Agriculture has become the lifeblood of this country, especially when the country's benefits from copper are declining.

Zambia has an area of 75 million hectares of land, of which more than 60% is arable land, and only slightly over 15% of the arable land is currently being cultivated for agriculture. These figures clearly show that Zambia has a tremendous potential for increased food production. At times, however, it has been compelled to import food.

To counteract the effects of future food shortages, the party and its government has called upon institutions within and outside the country to help it seek ways and means to develop technologies that will assist Zambia to become self-sufficient in her food requirements. This forum is one of the clear testimonies trying to seek both short and medium term solutions to the agricultural problems being experienced by the country.

The party and its government is always making concerted efforts to encourage increased food production by making available various incentives to farmers. It ensures good producer prices, low income tax for farmers of not more than 15%, and duty free importation of agricultural equipment, as well as providing short and medium term credit. It is hoped that the end result of all these efforts will be the overall increase in the productivity of the agricultural sector.

Comrade chairman, the effects of drought and soil degradation which have beset this part of the world have frustrated the government's ability to increase food production.

Consequently the government has been compelled to import food from any country willing to sell to Zambia. Indications nevertheless point to a recovery of crop production this season.

Despite the adverse drought effects being experienced by the country the government has continuously rendered support to the agrarian revolution.

Besides the environmental constraints to food production, other constraints have been identified. On one hand, the unfortunate growth in urban population has increased at an alarming rate, creating an imbalance between the urban and rural areas. It is therefore imperative that the reverse condition is created in order to bolster agricultural production in rural areas to acceptable levels.

Unless agricultural production in rural areas is increased, the country will be in more danger of facing growing urban unemployment, poverty and food shortages.

On the other hand, foreign exchange earning capacity of the mining sector is falling, thereby worsening the balance of

payments problems.

In view of these constraints, our agricultural policies and programmes should be designed to achieve the following objectives:

(A) Achieve a satisfactory degree of self-sufficiency in the production of major stable food crops particularly maize, cassava, sorghum, and millet so that incremental demand can be met by domestic production.

(B) Expand production of export commodities in order to increase the sector's contribution to the country's balance of payments with particular emphasis on those products with the highest potential for export such as beef, tobacco, coffee, groundnuts, day old chicks, fruits and vegetables.

(C) Increase production of import substituting commodities with proven domestic comparative advantage, especially dairy products, poultry products, vegetable oils and cakes, in order to meet increasing domestic demand for these products.

(D) Increase personal incomes and employment in rural areas and redress the imbalance of development between the urban and rural sectors. While all farmers need to be encouraged to produce through their response to incentives, the major strategy should be to increase the productive capacities of the peasant, emergent, and other small scale farmers.

Comrade chairman, against these objectives appropriate policies and strategies are required to steer the agricultural sector in achieving them. In a nutshell the following priority policy areas should be pursued:

1. Develop adequate storage capacity to minimise post-harvest losses.

2. Diversify food production in order to include all kinds of suitable crops.

3. Expand the export earning capacity of the agricultural sector.

4. Increase food reserve capacity to reduce the problems of famine and food shortages.

5. Improve agricultural marketing and provide sufficient incentives to stimulate increased production.

6. Develop suitable irrigation and water supply systems to reduce the effects of drought.

7. Review research policies in agriculture, veterinary and fisheries to develop suitable technologies.

8. Expand extension services to pass on research discoveries to farmers

9. Facilitate transmission of input supplies, credit and marketing.

10. Design appropriate mechanical technologies to suit the environment.

11. Develop suitable land conservation strategies to minimise land degradation.

12. And last, but not least, improve land tenure policies that are conducive for agricultural development.

Comrade chairman, these priority issues should be seen as complementing each other in order to achieve the four objectives I previously pointed out. The over-riding objective of the governments objective in the agricultural sector is to reduce poverty, ensure better nutrition, increase the export base and raise the quality of life for Zambians.

Comrade chairman, ladies and gentlemen, having briefly digressed into Zambia's agricultural and economic environment, allow me to briefly discuss Africa's environment to which Zambia is a part. The African continent as a whole has a population density which is relatively low, but unevenly distributed as one can find that there are areas of maximum capacity. The size of the industrial sector is extremely modest and agriculture remains the foundation of nearly all national development programmes. Most of the continent belongs to the poorest of the world's economy.

Africa's rate of economic growth has been bleak in relation to other regions of the world over the past 10 years. In terms of performance the agricultural sector in most African countries registered negative rates of growth over the past 10 years.

The declining agricultural production being experienced in most countries has led to what many observers are now calling an "agrarian crisis" or "Africa's food crisis".

Comrade chairman, since African nations attained independence most of them have been pursuing mixed economies with heavy emphasis on foreign aid, industrial development, education, and diversification of their economies. But whatever policies are being pursued, most African countries give low priority to Agriculture and especially to the farmers in the rural areas. Agriculture remains a "backward" sector.

During the last decade, almost all African governments have shifted from industrialization and have adopted the multiple goals of food self-sufficiency, improved nutrition, diversification of their economy, and increased economic cooperation among African nations. Examples of such cooperation are the Preferential Trade Area (PTA) and Southern Africa Development Coordination Conference (SADCC).

Comrade chairman, allow me to shift my emphasis to the current issue - the forum. It is a well known fact amongst you scientists and laymen that the soil's importance lies in the fact that it is the medium of crop production. We are all interested in the soil's economic potential to produce and thus contribute to the development of a nation.

It is therefore the detailed knowledge of the soil resources that is a major key in planning for rural development and strengthening the economies for our nations. Time immemorial has proved that unwanton destruction of soils through mismanagement can have disastrous effects on the quality of the environment. It is therefore important for us to conserve this basic resource so that we continue to benefit from it.

Comrade chairman, it is this concern that has brought about this large gathering of scientists from the developing and developed countries to share information and experiences with a common goal of attaining self-sufficiency in food production.

It is obvious that developing countries cannot afford the large research investments required to develop their own appropriate approaches to solving soil related constraints. It is therefore not only advantageous but essential that we gain directly from the experience of others in terms of agro-technology transfer.

There are a number of international institutions in other parts of the world where agriculture technology has been developed and tested and which can be transferred to similar environments. At new locations only adaptive research is necessary to validate the transferred technology before it is recommended to the farmers of those locations.

One such institution is the International Benchmark Sites Network For Agrotechnology Transfer (IBSNAT). Its function is to consolidate national and international research centres into a network for purposes of developing, validating, and utilising a scientific method for the effective transfer of agro-technology among and within countries in the tropics and sub-tropics.

To accelerate the transfer of technology IBSNAT identified the United States System of soil classification, commonly known as Soil Taxonomy, as a vehicle of communication.

Comrade chairman, I am informed that the government of Zambia through the directorate of Agriculture sought the assistance of IBSNAT initially for the purpose of establishing a national benchmark programme. This programme is being set up to characterise the major Zambian soils and to study relationships between soil properties on one hand and crop performance and soil management on the other hand, with a view to imparting the acquired information to the farmers.

Whilst contact with IBSNAT was being pursued, a problem of soil classification was identified, and the Soil Management Support Services (SMSS) of the United States Department of Agriculture was called upon to provide technical assistance in soil survey, soil classification, and the use and management of soils.

The call for technical assistance was promptly answered with the arrival of SMSS project coordinator Dr. Hari Eswaran, who amongst other things discussed the initiation of the benchmark soil network and of conducting a training session on soil management improvements and soil classification. I am also informed that this regional forum is a result of his visit to Zambia two years ago.

This forum, I am told, is intended to teach the United States system of soil classification and its application for agrotechnology transfer. One of the goals is to develop a collaborative programme whereby soil resources of each country in the region are inventorised with the same techniques and with the same quality.

Another institution worth mention is the International Board for Soils Research and Management (IBSRAM). Its formation was based on the need for developing country institutions to come to terms with the constraints on food production resulting from adverse soil conditions. Its emphasis is on problems experienced in the tropics and sub-tropics in relation to acid tropical soils, land clearing, clays and wetlands. Recently the board in conjunction with other organizations organised a workshop on acid soils. Zambia, which is covered by more than 50% of these acid soils endorsed her support for such an organization by sending delegates to attend the workshop in Brazil and Peru where a tremendous amount of research has been conducted. This workshop has been particularly noted here to underline the need for interactive discussions and research collaboration.

Comrade chairman, let me emphasise the point that as soil maps are increasingly becoming essential tools for planners and decision-makers, such information should be sought whenever possible as a basis for agricultural development and for opening up new lands. Previously, many feasibility studies have included soil survey information and more often than not the information has not been utilised in the subsequent layout of development plans. One of the contributing factors has been lack of

communication between soil surveyors and planners. It is therefore essential that firstly the mode of communication should have the attribute of translating information on soil maps to field conditions. Secondly the system should permit application of knowledge and experience to solving practical problems of land development and food production, and not just end up amongst the academics.

It should also be emphasised that the soil classification system adopted should be used as a technique for the restoration of soil fertility. To put it another way, the restoration of soil fertility should be the basis for classifying agricultural systems.

Lastly, to acknowledge the importance of soil and to quarantee its continued fertility for sustained crop production requires strengthening the national soil survey and research in terms of financial and personnel inputs. Training of personnel at all levels should be intensified.

I wish to assure all the visitors to Zambia that they should feel at home. I am informed that participants will go on a field trip to the north and south of Zambia. I hope you will enjoy the country-side which you are planning to understand in order that the children of our children will also be able to enjoy the same countryside.

It is now my honour and privilege to declare the 11th International Forum on Soil Taxonomy and Agro-Technology Transfer officially open.

Thank You.

INTRODUCTORY SESSIONS

Editor's Note

Following a film, the first five sessions of the Forum were talks to introduce the Soil Taxonomy. Papers were not presented at these talks, and the following records are from notes taken by the editor during these sessions.

INTRODUCTORY SESSION 1

THE ROLE OF SOIL SURVEY IN AGRICULTURAL DEVELOPMENT

R. Dudal
(Raporteur : P.R. Woode)

Any agricultural development process must be physically, economically and socially possible.

The physical factors to be considered are soils, landform, geology, climate, vegetation, diseases, and hydrology. A good soil survey covers most of these, with the exception of diseases (which may be important for example where animal draft power may be limited) and a little hydrology.

The economic possibility is vital for any agricultural plan. It is necessary to determine the level of technology, which can depend on the soils (eg with regard to draft power or fertilizer needs).

Socially it is necessary to determine if new techniques or crops are socially acceptable or not.

It can be seen that a soil survey, although an important tool, is not the only one. It must also be remembered that anything planned must be sustainable.

A soil survey consists of the following stages :

1. Characterisation of the soils:
2. Classification of the soils,
3. Distribution of the soils,
4. Mapping of the soils,
5. Interpretation of the data.

Very often a soil survey stops with the completion of stage 4. The interpretation is not carried out. There is a need for an interpretative section in the reports. Without this a soil survey will have a limited application. The interpretation of a soil survey depends upon the kind of classification and the mapping scale. This is what the forum is about.

It is not necessarily true that a detailed map is more

useful than a reconnaissance map. It is the minimum management area that determines the map scale. For example, there is no point in making a series map at a scale of 1:10,000 if the farmer cannot adjust his management to distinguish between many different series. Therefore the usefulness of a map does not necessarily increase with scale.

Often one considers soil surveys as a tool for planning only. We should, however, use the soil survey information as an aid to management during implementation. This is often forgotten.

We will now consider the role of land resources in the current African food problem.

All countries with food problems are south of 40 deg.N and north of 30 deg.S. The FAO soil map of the world was produced to try to monitor the effects of soil on this problem. The legend is based on Soil Taxonomy. From this the Agro-Ecological Zones project produced crop suitability maps by superimposing a climatic map onto the soils map. Africa is dominated by a growing period of more than 150 days, 50% of Africa has conditions too dry for rainfed agriculture. Rainfall can be erratic.

Table 1 shows that although Africa has only 10% of the world's population, it has 26% of the world's cultivable land.

Table 1. Stastics for Africa

Land Area (mha)	2886
% of world's total	22%
% of world's population	10%
Potential cultivable land:	
Africa	27%
World	26%
Area presently cultivated	21%

Compared to the rest of the world, Africa has vast potential for food production. This includes Zambia, which has huge areas of underutilised land.

One man with hand labour can only work less than 2ha. From this it can be shown that 22 African countries cannot feed themselves.

Less than 10% of the tropics have been soil surveyed at reconnaissance level, and only approximately 1% at semi-detailed level.

INTRODUCTORY SESSION 2

PRINCIPLES AND LOGIC OF SOIL TAXONOMY

S. Buol
(Raporteur : P.R. Woode)

Perfect classification is only possible when one knows everything about the classified object. We do not know every thing about soils. Soil Taxonomy, therefore, is a store of the accumulated knowledge to date.

Soil surveys were commenced in the USA in 1899. By 1950 it was realised that the classification was not quantitative, and therefore work was started on the soil taxonomy. The 7th approximation was produced in 1960. This was developed more in Europe by Professor Tavernier, and in 1970 Soil Taxonomy was officially adopted. It had been built up from series and mapping units that had previously been identified in the field.

Principles and logic.

1. The definition of leach taxon should carry as near as possible the same meaining to each user. This means having long and complicated definitions.

2. The definitions must be as explicit as possible to permit uniform applications by many pedologists working independantly.

3. Soil Taxonomy should be multi-categoric. The human mind can resolve only up to 10 things at once, so that the number of orders was limited to 10, Mapping can be carried out at different levels depending on the scale.

4. Because we want to be able to make the most important statements about taxa, the properties that are important to plant growth and that result from or influence soil genesis should be considered in the higher categories.

5. Soil taxa should be concepts of real bodies of soil that are known to occupy geographical areas.

6. Natural classification systems attempt to divide soils into groups based on naturally occuring assemblages of properties.

7. Differentia should be soil properties that can be observed in the field or can be infered either from other properties that are observable in the field or from the combined data of soil science and other disciplines. This means that laboratory data should only be used where a property is not otherwise observable in the field.

8. The taxonomy should be capable of modification to fit new knowledge with a minimum of disturbance.

9. The differentia should keep an undisturbed soil and it's cultivated or man-modified equivalent in the same taxon wherever possible.

10. Surface soil characteristics are of great agronomic significance and difficult to use in natural classifications because they are easily altered. Most agronomic practices deal with the topsoil.

11. The taxonomy must be capable of providing taxa for all soils in a landscape.

12. The taxonomy should provide for all soils that are known, wherever they may be.

13. Soil properties are the result of soil forming processes which are controled by soil forming factors. Soil properties which can be observed and measured are the basis of Soil Taxonomy. Processes and factors are only infered eg clay translocation is infered in an argillic horizon.

14 Because genesis cannot be seen it must be secondary.

15. Soil Taxonomy, with it's quantitative criteria and explicit considerations of soil temperature and moisture regimes greatly facilitates the use of soil classification as a basis for efficient and economical transfer of all soil related technology.

16. A different classification is needed for each use for which we make interpretations. Soil Taxonomy is for soil scientists. However, a farmer or agronomist is not interested in the Soil Taxonomy classification. This is where interpretations are needed.

Endquote "Soil classification could be a fascination, the lingo is however a botheration, it's study leads to frustration, but one is left in admiration at seeing man's simplification of God's work."

INTRODUCTORY SESSION 3

THE STRUCTURE AND NOMENCLATURE OF SOIL TAXONOMY

R. Tavernier
(Raporteur : P.R. Woode)

The system is multi-categoric.

The ORDER is the first level of simplification.
Soil forming processes are only recognised in orders when they have left distinctive marks on the soil.

SUB-ORDERS are not always subdivided in the same way. There are 47 sub-orders.

GREAT GROUPS have as their main criteria temperature and moisture regimes. There are 265 great groups.

SUB-GROUPS have a typic subgroup which is the most representative soil of the sub-group. Intergrades occur in the sub-groups, either to other groups or to non-soil (eg hard rock).

There is a key down to sub-group level.

The FAMILY introduces properties mainly due to parent material, particle size class, temperature regime, and mineralogy.

The SERIES is a sub-division of a family. This can be on the basis of slight differences in texture or drainage for example.

The nomenclature of the system conveys a meaning. The name tells you the category level.

SOL is used at the order level. If there is a Greak root then "o" is the joining vowel, and if the root is Latin then "i" is the joining vowel.

For the sub-order the last sylable of the order is taken.

A pre-fix is added on for the great group.

For the sub-group a second work is added.

Series names are geographical.

INTRODUCTORY SESSION 4

Editor's Note

Copies of the relevant pages of Soil Taxonomy were distributed with this talk. These are not reproduced in these proceedings.

DIAGNOSTIC SURFACE HORIZONS

H. Eswaran
(Raporteur : P.R. Woode)

A Pedon is a unit of description. An epipedon is generally a surface horizon. However it is not true that the epipedon is always synonymous with the A-horizon. The lower limit of the epipedon is where it's requirements are no longer met, and that may extend into the B-horizon:

```
------------                 -------------
                   BSP 60%        ¦
    A1                            ¦
------------       BSP 55%        ¦
                              MOLLIC EPIPEDON
    A2             BSP 53%        ¦
-------------                     ¦
                   BSP 51%        ¦
                              --------------
    B2t

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```

Also, epipedons and sub-surface horizons are not mutually exclusive:

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                  ----------------------------

--------------------------        MOLLIC

                  ----------------------------
ARGILLIC

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All epipedons have a minimum thickness. There are 6 epipedons in Soil Taxonomy. The definitions are strict and one should always read everything in the text.

MOLLIC - From Latin for "soft". All requirements must be met:

1. Structure must not be massive. Also consistence must not be hard or very hard when dry (as in name).

2. Colour is dark. Also colour is compared to colour of

underlying horizon and to parent material.

3. BSP is >50%

4. Organic carbon is >0.6% and >2.5% where lime is present. There is also an upper limit.

5. Thickness, If rock at shallow depth the >10cm, but in all other cases the epipedon must be at least 18cm thick.

6. P_2O_5 content must be <250ppm.

7. The moisture condition is specified.

8. The n-value (bearing capacity).

UMBRIC - As mollic but BSP <50%.

ANTHROPIC - As mollic but no moisture or BSP requirement.

HISTIC - Main definition is on organic matter content.

PLAGGEN - Man made horizon

OCHRIC - The "dustbin" for epipedons that do not qualify for the first 5.

INTRODUCTORY SESSION 5

Editor's Note

Copies of the relevant pages of Soil Taxonomy were distributed with this talk. These are not reproduced in these proceedings.

DIAGNOSTIC SUB-SURFACE HORIZONS

F. Moorman
(Raporteur : P.R. Woode)

These epipedons are genetic in expression. They are defined in morphological terms.

CAMBIC - Weak, initial development, still has many characteristics of the parent material. Iron may be dislocated during wetting and drying cycles so forming mottles. In the field there are differences in colour between A, Bw, and C horizons. The cambic horizon is often more vividly coloured that the C horizon, and usually has a more developed structure. Sands are excluded from the cambic.

ARGILLIC - Here there is a very specific genetic statement from the clay illuviation. In homogeneous material there is a clay bulge. In the tropics there are some difficulties. In eroded terrains there is no clay bulge, so clay skins are used as the criteria.

KANDIC - Occur in areas of low activity clays. Here, even with a clay bulge it can be difficult to find clay skins. There are characteristics of an oxic horizon. To qualify as kandic the clay increase has to be within 15cm. It can be felt in the field in the field, so does not rely on laboratory data. A kandic horizon is not argillic. It may have formed in many ways - termites may have removed clay skins, or there may have been selective erosion or clay destruction in the epipedon.

The remainder of the talk followed the relevant pages from "Soil Taxonomy" (ed.).

USE OF SOIL TAXA AND MAP UNITS IN EVALUATING AGRICULTURAL LAND USE

S. W. Buol

Soil forms a continuous cover on the land surface, interrupted at frequent intervals by "not soil" material such as bare rock or deep water. In his attempt to organise what is known about soil, man has defined limits of characteristics and invented names for each defined range of characteristics. Many systems of classifying soils have been used. The one presently used in the U.S. is called Soil Taxonomy. Each unit in the system is called a taxa. The taxa with most restrictive range of characteristics is the soil series. This attempt to quantitatively define the limits and define each taxa has as its goal more efficient communication among persons interested in soil properties.

At the same time there is a need to inventory not only soil properties but also to record and display locations where different soils occur. This is usually done on a map. Each map is made with a specific purpose in mind and maps of the same area can be as varied as the uses for which they are intended and the number of people that make them. Because any map is a drawn representation of the real thing, at a reduced scale, no two maps of an area are any more alike than the portraits of the same person by two artists. This does not necessarily mean that one is wrong and one is right. The name and description of each map delineation determines whether the map is correct or not. The soil map is designed to relate to differences as they specially occur in nature.

For many years I did not consider it necessary to separate the concepts of soil classification and soil mapping. I had mapped soils and clearly understood that my job was to put a line around an area on my aerial photograph that corresponded to what I saw on the ground around me. The area delineated was labeled with numbers and letters on the list of approved numbers and letters which was the mapping legend. My party chief, and the August climate in southern Wisconsin cornfields, had caused me to learn that inclusions of small areas of different kinds of soil were a normal occurrence in a mapping unit. I also learned that a line on the map that could not easily be justified on the basis of a topographic, geomorphic or vegetative feature was going to be severely questioned when the party chief inspected my work. From this I learned that even though loam and silt loam are two distinct names used to classify soil texture, to draw a line on the map only on the basis of where I perceived the 50% silt content to be , was clearly not acceptable. The map unit range clearly had to fit some feature clearly visible in the field.

A few years later I found myself defining soil series and other higher category taxa in the "7th approximation" and now

what we know as Soil Taxonomy. At first the task appeared the same as defining a mapping unit, but slowly it became apparent that there was one major difference. In a taxonomic unit it was not necessary to find natural topographic, geomorphic or vegetative expressions of the limit. It was desireable to find some limit, but in every case where the limit of a soil property corresponded to a geomorphic or topographic limit in one area, it would not be the same in the next area I studied. Slowly the realization began to take shape that soil taxa were abstract concepts defined in multi-dimensional space of soil properties measured by physical, chemical and mineralogical parameters. All of the soil profiles fitted into each one of the defined units but in no case did any single pit display the entire range defined. Further, it was not possible to find any area that you could draw a line around and call a mapping unit that had the entire range of conditions defined by the taxonomic unit. Thus I began to realise that the mapping unit is much more specific than a taxonomic unit. It usually represents only a portion of the total range of characteristics defined in a taxonomic unit. But at the same time there are inclusions of other kinds of soil, other taxa, in the mapping unit. Didn't the fact that one always found some "odd-ball" holes when augering in a unit mean that the mapping unit was more general than the taxonomic unit?

Faced with the two sets of observations I was confused. The only answer seemed to be that soil taxonomic units and soil mapping units were in no way related. Each was more specific and at the same time more general in concept than the other. In reality, they were entirely different concepts, yet they had nearly the same name. In fact, as I listened to people discuss them, they made no distinction - I had not been making any distinction. For example, I said that Cecil soils had loamy sand or sandy loam textured surfaces over clay textured, red coloured subsoils. The series description, however, allows clay loam and sandy clay loam surface textures. True, these were eroded areas, but they were named in the taxa Cecil. They were delineated as different types and phases in the mapping unit but I seldom, if ever, heard the mapping unit mentioned when agronomic research was reported on Cecil soils. In general we spoke of Cecil soils, Appling soils, or Ultisols, all taxonomic names, rather than Cecil clay loam, etc..

Limitations of Soil Taxonomic and Mapping Units.

To properly compare map units and taxonomic unit it is necessary to realise the intended use of each. Soil taxa were established using soil profile criteria that are least likely to be altered by management practices and most likely to be predicted from a knowledge of soil genesis. Map units are designed to best picture, at a reduced scale, the natural occurrence of soils on the landscape.

With these considerations there is no doubt that identification of any site requires both the taxa and the map

unit to be identified; the taxa to define the subsurface properties, and the map unit to identify the plow layer texture and slope characteristics. The management practices in place at a site also need to be identified. For example, all of our poorly drained soils are worthless for cultivation unless drained. Then they become some of our most productive soils. The taxonomic unit relates to soil properties as they relate to other soils in the world. The soil mapping unit relates soil features as they occur in a local area. With respect to agricultural uses, only the map unit designation can show slope and surface textural conditions so closely related to normal tillage and fertility practices carried out in agricultural management. Because the proper map unit name uses a taxa name in most cases, it will be sufficient. However, it must be remembered that many areas within a mapping unit delineation may be outside the taxonomic name of that mapping unit. Also, the soil within a mapping unit may represent only a small range of the taxonomic unit.

Agronomic Significance of the Mapping Unit.

Does the map unit make a difference to agricultural use, or is the taxonomic description more important? There are several ways to make comparisons. First we will look at estimated yields for a few soils in North Carolina (Table 1).

Table 1.

				Estimated yield		
				Tobacco	Corn	Soyabeans
Series	Map Unit			lbs/ac	bu/ac	bu/ac
Norfolk	SL	0-1%		3000	125	50
	SL	1-6%		2800	115	45
	SL	1-6%	eroded	2400	100	40
Aycock	fSL	0-1%		3000	125	50
	fSL	1-6%		2900	120	45
	fSL	1-6%	eroded	2200	115	40
Cecil	SL	2-6%		2100	95	
	SL	5-10%		2000	90	
	SL	10-15%		1900	80	
	SCL	2-6%	eroded	--	70	
Enon	SCL	6-10%	eroded	--	60	
	fSL	2-6%		1900	75	
	fSL	6-10%		1700	65	
	fSL	10-15%		1700	65	
	CL	2-6%	eroded	1700	65	
	CL	10-15%	eroded	--	--	

From these few examples it can be seen in some cases that the taxonomic unit is of little significance to the estimated yield, while map unit, slope and surface texture usually influence the estimated yield. In other situations the taxonomic unit is more significant.

Estimated yield or even actual yield is only one parameter for evaluating agricultural use of land. Perhaps the most significant aspect to agricultural use in North Carolina today involves the size and shape of a piece of land. Mechanization is a fact of life and machines require space to operate effectively. A management unit, i.e. a field, for example, usually includes more than one soil mapping unit. How comparable the different mapping units are to the same management practices determines to a large extent the use of the area. The association of small unmanageable areas within desirable areas can render the whole area undesirable. The significance of areal uniformity or compatibility is considerably more important to agricultural use evaluation than many of the soil related considerations used to taxonomically classify a soil.

Range of Soil Characteristics in Named Units.

Although every site can be classified both into soil taxa and soil mapping units, any one site or field represents only one portion of that taxa or mapping unit. It is common to hear one scientist, upon viewing a given named site, say "this is not like this soil where I know it in such-and such county." Because both taxonomic units and mapping units represent ranges of soil properties, it is unlikely that any given site is exactly like any other given site.

According to scientific practice, if you cannot control a variable, the scientist is obliged to describe that variable. Naming soil conditions is an aid in this respect, but variations within any given soil name are quite broad. Table 2 shows certain soil properties that are possible, but not necessarily present, in soils that properly fit soil taxonomic and mapping unit names. It is clear that any given site does not represent the entire range of conditions possible in either a taxonomic or mapping unit. Must, if not all research is concentrated on modal representatives of soil taxa or mapping units, usually the uneroded phases. How does this work relate to the real world of the farmers eroded field? We do not know, but probably not very well.

We must never loose sight of the fact that past liming, fertilization and cropping sequences are extremely important agronomic results, but soil surveys do not evaluate them, and in fact, consciously avoid, these parameters. Weed and pest control seed bed preparations, planting date, viability of seed, and a multitude of other parameters often grouped under the heading of management greatly influence agricultural yields. Soil classification does not classify these variables.

The combined effect of all these variable make exact predictions of agronomic results improbable even if the range of characteristics of either a taxonomic or mapping unit are narrowed.

Table 2. P sible ranges in named soil taxa and soil m pping units.

soil Series name	Percent clay Ap	Percent clay B	Percent Base saturation Ap	Percent Base saturation B(to 1.8m)
Cecil	0-100	35-100	0-100	0-100
Norfolk	0-29	18-35	0-100	0-100
Lakeland	0-15	0-15	0-100	0-100
Marlboro	0-100	35-100	0-100	0-100
Map Unit				
Cecil LS	0-15	35-100		
Cecil SL	0-20	35-100		
Cecil SCL	20-35	35-100		
Norfolk LS	0-15	18-35		
Norfolk SL	0-20	18-35		

AGRONOMIC TAXONOMY.

S. W. Buol

The most impressive part of the National Cooperative Soil Survey (NCSS) is its attention to interpretations of soil map units. A few years ago I would not have made that statement. In reality, very little professional acknowledgement is likely to come from attempts to improve interpretations. But, publishing a soil survey report that conveyed interpretations about soils to users of soils, in terms they could easily understand, has been the basis of the National Cooperative Soil Survey Programme. There has been continued public support for soil surveys. Such attention to the use of soil surveys has not been a major part of soil survey programmes in many other countries. Consequently, foreign soil scientists are amazed to learn how much of the NCSS programme is supported by state and local funds but are totally aghast at our soil survey reports which devote approximately 2 or 4 percent of the volume to soil taxonomy and soil genesis. Sometimes our concern with septic fields and landfills are belittled by our international peers, but they are all covetous of the support we enjoy. While there is no doubt in my mind that the NCSS programme is doing a great job, there are always opportunities for improvement.

One area where full support for the soil survey is not realised is the agronomic profession. By agronomic profession I include colleagues in soil fertility, soil management, soil testing, as well as extension and crop specialists -- in short our fellow soil scientists or agronomists, according to many definitions. Their flagrant neglect of our soil survey reports has certainly been decried by all of us at one time or another, and despite our individual efforts, which are often successful on a local basis, I believe the overall utilisation of soil survey information by this group of professionals to be too low. Several reasons can be advanced in attempts to explain the low utilisation rate. Among soil scientists, one often hears that agronomists just aren't scientific enough to understand soils, or they don't get into the field enough to appreciate the real world. While these statements perhaps aren't 100% false, they certainly do nothing to improve the situation.

Physical relationships.

A critical look at the fundamental concerns of both groups, soil scientists vs. agronomists, goes a long way in explaining the lack of mutual reinforcement. First, the soil scientist is rightly concerned with being able to correctly identify and locate identifiable kinds of soils. He would like to be able to go back the next year and find the same thing and have the principal correlator agree with him. The final review may be some 5 to 10 years after he identified the site. To accomplish this, soil scientists, over the same 84 years of practical

experience in the United States, have selected similar properties as criteria for soil classification that are somewhat insensitive to change by expected soil management techniques. We are not totally successful in this respect, but as you are all aware, the spodosol criteria is an attempt to eliminate the mixing action of the plough layer from affecting the taxonomic placement. Likewise, the 1.8m from the surface, or 1.25m below the top of the argillic of the Alfisol-Ultisol base saturation limit is deeply placed to avoid the recharge of bases from long term use of lime, a common practice on acid soils. In effect, to the soil scientist a soil is primarily defined by properties that are difficult to alter.

The agronomist's objective is to manage soils. He, or she, is concerned with properties that can be changed. In many cases the actual measurement is not different in kind from that made by the soil scientist, but, almost without exception, the two professions sample different parts of the profile. Soil management is almost exclusively limited to the upper few inches of the soil, with some notable exceptions of drainage and irrigation.

In like fashion, the upper few inches are excluded from soil taxonomic consideration, again with a few notable exceptions such as categories that utilise various epipedons for class criteria. The family category specifically avoids the surface layer in most soils.

It is really not very useful to argue about whether or not more attention needs to be paid to the subsoil by the agronomist. In several regression studies of variables affecting row crop yields, the properties of the topsoil always are more significant to crop growth than subsoil properties. It can be argued that only satisfactory subsoil properties are incorporated in the selection of suitable sites. The folly of prolonging the argument is that the agronomist has almost no technology to change most soil properties below plough depth or subsoiling depths of perhaps 50cm. Although soil scientists are fond of pointing out the completely controlling influence of shallow bedrock, fragipans, duripans, etc have on land use, we have to remember that these choices of land use have already been made before the working agronomists gets involved. In fact, much of the disregard given to soil survey information stems from the fact that within any local area most of the soils that are intensively used for a crop are similar in many respects, and those soils not responding to conventional managements have been sidelined.

Soil Properties - Agronomic Operations.

No attempt will be made to create a definitive list of management practices and of how the presence, absence, or degree of a given soil property influences the agronomic operations. However, there are a few categories of problems that I think we

can address. One potential area is that of fine-tuning soil test interetations. All soil test procedures attempt to extract an arbitrary fraction of several elements from a soil sample and then predict how much fertilizer will be needed for 60 to 120 days, or longer. There are many situations where this works very well, but the real problems result when interpretations are made in soil material not like where the calibration was developed. The impulse of the agronomist has been to look for a universal extractant, but perhaps by grouping soils according to their management layer ion release and/or fixation properties (i.e. texture, mineralogy, etc.) better interpretations can be made by developing soil group specific conversion factors from soil test extraction quantities to application rates.

Methods of fertilizer application are very much a soil property, as well as crop related. High P fixation favours banding or slow release formulations. One or two side dress applications of nitrogen as routine or emergency recommendations for supplemental N after excessive leaching conditions are based on texture, depth to an impeding layer, etc.

Soil management is not only fertilizer and other amendments such as lime, but also mechanical operations such as subsoiling, bedding, mulching, and limited till planting. I do not propose that we attempt to compete with soil test or on-site management services, but rather attempt to present soil properties that address their concerns in a fashion of convenience for them.

Where is the Data?

By now most of you are probably correctly concluding that most of the data needed by the agronomists along with the spatial distribution of soil properties can be found in the map units of any modern soil survey report. All the agronomist needs to do is know soil taxonomy, which is easier to learn than plant taxonomy, consult the descriptions of series to pick up the profile differences that are not evident in families, and then determine the surface texture, stoniness, slope, etc. from the various map units. After all, he or she took a soils course and maybe even a soil classification and mapping course, probably belongs to the American Society of Agronomy, and may even subscribe to the Soil Society of America Journal. That seems to be about where we in the National Soil Survey have left the ball with respect to what some may call our closest academic relatives.

By comparison, how have we treated some of our not-so-close academic relatives? I would venture that we have been considerably more energetic in attempting to translate our expertise into their language. For the banker or real estate investors we have estimated yields per acre of all adaptable crops, including range potential, for irrigated, drained and slope phases. Where applicable we provide a technical classification of each map unit for woodland suitability as well as lists of suitable trees, site index, seedling mortality, etc.

We also have wildlife ratings for 10 separate categories for each mapping unit. In addition there are some 20 technical classifications of each map unit for its suitability of limitation for major uses. These interpretations cater directly to land use planners and in some cases to regulatory functions.

As I stated in the beginning, this is probably the most impressive part of the soil survey programme in the United States, when compared to any other nation in the world. But, simply, I do not see any effort made to communicate with the agronomist, which in reality is one of our continuing links to the managers of most of the land in the United States after we have completed the detailed county soil survey report and deposited it on the library shelf. Fortunately, I think all of us have at least a few experiences where a district conservationist or a county extension agent, or both, has taken the time to understand the sets of soil properties that went with each mapping unit in the country and can fluently group map unit 428 with 528 for some uses and declare that they are different for other uses. In my experience, such an individual usually, but not always, had a hand in the making of the soil survey. Maybe this is what the individual from the northeast region had in mind when he pointed out during the last soil survey work planning conference just what an unusual professional a soil scientist was. To paraphrase his statement, most professions try to maintain high standards around more and more territory and insist that only highly qualified, like professionals are allowed to practice that art. Soil scientists spend an equal, if not greater amount of their time maintaining high standards, but work even harder at assuring that non professionals are allowed to administer the resulting information. I haven't made up my own mind as to whether this is good or bad, desireable or undesirable, or inconsequential. But it rather accurately describes what we do for most potential users but not for the agronomist.

Attending to the Agronomist's Needs.

Having portrayed what we have done in the way of developing technical classification or interpretive groups, whatever you wish to call the aggregation of map units on our form 5's and ultimately in each soil survey report, hopefully I have created some sympathy for our oftimes baffled cousins, the agronomist. He has been told to learn series names, just in time to see them correlated to another soil temperature family. He has thought he was getting uniformity within a series only to find that eroded phases of that series had a plough layer of clay loam when all the research work at the local state research station was done on a loamy sand type (uneroded). Also, the research was probably on an A slope phase, while 90% of that soil in the county was B to D slope, eroded phase. Since his experiences had taught him that there was a clear difference in performance between a sandy loam plough layer and sandy clay plough layer he concludes that either the mapping is wrong because the map unit is not the same

"series" he was shown at the local experimental station, or that this damn soil classification business is useless -- probably both.

On the other end of the spectrum, but equally as damaging to an agronomists confidence in soil survey, are the taxonomic and mapping separations that are of little or no consequence to agronomists concerns. A recent experience along this line served to alert me to this problem. A very energetic graduate student placed stakes on a 20m grid over a 5 acre portion of clean cultivated field. After comparing on-site evaluations by independent soil scientists and augering at each stake and producing a computer generated map, he used ribbons to delineate taxonomic differences, septic interpretation differences, etc. on a one-to-one basis for use on a health department training programme, and as my student was explaining his work to the health department personnel I found myself ushered off to the side by one very alarmed county agent. His concern was: How in the world am I going to explain all the differences to the farmer? In fact, there were no differences to explain to a farmer. The differences were very significant to the health department personnel because they involved subsurface charasteristics, but in showing these differences on our maps we introduce what can only be considered as "noise" to an agronomists.

Some years ago as part of our international programme I set out to classify soil management problems in terms of soil properties. During the early course of the work it consisted entirely of informally questioning leading agronomists and soil fertility professionals as to how they evaluated agronomic needs in a new area. I was, so to speak, professionally insulted in that I did not find the use of soil surveys high on anyone's mode of operation. However, I found that I could have usually told them almost everything they wanted to know from what we would expect in a map unit description. I could not do this from a taxonomic placement primarily because of the question that emerged to be number one among the agronomists. Simply, they wanted to know: what is the surface texture? As one individual put it, "I first give the soil a kick to see what the texture is." I concluded I didn't have to be too precise about texture if it could be done with a kick but I had better lead off a soil description by giving a surface texture if I am to get an agronomist's attention.

After rather unanimous agreement on surface texture, the backgrounds of the individuals made for a rather diverse list of concerns. Certainly pH was high on the list, as was subsoil texture, soil test levels, past cultural practices, and rainfall and temperature. It became apparent that what agronomists wanted to know about soils was far less than what we had stored during most of our soil survey operations. Most of the time the methods were not the same, the units or expressions were different, and there was a host of reasons why they did not relate to the

various soil survey reports. Most of these apparent problems faded, however, when the agronomists were asked to put "quantitative criteria" on their categories of "high P fixing soils", "rapidly leached soils", "wet soils," etc. It was obvious that they had almost no creditable way of communicating with each other. Consequently, they didn't communicate well, and I think evidence of this lack of communication is reflected in verbal and published statements to the effect that "This is the practice, to use in state X, while in state Y or county Z another practice is to be preferred." It seems they can usually agree on the political boundaries on a map, but that doesn't appear to be a scientifically satisfying way to communicate cause and effect of soil management techniques.

What followed was a series of approximations to express the concerns of agronomists in a formal fashion and with quantitative class limits. As we all know, essentially all soil properties form a continuous solid series and any class limit is going to fit better in one part of the world than in another. Thus, the limits I use have been arrived at either because they can be conveniently borrowed from soil taxonomy or they can be agreed to by agronomists as limits that are critical to key agronomic technologies. This relationship to technology, although critical for a technical classification, is always time dependant as technologies change.

What has evolved over the last 10 years is known as the "Fertility Capability Soil Classification System" and is presented in table 1 as it most recently appeared in Geroderma, 27:283-309 by Sanchez, Coute and myself. There are many questions that have been raised over the years about the system, and perhaps I can address some of the more general ones at this time.

First, the rationale for the system was simply to provide a framework within which problems of soil management, primarily correctable problems, and fertility problems could be quantified for better communication. This always leads to the question: Why is it called "capability" rather than a "problem" or limitation classification? Well, quite simply, that is "Madison Avenue" or "sex appeal". Over the years the popular appeal of the "Land Capability Classification" has always amazed me. It speaks more of limitations and hazards but who wants limits? Think positive!

Anytime you create class limits, procedures have to be specified as we found during the development of taxonomy. Rigid requirements can severely limit the use of the system. Since what is being grouped are soil properties that can be expected to respond similarly to agronomic management within groups, and different from other groups, one has to apply a form of the law of the minimum. As Professor Emil Truog demonstrated, the "scientific" way to accurately measure a 100 yard football field was to pace the first 99 yards and then measure the final yard with a micrometer to be sure the field was a "reagent grade"

field. Thus, over the years we have added "alternative" methods to define many of the condition modifiers. These are designed to allow the FCC system to be compatible with existing surveys and systems of soil classification. Note that the system is open ended and additional features considered of local importance can be added as prim (') or perhaps asterisks (*). I have resisted adding a multitude of other condition modiers, not because they may not be important, but because it is already a bit longer than I consider ideal.

The concept that FCC attempts to foster is that kinds of soils can be grouped for agronomic interpretations. I do believe soil scientists should take the lead, but with input from agronomists. It should be made clear that we want groups of soils created about which agronomists feel comfortable in making statements and extrapalatory technology, their technology. Interpretative statements about each FCC conditions modifier have been suggested but local editing should be encouraged.

Fitting Into the NCSS.

In this same vein it would be possible to list phases of series with FCC placement on the soils-5 for each series. Perhaps sample or suggested interpretation could be there or in separate handbooks. It would form a table or part of a table in the soil survey publication.

We need to be careful about not overstating the use of FCC. It does not make fertilizer recommendations, for example. Soil tests are still the basis for this because the criteria used to place the soil in FCC may be altered, in fact should be altered, by the management practice. In this sense each FCC placement is like the drained phase interpretation. Energy is required to keep it drained, as energy is required to keep the plough layer ploughed and fertilised.

In conclusion, I believe the need for a technical classification of soils according to criteria of significance to the agronomist is needed. The FCC system is one attempt, and like all classification systems it only reflects the state of the art. It can and should change with time and data. I do not believe we can develop a system for technical uses after we have collected all the necessary data to prove the groups are correct, especially in agronomy where new cultivars, for example, are now available that show tolerance to high Al concentrations. Because methods of management change, the FCC simply provides a basis for grouping soils with which the agronomist can both research and extrapolate his findings with greater confidence than he can to the entire population of soils.

Table 1. The FCC system.

Type. Texture of plough layer or surface 20cm, whichever is shallower:

S = sandy topsoils: loamy sands and sands (by USDA definitions)
L = loamy topsoils: less than 35% clay but not loamy sand or sand
C = clayey topsoils: more than 35% clay
O = organic soils: more than 30% O.M. to a depth of 50cm or more

Substrata type (texture of subsoil). Used only if there is a marked textural change from the surface, or if hard rock or a restricting layer is encountered within 50cm:

S = sandy subsoil as in type
L = loamy subsoil as in type
C = clayey subsoil as in type
R = rock or other hard root-restricting layer

Modifiers. Where more than one criterion is listed for each modifier, only one needs to be met. The criterion listed first is the most desireable one and should be used if data are available. Subsequent criteria are presented for use where data are limited.

g = (grey): soil or mottles of < 2 chroma within 60cm of the soil surface and below all A horizons, or soil saturated with water for >60 days in most years.

d = (dry): ustic, aridic or xeric soil moisture regimes (subsoil dry for > 90 cumulative days per year within 20-60cm depth).

e = (low cation exchange capacity): applies only to plough layer upper 20cm, whichever is shallower: CEC < 4meg/100g soil by bases + KCL extractable Al (effective CEC), or CEC < 7meg/100g soil by cations at pH 7, or CEC < 10meg/100g soil by cations + Al + H at pH 8.2.

a = (aluminium toxicity): > 60% Al-saturation of the effective CEC within 50cm of the soil surface, or > 67% acidity saturation of CEC by cations at pH 7 within 50cm of the soil surface, or > 86% acidity saturation of CEC by cations at pH 8.2 within 50cm of the soil surface, or pH < 5.0 in 1:1 H_2O within 50cm, except in organic soils where pH must be < 4.7.

h = (acid): 10-60% Al saturation of the effective CEC within 50cm of soil surface, or pH in 1:1 H_2O between 5.0 and 6.0.

i = (high p fixation by iron): %free Fe_2O_3/%clay > 0.15 and > 35% clay, or hues of 7.5YR or redder and granular structure. This modifier is used only in clay (C) types; it applies only to the plough layer or surface 20cm of soil surface, whichever is shallower.

x = (X-ray amorphous): pH > 10 in 1N NaF, or positive to field NaF test, or other indirect evidences of allophane dominance.

v = (vertisol): very sticky plastic clay: > 35% clay and > 50% of 2:1 expanding clays, or severe topsoil shrinking and swelling.

k = (low reserves): < 10% weatherable minerals in silt and sand fraction within 50cm of the soil surface, or exchangeable K <0.20 meq/100g soil or K <2% bases if bases <10 meq/100g

b = (basic reaction): Free $CaCO_3$ within 50cm of the soil surface (effervescence with HCl), or pH > 7.3.

s = (salinity): 4 mmhos/cm of electrical conductivity of saturated extract at 25 deg C within 1 metre of the soil surface.

n = (natric): >15% Na-saturation of CEC within 50cm of soil surface.

c = (cat clay): pH in 1:1 H_2O is <3.5 after drying and jarosite mottles with hues of 2.5Y or yellower and chromas of 6 or more are present within 60cm of the soil surface.

, = (gravel): a prime (') denotes 15-35% gravel or coarse (>2mm) particles by volume to any type or substrata type texture (example S'L = gravelly sandy over loamy; SL' = sandy over gravelly loam;) two prime marks ('') denote more than 35% gravel or coarser particles (>2mm) by volume in any type or substrata type (example LC'' = loamy over clayey skeletal; L'C'' = gravelly loam over clayey skeletal).

% = (slope): where it is desireable to show slope with the FCC, the slope range percentage can be placed in percentages after the last condition modifier (example Sb (1-6%) = uniformly sandy soil, calcareous in reaction, 1 - 6% slope).

The soils are classified by determining whether the characteristic is present or not. Most of the quantitative limits are criteria present in Soil Taxonomy. The FCC unit then lists the type and substrata type (if present) in capital letters, and the modifiers in lower case letters, the gravel modifier as a prime (') and the slope, if desired, in parentheses. For example, many oxisols belong to the FCC unit Caeik (ie clayey, Al toxic, low CEC, high fixation by iron, low K reserves), many vertisols to Cdvb (ie clayey, dry season, vertic, calcareous), whereas a young alluvial entisol with no fertility limitations is simply classified as L (loamy soil). The absence of modifiers suggests no major fertility limitations, other than nitrogen deficiency.

FCC Sample Interpretation.

Interpretation of types and substrata types:

S : High infiltration, low water holding capacity.

L : Medium infiltration, good water holding capacity.

C : Low infiltration, good water holding capacity, potential high runoff if sloping, difficult to till; When i modifier is present, these (Ci) soils are easy to till, have high infiltration rates and low water holding capacity.

O : Artificial drainage is needed and subsidence will occur; possible micronutrient deficiencies; high herbicide rates usually required.

SC, LC, LR, SR : Susceptible to severe soil degradation from erosion exposing undesirable subsoil; high priority should be given to erosion control.

Interpretation of Modifiers.

When only one modifier is included in the FCC unit, the following limitations or management requirements apply to the soil. Interpretations may differ when two or more modifiers are present simultaneously or when textural types are different.

g : denitrification frequently occurs in anaerobic subsoil; tillage operations and certain crops may be adversely affected by excess rain unless drainage is improved by tilling or other drainage procedures; good moisture regime for rice production.

d : moisture is limiting during the dry season unless soil is irrigated; planting date should take into account the flush of N at onset of rains; germination problems are often expc. enced if first rains are sporadic.

e : low ability to retain nutrients against leaching, mainly K, Ca and Mg; heavy applications of these nutrients and of N fertilizers should be split; potential danger of overliming.

a : plants sensitive to Al toxicity will be affected unless lime is applied; extraction of soil water below depth of lime incorporation will be restricted; lime requirements are high unless an e modifier is also indicated; this modifier is desireable for rapid disoliution of phosphate rocks and for good latex flow in rubber; Mn toxicity may occur on some of these soils.

h : low to medium soil acidity; requires liming for Al sensitive crops such as cotton and alfalfa.

i : high P fixation capacity; requires high levels of P-fertilizer of special P management practices; sources and method of P-fertilizer application should be considered carefully; with C texture, these soils have granular soil structure.

x : high P-fixation capacity, amount and most convenient source of p to be determined; low organic N mineralisation rates.

v : clayey textured topsoil with shrink and swell properties; tillage is difficult when too dry or too moist, but soils can be highly productive; P-deficiency common.

k : low ability to supply K; availability of K should be monitored and K fertilizers may be required frequently; potential K-Mg-Ca imbalances.

b : calcareous soils; rock phosphates and other non-water-soluble phosphates should be avoided; potential deficiency of certain micronutrients, principally iron and zinc.

s : presence of soluble salts; requires drainage and special management for salt sensitive crops or the use of salt tolerant species and cultivars.

n : high levels of sodium; requires special soil management practices for alkaline soils, including use of gypsum amendments and drainage.

c : potential acid sulphate soil; drainage is not recommended without special practices; should be managed with plants tolerant to high water table level.

By using the individual guides for each type, substrata type, and modifiers, it is possible to prepare composite interpretation guidelines for all the possible FCC units. More comprehensive interpretative statements are possible when interactions of two or more soil conditions are considered. No necessity is seen for a complete listing of all possible combinations because only a limited number of FCC units will be found in any area under consideration. At the local level, however, interpretation of FCC units found in relation to the main crops and specific farming systems used would be a valuable extension tool and local expertise is expected to supplement the following brief statements where experience warrants.

Sample Interpretations of FCC Units.

Lenk : Good water holding capacity, medium infiltration capacity; low ability to retain nutrients for plants, mainly K, Ca, Mg; heavy applications of these nutrients and N should be split; requires liming for Al-sensitive crops, potential danger of overliming because of low CEC, low ability to supply K; availability of K should be monitored and K-fertilizers may be required frequently for plants requiring high levels of K.

Lgh : Good water holding capacity, medium infiltration capacity; limitations in drainage so that tillage operations and some crops may be adversely affected unless drainage is improved by tilling or other procedures; strong to medium acid soil; liming required for some crops; excellent soil for flooded rice, as acidity will be eliminated by flooding.

LCgeak : Erosion or other removal of surface soil will expose undesirable clay-textured subsoil; drainage limited so that tillage operations and some crops may be adversely affected unless drainage is improved by tilling or other procedures; low ability to retain nutrients for plants, mainly K, Ca, Mg; heavy application of these nutrients and N fertilizers should be split; plants sensitive to Al-toxicity will be affected unless lime is deeply incorporated; however, deep liming practices are difficult because of clay-textured substrate; due to low CEC in the surface there is a danger of overliming; due to low ability to supply K, availability of K should be monitored and K fertilizers may be required frequently for plants requiring high levels of K.

L : Excellent soil with no major fertility constraints; N deficiency likely with intensive use.

SOIL CLASSIFICATION

S. W. Buol

Everyone at one time or another has probably classified soil. Red, black, sandy, clayey, deep, shallow, and nasty are all terms used by people to classify soil. Add to these terms others such as upland, floodplain, wet, dry, and fertile, then start using the terms in combination, such as "black fertile" or "red clayey" etc., and one can quickly accumulate an almost infinite number of names to classify soils. Each and every one of such terms are proper and correct in some sense of classifying soils. The act of classifying soils is simply the grouping of similar soils and identifying them as different from other soils.

Soils are a very intimate part of every person's experience. Probably no day passes that each of us does not come in contact with soil or soil material. Thus, we almost instinctively obey a human desire to organise and classify our observations. Man has an inherent desire to classify objects. An object as common as soil knows no end of systems for its classification. As long as the system for classification meets the fundamental objectives of grouping objects and conveying information, it is a useful system.

In light of these statements several questions about why or how an occupation of soil classification is defined could be raised. How does soil classification fit in the total discipline of soil science or agronomy? Classification in any science can probably be best described as the half way house between the point in the development of the science occurring after the science has first described objects of interest and the point where all the answers about those objects are known, quantified and reduced to a mathematical formula. It has been said, "Show me your classification and I will know how far you have advanced in your knowledge of the subject." The trend in the classification of all subjects is from the qualitative descriptive terminology towards the precise quantitative terminology needed for mathematical computation. Thus terms such as black soil, clayey soil or fertile soil immediately raise the questions "how black?", "how clayey?" or "how fertile?".

Although people have probably always been classifying soil, the first known written systems date to about 4000 B.C. in China. Systems of soil classification have changed since that time and will continue to change as we learn more about the soil. A perfect scientific classification is possible only when everything is known about the objects you are classifying.

In addition to the previously mentioned descriptive soil classification systems, there are several more quantified systems. In fact, there are so many systems that the systems themselves have to be classified. Some systems classify soil

material only after it has been removed from the field. The best known of these are the engineering systems such as the United or AASHO classifications. Classification systems for soils as they exist in the field can be classified as either natural or technical.

Of the natural systems the Soil Taxonomy used in U.S. National Cooperative Soil Survey Programme is probably the best known in the U.S., and is rapidly becoming well known throughout the world. It consists of six levels or categories. The highest category is the order into which all of the soils of the world are classified into one of 10 orders. Each soil, once certain of its characteristics are known, can be progressively classified into a Suborder, Great Group, Subgroup, Family and Series. At the present time we recognise, name and use about 11,000 Series, or different kinds of soil in the United States. No summary is available of series outside the U.S.. Soil Taxonomy is, in a manner of speaking, the "main library" of all that is known. Each Series is a book in that library. The criteria for placing each soil into its proper place are the characteristics of the soil that can be measured and quantified. Obviously, as we do more research and develop better methods of measuring soil properties, more categories will be developed and the placement of some series will be changed.

Less well known academically, but probably in much greater use are a large number of technical soil classification systems. Basically, technical systems are those systems that have criteria determined by the demands of a particular use of the soil. These systems are specialty classifications, or using the same analogy as before, they are "reserved reading rooms" of the library. For example, all the soils in the U.S. are placed into three groups with respect for their suitability for home septic waste disposal systems. All of the soils are grouped into eight categories with respect to their suitability and limitations for crop, forest, range, and wildlife habitats. There about 35 groups used to denote woodland suitability. The list of technical systems if as long as the list of soil uses.

Like the natural systems, the technical systems are subject to change. As new technology becomes available, the critical limits for a particular soil use changes, and in order to remain useful the system must change. For example, soil content of native nitrogen was important when average yield of crops were 15 to 30 bu/acre. With present yields, most of nitrogen has to be supplied by fertilizers or other measures, and the critical feature of the soil is related to its ability to retain nitrogen against leaching, rather than the native ability to supply nitrogen.

The value of classification does not rest in its ability to store and preserve information in ivory towers of academia any more than the value of a library does for preserving works of literature. To be useful, the library has to be open to the

scholars, but they have to go to the books. As with the library, the information stored in soil classification systems has to be sought. By providing an orderly arrangement of soil properties, the user is assured that when he goes to one particular shelf or category, he will find soils with many similar properties. All soils in one category will not be exactly alike any more than the books catalogued onto one shelf in a library are alike. Thus two fields similarly mapped and classified are not exactly alike. But within reason, classification does allow us to extrapolate our experimental results from one field or research station, to others having similar soils. We should not expect exactly the same results any more than we should expect the same yields from the field every year.

Finally, a classification system will solve no problems in and by itself. It is simply like the well known computer slang GIGO (garbage in garbage out). If reliable quantitative characterization data is used in classifying a soil into the system, you will be able to get reliable results when using the system. If questionable data is used to classify a soil, the information available will be of similar value. Using the nomenclature of the Soil Taxonomy, a Norfolk soil (typic Paleudult; fine loamy, siliceous, thermic) has a precisely defined range of characteristics. A "sandy yellow soil in Pumpkin County" may be one way to classify the same soil, but it leaves a much wider range of characteristics, and thus more room for error in attempts to predict the outcome of management expenditures.

In some respects some soils resemble all other soils. Collectively, all soils represent a wide range of characteristics. Thus, few true statements can be made about all soils. The better an individual is able to recognise and evaluate the various soil differences, the better he is able to adapt management techniques to that soil. It follows that the better the management success, the better and more efficient the resource is utilised. Ability to recognise the important differences in soil for any particular use is the mark of a successful farmer. Often he has several years to learn these differences on the family farm. There is no substitute for this type of experience in classifying his soils for management practices on the family farm. If, however, he wishes to try practices that have worked well on experimental stations or neighbors farms, he needs to assure himself that his soils are similar to those in the other area to afford a reasonable probability of success. Also, in leasing land not well known to him, or in selecting a site for a house, he needs to know the characteristics of the soil at the proposed site in order to evaluate if it will respond to his expectations. The more precisely he is able to identify and classify the soil, the more precise he will be in his ability to predict the outcome of his project.

In perspective, soil classification is a method of

communication. It allows everyone a way of telling others about their experiences with soil related management, and enables one to learn from the experiences of others. This type of information exchange occurs almost every time soil related subjects such as crop yields, tillage operations, etc., are discussed. Classifying a soil as a Lithic Dystrochrept may be no better from the standpoint of communication than calling it a "shallow stoney mess", but "show me your classification and I will know how far you have advanced in your knowledge of the subject."

EROSION AND TAXONOMY

S. W. Buol

"...the removal of a few inches of the surface by erosion, blowing, or grading, should not in itself change the classification, except possibly at the lowest categoric level." (Soil Survey Staff, 1960).

Since these words were written a decade and a half ago we have seen the adoption of the "7th approximation" as the soil taxonomy in the U.S.A. and in many other countries. Certainly no other system of taxonomy demands such detailed data for entering a soil into the system nor offers so much in return to the user.

With the passing of time we have also seen a dramatic increase in the use of soils information contained in the library that is soil taxonomy and displayed on the detailed soil surveys of the National Cooperative Soil Survey. There is no place in the world where soil survey commands as much "grass roots" respect and support as in the U.S.. We are succeeding in getting information to the taxpayers that support most of us, and they want more and better information faster.

By dusting off a few of our older soil surveys and attempting to glean some user relevant information from them, some of the reasons why our newer soil surveys do not collect dust become apparent. Our present surveys are directed to users and not to our peers and ourselves. We are less concerned with impressing our fellow natural scientists and more concerned about the properties which influence the use and management of a particular field or house lot. We are less concerned about how relief or vegetation factors create a slight colour difference in the soil and are more concerned with what these colour differences mean to the present and future use of the soil.

Two assumptions set forth to guide the development of the "7th Approximation" state:

2) A natural classification should be based on the properties of the objects classified.

3) The properties selected (for classification criteria) should be observable or measurable, though instruments may be required for observation or measurement. Properties which can be measured quantitatively are to be preferred to those which can be determined only qualitatively" (Soil Survey Staff, 1960).

With respect to the previously quoted assumptions, there seems to be a rather clear conflict. If we are to use properties of the object to be classified in the system, can we use eroded A horizons as criteria for placement of a soil in the same series

as an uneroded soil? Certainly our estimate of previous erosion is less quantitative than our measurement of the properties of the soil as it now appears on the landscape. Phases and types, as appendages to our taxonomic system, are one way of handling the information. It is the way we have been doing it for many years; we all understand how it works and probably feel rather comfortable in using that nomenclature.

There may be some reluctance to consider alternatives because the past few years have seen more changes in nomenclature than during the first 60 years of soil survey in this country. However, the magnitude of the differences made in interpretations made about soils which are based upon criteria in the phase and type nomenclature, and thus not part of the taxonomy, are rather great and often overshadow differences relating to the criteria used in series and higher categories. The differences are most apparent in those soil uses that relate to the properties of the topsoil and became rather vivid when one examines the interpretation forms on the new official series descriptions of the estimated average yields tables in published soil surveys.

I frequently feel uncomfortable expounding the virtues of taxonomy when I have exactly the same agronomic interpretation for two series, but highly contrasting interpretations for different phases of the same series. My agronomist, but nontaxonomist, friend asks, "Why should I learn the taxonomy?" One can always tell him its good for him, like castor oil, or extol the fact that the criteria used to separate the taxonomic units have interpretive value for other users. Since much of the information he wants is contained in the phase and type criteria he writes this off and concludes the system in toto is of no use to him.

Numerous criteria in taxonomy are vital and apparent to agronomic interpretations (i.e. aquic, lithic, cummulic etc.). However, from the way we arrange our interpretations, it is obvious that we recognise that phases are vital criteria. Clearly, erosion is a process, not a soil property. It is the clay or clay loam texture of a present plough layer, in what was a sandy loam plough layer before erosion that is the property of the present soil to be classified. It is doubtful that many of the soils that have their argillic horizons exposed by erosion will redevelop their original A1-A2 horizon textures within the life expectancy of the survey. Rocks and stones can be removed, but the features created by erosion are relatively permanent.

One function of a hierarchical system of taxonomy is to permit successive degrees of generalization at various levels in the system. From the standpoint of agronomic practices that are most directly influenced by properties of the Ap horizon, our present taxonomy appears to leave somewhat of a void. One has to go beyond the taxonomy, to phases, for most Ap horizon features. Thus, many surface features are not subject to accumulation at successive levels of taxonomy, because they do not enter into the

taxonomy for all soils. To be sure, surface features are considered directly in some soils such as Mollisols, and Vertisols, but only indirectly in several other soils. The most notable exclusion of Ap horizon characteristics is in the Ultisols and Alfisols, precisely where the process of erosion leaves the most indelible imprint by exposing contrasting argillic horizon material.

Limiting the surface texture of a taxonomic unit (e.g. a series) to only textural phase and other thickness criteria that may be applied to series irrespective of whether or not the thickness resulted from erosion would certainly increase the number of series in the system. However, one advantage that may occur from such a move may be to include surface texture criteria in some families. Such "eroded" families could be limited to soils containing argillic horizons. This should greatly enhance the applicability of family criteria for soil management where a great number of practices such as cultivation, fertilization, liming, and herbicioe management are keyed to plough layer texture and organic matter content. It should not destroy the genetic groupings if retained in the lower categories of the system.

I have used the term phase throughout while most of my comments have been directed at erosional phases and resulting soil types. Slope phases are certainly as important to interpretation as type or erosional phase. Whether or not slope limits should be placed on taxonomic units is another topic that should be debated. Presently, I am of the opinion that slope is best left as phase although its permanence and influence on interpretations would argue for its inclusion in taxonomy.

Perhaps the addition of more series to a report could be considered an added expense. However, when you are trying to remember if the map unit you are looking up in an interpretive table of a report is C1B3, Cecil clay loam, 2 to 6% slope severely eroded, capability unit IIIe. 2, or CeB Cecil sandy loam, 2 to 6% slope, capability unit IIe.1, it may be as easy to remember CeB Cecil, 2 to 6% slope or CuB.Cutup, 2 to 6% slope (Cutup is a fictitious series to represent Cecil clay loam severely eroded). Since in the new Soil Survey Report format all lead-in material is by map unit little difference would be anticipated.

Monotype series would seem to subject our work to more rigid quality control than our present use of multitype series with eroded phases. While this no doubt would increase the correlation load, a benefit would be the incorporation of the soil layer most critical to crop management into taxonomy. The irreversible nature of surface texture would argue that it could be considered as permanent a soil property as any other property we use as taxonomic criteria. Our ability to measure what is present in the soil certainly exceeds our ability to estimate what was there prior to erosion. Finally, what is now present is

the basis for our interpretations and is what the public wants to understand and evaluate. How those properties got there is of interest to only a few.

As is so well stated in the "brown book" (p. 11, Soil Survey Staff, 1960), "Probably no one person will approve of all the details of this system; very few will be able to agree upon all of the desirable changes. This, we think, is as it should be at this stage of our knowledge."

Reference

Soil Survey Staff, 1960. Soil Classification, A Comprehensive System, 7th Approximation. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C

ROLE OF SOIL TAXONOMY IN SOIL MAPPING

S. W. Buol

Soil classification and soil mapping are two separate and distinct disciplines. The two disciplines meet in the process of conducting a soil survey but it is imperative that each be clearly identified in the scientists mind.

Soil mapping is the act of portraying the soil present in a given area, at a reduced scale, on a soil map. The function of a soil mapper is exactly the same as that of a naturalist painter. He or she uses the term "reduce to canvas" when referring to painting a natural scene.

As in the painting of a natural scene an artist must portray certain distinct boundaries that can be recognised by others. Sky, land, water, etc., must be clearly identified in the painting. If they are not it becomes abstract art. So it is with the soil map. Distinct landscape units must be recognised and faithfully recorded on the soil map. Such natural and observable features as slopes, erosion, streams, etc., must be delineated if the map is to be usable and appreciated. Very simply, the map, and its identified and defined parts, the mapping units, MUST accurately portray what is actually presently in the field. It is unlikely that any two mapping units are exactly alike. Thus if soil survey was carried out solely as an exercise in reducing natural areas to a map scale, a scientist would not be needed. Artists, who I believe could be hired for less money, would do very well.

It was only after about 50 years of experience with soils mapping in the U.S. that it became obvious that recording soils information only by soil mapping had its limitations. Certainly for the area that was mapped the mapping unit was perhaps all that was needed. But how do you extrapolate the experience in use and management of an area to 1) another area, 2) another individual or 3) another generation? A quantitative system for recording, describing and naming soil properties (not map unit properties) has to be devised.

Soil Taxonomy is a morpho-genetic soil classification system. In basic terms this means that both morphological features of the soil as well as theories about genesis of the soil are used in construction of the system. Definitions of the various categories in the system are quantitative in terms of morphological properties that can be quantitatively measured. Albeit some measurements may be difficult, time consuming and subject to error. Only the arrangement of classes within the system are dependant upon the fickle and fashion prone theories of soil genesis. As such, perhaps almost all the criticisms of the system that are encountered can be answered in one statement: "Perhaps you do not like where a certain kind of soil (pedon) is

classified, but it is the only system within which you can find where, how, and why it is classified as it is."

Classification thus has the obligation to recognise, group and identify all specific kinds of soils. Soil mapping has the obligation to clearly recognise, group and identify all specific parts of a landscape.

The two obligations are not the same. Perhaps in a sterile academic sense it is correct to say that one can classify soils without mapping soils and also to map soils without classifying them. It seems fruitless to debate these points. In practice the Soil Taxonomy has assimilated the accumulated experience of thousands of soil scientists over about the 100 years that soil science has been recognised as a separate discipline. While it will not serve as a mapping legend for any specific area it has distilled soil units that serve as guidelines for the decisions the soil scientist must make when he establishes the criteria for each mapping unit delineation. One probably never finds an area where the units defined in Soil Taxonomy fit uniformly on the landscape. This is readily understood if you consider that Soil Taxonomy has taken the world as its mapping area. It has attempted to assimilate every kind of material that is defined as soil and define this continuous spectrum into discrete quantitative groups called taxonomic units i.e. series. Seldom, if ever, will one of the taxonomic units (series) be found in toto at any location in the field.

If one is to consider a taxonomic unit (a series) in relationship to other series in the universal space of soil property parameters it could assume a cubic shape. The boundaries of series that are adjacent to that series, in universal space. Because Soil Taxonomy was developed in conjunction with soil mapping it is probable that at least one limit of each series can be expected to directly contact the limit of another series some place in the landscape in some area. But this side by side fit of series will not always be found to correspond to natural landscape lines that must necessarily be drawn in the process of mapping.

In reality, then, the task of fitting taxonomic units to mapping units and/or mapping units to taxonomic units, is like the proverbial fitting of square pegs into round holes. The practice of naming map units for taxonomic units i.e. Colfax soils on Colfax series, often serves to further the confusion.

"Colfax soils" is a mapping unit, the description of which has to include mapping inclusions as well as be limited to encompass only that part of the Colfax series actually present. The "Colfax series" must not include mapping inclusions and be defined according parameters that are mutual with the taxonomic units that bound it in universal space.

Conclusion.

Soil Taxonomy has a distinct role in the organization and extrapolation of the information obtained in the course of a soil survey. The soil scientist must adhere to the strict nomenclateur and definitions that are implicit in the definition of taxonomic units. The soil scientist also has an even greater obligation to accurately delineate and accurately describe the segments of the landscape he finds in the field. The use of the taxonomic units, and associated vocabulary, of the soil taxonomy has greatly facilitated this professional obligation. There is a great tendency on the part of unexperienced soil scientists to reverse these priorities and concern himself with the taxonomic correctness of his observations. While this is important, the paramount test of his competence is the mapping unit description. To this end the taxonomic units (series in detailed mapping) is a great aid in-so-far-as they bring together the accumulated knowledge of many people over many years. The correct use of these taxonomic units in mapping compexex, associations, and mono taxa units along with attention to observed relationships and associations of individual soils to each other and other components of the ecosystem is the ultimate test of a soil scientists ability.

CHEMICAL ANALYSES FOR SOIL TAXONOMY

R. J. Cheatle

Introduction

Site selection, thorough description of both site and soil together with appropriate soil sampling are pre-requisites for analysis and relevant classification of the mapping unit. Once these tasks have been completed the first set of classification possibilities, these based upon the field observations, can be prepared.

At this stage copies of all the relevant information together with samples can be handed to the laboratory staff. At the time of sample submission an in depth discussion with the laboratory manager will enable the preparation of a suitable scheme of analyses to do the job. In this case the objective is to classify the soil according to the rules of soil taxonomy. This all seems very straightforward but there are pitfalls.

Variability in the field

Any set of profile samples can be analyzed and the information used in the classification process. Yet if the result is to be meaningful the samples must be representative. It is not the purpose to explore sampling procedures or other aspects related to soil mapping for these are more properly considered as field problems but with a couple of examples to emphasise the notion of the requirement for acceptable representation.

A pit dug to a lithic contact in a one hectare block with horizontal dimensions of one square metre may be considered as a 1:10,000 sample. This is already small yet when soil is sampled from identified but unconfirmed horizons the samples become miniscule in relation to the total quantity of soil in that block and even if the site is representative the samples may not relate to the actual horizons. Other common problems include contamination at sampling and wrong labelling of samples.

For table 1 the use of one standard deviation to each side of the mean as a basis for discrimination enables four low spots to be identified along one transect and eight high spots on the other. The samples were taken from 0-15cm and the high and low spots were confirmed by data from the B horizon.

These data demonstrate the relative homogeneity of this particular Oxisol. Other data support this feature. Yet there are trouble spots. In this case the demonstration utilizes a parameter that appears effective in fertility assessment for crop growth but is one that is not in regular use in soil taxonomy.

Table 1. Determinations of soluble aluminium along two 50m. transects in a Typic Haplustox with 0.02M $CaCl_2$ as extractant

T	36		T	32			
R	31		R	39			
A	32		A	40			
N	33		N	41			
S	32		S	41			
E	33		E	38			
C	31		C	38			
T	32		T	37			
	33			34			
1	35		2	31			
	27			34			
"	35		"	47	H		
	28			40			
	36			37			
T	36		T	40			
1	31		2	41			
	39			32			
	30			39			
	29			37			
	31			39			
	33			34			
	27			48	H		
	12	L		36			
	22	L		33			
	33			44	H		
	07	L		41			
	23	L		41			
	33			37			
	28			46	H		
	28			38			
	33			40			
	35			34			
	35			42	H		
	32			42	H		
	35			42	H		X
	31			42	H		X
	28			39		T	X
	29			36		1	X
	25	L		42	H		X
	37			42	H		XYYYYYY
	30			31			T2
	38			38			
	29			40			
	28			49	H		
	32			42	H		
	26	L		30			
	31			30			
	28			32			
	28			42	H		
	34						

OVERALL MEAN : 34
STANDARD DEV. : 7

L : LOW SPOT
H : HIGH SPOT

Assume the values remain but the scale is expanded with a distance of 100m between sampling points and that data from a pit in one of the low spots serves as the basis for evaluation and later a plan to grow wheat in a square about the transect axes. The approximations of table 2 are drawn from research experience in Zambia.

Table 2. Approximations of yield expectation for two wheat varieties in relation to soluble aluminium content of the soil (0-15cm) as determined by extraction with 0.02M $CaCl_2$.

Variety	Al (ppm)	Yield expectation
Jupeteco	0 - 3	Good
	3 - ...	Poor
Whydah	0 - 20	Good
	20 - 35	Satisfactory
	35 - ...	Poor

With aluminium at 35 ppm Whydah has been known to yield 1300 kg/ha and Jupeteco 100 kg/ha. Clearly Jupeteco would not be chosen but Whydah might be with unfortunate consequences.

The above example is from an area in the north of Zambia where mature woodland was cleared three years ago. Within any ecosystem there is difference due to lithological variability, the community of vegetation and animal activity. Where human animals intervene the images of soil obtained can be very complex. This subject of field variability is more fully covered in the American Society of Agronomy (ASA) special publication number 34. Professors Buol, Dudal, Moorman and Van Wambeke contributed to this work and will no doubt be prepared to discuss this subject.

The following example relates to a red soil within a one hectare block on a near level portion of the Lusaka plateau. Soil of this kind is widespread and usually is classified as an alfisol. In this case the soil was used for arable agriculture by commercial farmers but was abandoned to fallow about twelve years ago.

Grid sampling at 10m intervals with subsequent analysis of samples collected demonstrated a clay soil with considerable variability. Generally the effective depth was greater than 1m but a shallow portion of the block was identified. Table 3 demonstrates something of the ranges met with. Here the maximum and minimum values for ECEC are shown with associated data.

Table 3. Extremes of data for arid sampling (50-70cm) of a one hectare block at 10m intervals.

	Ca.	Mo.	K.	Na.	Al.	ECEC.	CEC.	Clay.	pH.	Base Sat.
	m.e.%							..	CaCl2	%
1.	0.74	0.58	0.17	0.03	2.31	3.83	5.82	35	4.0	26
2	13.37	2.48	0.98	0.02	0.00	16.77	18.15	42	7.3	92

3. No data - lithic contact at 17cm.

Field evidence would suggest to many that the samples are taken from an argillic horizon. No explanation is offered here for the data but note the possibilities for classification. Item three will perhaps be a lithic ustorthent while item two may go into the alfisols and item one into the ultisols.

In the above case a subsoil example was deliberately chosen. Even greater variability in topsoils is met with. The suggestion therefore is that the utmost rigour be practised in site and sample selection before any request is made for laboratory services.

Analytical requirements

Many samples are submitted to laboratories for a "routine analysis" This is because the objective(s) for an analytical request are not clearly identified. Here the objective as stated above is clear. For this purpose of classification much data can be gleaned in the field and where there has been in depth characterization of relevant "bench mark" sites these can be refereed too when support through extrapolation may be possible. Usually the field evidence and such data as is provided will provide a useful foundation for evaluation purposes. Detailed laboratory investigation for specific crop purposes is included at the execution stage of a management plan and is most appropriate at this stage.

Laboratory analyses are very expensive and time consuming. As at June 1985 the cost of a routine set of nine determinations in Zambia is of the order of and equivalent to 42 U.S. dollars. Thus the need for sound preliminary work and the most careful consideration before a request is made is reemphasised. The field pedologist must select carefully in relation to specific objectives. In order to discriminate from the first set of classification possibilities questions of the following kind will be asked: "Will the laboratory please support/refute my notion that this is a spodic horizon?" With approaches of this kind one of the advantages of this classification for many cases is revealed. Often very few analyses are needed to resolve the classification problem.

Listed in table 4 alphabetically as categories are soil orders together with some diagnostic horizons and soil properties. For each is provided a list of some of the analyses that may be required to confirm placement in that category. For

Zambian participants an indication of availability is also given.

Table 4. Selected categories for soil taxonomy and some associated analyses.

Number	Category & Analyses	1	2	3	4
1	Abrupt textural change (Kandic type properties)				
	Particle size (Selected sampling)	x	-	-	-
2	Amorphous material				
	Clay separation	x	-	-	-
	CEC clay at pH 8.2	-	x	-	-
	15 bar moisture	-	-	x	-
	pH - sodium fluoride	x	-	-	-
	Organic carbon	x	-	-	-
	DTA	-	-	x	x
	Bulk density	-	x	x	x
3	Anthropic				
	As Mollic Citric Acid soluble phosphate	x	-	-	-
4	Alfisol				
	Extractable cations	x	-	-	-
	Base saturation	x	-	-	-
	CEC : Ammonium acetate	x	-	-	-
	Particle size	x	-	-	-
	pH - Calcium chloride	x	-	-	-
	15 bar moisture	-	-	x	-
	Weatherable minerals	-	-	x	x
5	Andic				
	CEC - Ammonium acetate	x	-	-	-
	15 bar moisture	-	-	x	-
	pH - Sodium fluoride	x	-	-	-
6	Argillic				
	Particle size	x	-	-	-
	15 bar moisture	-	-	x	-
	Micromorphology	-	-	-	x
	Ntokhota-Cheatle green label luvo test	xx	-	-	-

7	Calcic				
	Carbonates	-	x	-	-
	Gypsum	-	x	-	-
8	Cambic				
	CEC - Ammonium acetate	x	-	-	-
	Organic carbon	x	-	-	-
	Carbonates	-	x	-	-
	Weatherlable minerals	-	-	x	x
9	COLE	-	x	-	-
10	Duripan				
	Acid/KOH silica destruction	x	-	-	-
11	EUTRIC/DYSTRIC				
	Extractable cations	x	-	-	-
	CEC - Ammonium acetate	x	-	-	-
	Base saturation	x	-	-	-
	pH - Calcium chloride	x	-	-	-
12	Gypsic				
	Gypsum	-	x	-	-
13	Family mineralogy				
	Particle size	x	-	-	-
	XRD	-	-	-	[illegible]
	Grain identification & estimation	-	-	x	x
14	Histosol				
	Identification & estimation of fibrous materials	-	x	-	-
	Organic/Mineral proportions	x	-	-	-
	pH - Calcium chloride	x	-	-	-
	Loss on ignition	-	x	-	-

15	Inceptisol				
	Extractable cations	x	-	-	-
	CEC - Ammonium acetate	x	-	-	-
	Particle size	x	-	-	-
	Weatherable minerals	-	-	x	x
16	Lime. soft powder				
	Identification	x	-	-	-
17	Mineral/organic proportions	x	-	-	-
18	Mollic				
	Organic carbon	x	-	-	-
	Extractable cations	x	-	-	-
	ECE - Ammonium acetate	x	-	-	-
	Base saturation	x	-	-	-
	Particle size	x	-	-	-
19	Natric				
	Electrical conductivity	x	-	-	-
	Extractable cations	x	-	-	-
	ESP/SAR	x	-	-	-
20	Oxisol/Oxidic				
	CEC- Ammonium acetate	x	-	-	-
	Dithionate-citrate extractable iron	x	-	-	-
	Particle size	x	-	-	-
	Weatherable minerals	-	-	x	x
21	Pale				
	Particle size	x	-	-	-
	15 bar moisture (udic-ustic-aridic)	-	-	x	-
22	Plaggen				
	C/N ration	x	-	-	-
	Confirmation of spade marks	-	-	-	x

23	Reaction				
	pH-water, calcium chloride, potassium chloride, sodium fluoride	x	-	-	-
24	Salic				
	Electrical conductivity	x	-	-	-
	Soluble salts	x	-	-	-
	% salt	x	-	-	-
25	spodic				
	Particle size	x	-	-	-
	Sodium pyrophosphate extractable aluminium & iron	x	-	-	-
	Dithionite-citrate extractable aluminium & iron	x	-	-	-
	Potassium hydroxide extractable aluminium	x	-	-	-
	CEC - Ammonium acetate	x	-	-	-
	Organic carbon	x	-	-	-
	15 bar moisture	-	-	x	-
26	Sulfidic/sulphuric				
	H_2O_2/ pH check	x	-	-	-
	Redox potential	x	-	-	-
	pH- water	x	-	-	-
	Water soluble sulphate	-	x	-	-
	Total sulphur	-	x	-	-
27	Tonguing & interfingering				
	Cheatle lab-field homosystemic cum sapienscontra test	x	x	-	-
28	Ultisol				
	Extractable cations	x	-	-	-
	ECE - Ammonium acetate	x	-	-	-
	Weatherable minerals	-	-	x	x
29	Umbric				
	See mollic				

30	Vertisol				
	COLE	-	x	-	-
	Particle size	x	-	-	-
	Bulk density	-	x	x	-
31	Water retention	-	-	x	x
32	Weatherable minerals				
	Mineralogy/ micromorphology				
	Grain identification	-	-	x	x
	Thin section prep.	-	-	-	x
	XRD	-	-	-	x
	DTA	-	-	-	x
	Electron microscopy & other confirmatory approaches	-	-	-	x

Legend for single x

1. Available 2. Available but not fully developed. 3. Unavailable in soil survey unit but local assistance may be possible in some cases. 4. Unavailable.

Legend for double x

xx Do not proceed without reference to a standard text.

In some cases the analyses may proceed as a series of steps. For example submission of a sample from a suggested natric horizon may be passed forward for determination of electrical conductivity. A low conductivity value will refute the suggestion and obviate any requirement to proceed. A high value will require determination of "exchangeable" sodium percentage and the sodium absorption ratio.

The tabulated data should direct choice. Yet a full statement of the problem will permit laboratory personnel to assist. Effective communication, usually face to face, will enable a mutually satisfactory scheme of analyses to be set up. Clearly once the problem is known in the laboratory supplementary analyses can be provided where necessary.

Laboratory procedures

Once samples are accepted by the laboratory other problems emerge. The USDA laboratory manual states: "Thoroughly mix and roll the sample with a wooden rolling pin to break up clods to pass a 2mm sieve. ..... "A mechanical sieving device may be used to break up the clods and separate the >2mm fraction. This is a double prescription. In Zambia it is often a treat for the eyes

to see our staff whacking a soil clod with a great mallet. What happens to those relatively soft nodules in each of these procedures? One may preserve them and one destroy them with obvious implications in relation to the planned analyses. The problem of the need to standardise will be returned to again.

The laboratory work produces variability in the analytical results even in the first preparations of the sample. A number of effects may be cumulative and add on to effects arising as a result of field selection.

Preparation differences due to variation in drying, grinoing mixing and sieving are produced. The time and temperature of drying are important for example. Important microbiological changes may be produced when a sample is air dried slowly in a humid atmosphere when compared to quicker drying in a warmer and drier environment.

In any laboratory the bench factor of operator error is in evidence. Incorrect preparation of solutions, improper use of instruments and/or inaccurate calculations can produce variation. Providing that adequate quality control measures are employed this kind of problem can be minimised.

Downwind and well in range from a cement factory in the prevailing direction lies the Zambian soil survey laboratory. Cement dust in this case is just one contamination problem that has to be overcome.

Most methods employed are reproducible well within the spatial variability of the field but it must be appreciated that variability does exist in all laboratories. Table 5 shows estimates of variability recorded in the soil survey unit laboratory for some routine determinations employed.

For methods employed see Cheatle & Van'T Klosster (1985). Under well controlled conditions replications may well be within this variation at the laboratory in Zambia. Variations between laboratories are notoriously high. Coefficients greater than +/- 100% have been met with for some analyses. It is not the intention to explore this issue as some relevant aspects will be introduced in the LABEX discussions scheduled for late in the programme.

Let us assume that the variation of +/- 11% applies to CEC. Then for critical boundaries about 16 & 24 m.e.% we are looking at critical ranges for general use from 14 - 18 and 21 - 27 m.e.% not critical values. Even accepting this case as stated we have not accounted for the variability about clay when the CEC/clay is utilised.

Table 5. Some estimates of analytical variation for selected determinations completed at the Soil Survey Laboratory, Zambia.

Determination	Coefficient of variation
pH ($CaCl_2$)	+/- 0.1 unit of pH
Organic carbon	17% values <1%O.C.
Ex. Bases	Oxisols (Ca < 1m.e.%) Ca. Mg. K. Na. +/- 22% 15% 3% 10%
CEC	Series of tests procured a mean of +/- 7% with range +/- 2-11%
Particle size Texture groups as identified by the texture triangle	Clays +/- 8% Sands +/- 5%

The base exchange characteristics as identified are important at several levels of soil taxonomy. Note their use for example in cambic, oxic, mollic, umbric, alfisols, oxisols and ultisols. These are areas where we in Zambia frequently seek to discriminate. Table 6 illustrates some of the critical values.

Table 6 Some base exchange properties used for classification.

Class level	Property for characterisation
Acric subgroup Haplustox	CEC <1.5 m.e./100g clay For clayey materials Base saturation <50% For loamy materials Base saturation <35%
Mollic epipedon	Base saturation >50%
Oxic horizon	ECEC <10 m.e./100g clay CEC <16 m.r.? 100g clay
Oxic subgroup	CEC <24 m.e./100g clay in most of the argillic horizon
Ultisol	Base saturation <35% with extraction at pH 8.2

Bear in mind the variations calculated for some oxisols where "exchangeable" calcium is below 1 m.e.% as shown in table 5. All these co-efficients can be cumulative and linked to

others from the field and the laboratory. In this case variation of +/-50% is possible in respect of the base cation results alone.

These problems can be further complexed by use of methodologies other than those prescribed. There are several approaches to the identification of base exchange properties. For example the base saturation percentage is sometimes calculated on CEC (at pH 7 and at pH 8.2) and on ECEC. In Zambia only aluminium saturation percentage is calculated in the laboratory when ECEC is used. For any one of the three approaches modification of methodology will affect results. In some cases assumptions for conversion are made. Base saturation calculated as 50% on pH 7 basis may or may not be equivalent to base saturation of 35% at pH 8.2. All these possibilities from increasing variation may be cumulative upon the other sets mentioned above. Often though variation from one source will oppose that from another source.

These exchange properties are also variable for a single site and may be somewhat ephemeral through time also.

Table 7. Single site data from Katito. Zambia illustrating some changes five years after the addition of 6 tonnes of lime.

	Ca	Mg	K	Na	Al	CEC	Base saturation
	meq%						%
Pre-liming 15-30cm.	0.29	0.26	0.10	0.01	1.74	4.66	14
Post-liming 15-30cm.	2.80	0.80	0.10	0.01	0.10		80
Pre-liming 30-45cm.	0.14	0.22	0.10	0.01	1.23	5.18	09
Post-liming 30-45cm	1.20	0.80	0.08	0.01	0.40		40

Table 7 serves to illustrate that changes do occur and sometimes rapidly. Also and most important that class boundaries can be crossed. Note here that initially base cations total less than 1 meq and that base saturation is well below 35% in both cases. Yet the problems can be overcome. Assume here a sound basis for an argillic horizon. Even with heavy liming the use of a base saturation range about 35% this applied as required over the greater part of the argillic horizon the ultisol order would probably be retained but such notions must be examined in detail.

In some circumstances variation produced in a laboratory on a day to day basis can exceed the stated general level of variation. This is an important point to bear in mind. Table 8 demonstrates this. This table also illustrates difference that can arise when a method other than that prescribed is used.

Table 8. Range of values determined with 15 replications of two samples for particle size by the pipette and hydrometer methods at the Soil Survey Laboratory, Zambia.

Laboratory Number	Clay %	Silt %	F.Sand %	M.Sand %	C.Sand %	Method
83/616	07-10	04-07	13-26	57-69	03-09	Hydrometer
83/616	01-03	01-02	25-31	45-51	16-20	Pipette
83/618	53-68	18-26	10-18	01-04	01-02	Hydrometer
83/618	47-48	17-18	26-27	06-06	02-03	Pipette

There is difference produced due to the different methods employed. It must be recalled that classifications are made according to soil taxonomy even though the method utilised to obtain a particular parameter is not that specified. Apart from the obvious problem arising in classification it must be pointed out that for countries with a considerable data base obtained with one method, change to another is not straightforward and requires not only comparative development work to permit the change but the most careful consideration to avoid capricious movements. Even when a change is agreed it may be several years in what are sometimes known as Lesser Developed countries (LDC's) before appropriate equipment and materials for a new method can be obtained and the method brought into use.

In the above case the two separate sets of data would have been closer together but for an intrinsic problem of the method. The hydrometer method here produced higher results for finer fractions because the operator did not rinse out properly the salts used in an earlier part of the determination hence the density of the solution measured with the hydrometer was greater.

Note the lower variability of the pippete method. Note also the range in clay from 7-10% of the first sample. Upon extrapolation from these figures a range of 12-15% might have been produced in the horizon immediately below. Now consider this in the context of abrupt textural change where, "if the clay content is <20%, the clay content should double within 7.5cm. One inference of the data is that reporting could be 7-12% (no abrupt change) or 7-15% (abrupt change). This kind of problem relates to high levels of soil taxonomy, abrupt textural change and the proposed Kandic concept for example.

Particle size relationships are more stable properties of the soil. Others may be regarded as ephemeral. Measurements of organic carbon are widely quoted and incorporated at a high level in soil taxonomy. Such measurements are sometimes related to organic matter and assumed to be a crude measure of fertility status.

The Soil Conservation Service (SCS) laboratory uses a modification of the Walkley approach to determining organic carbon while the Zambian laboratory uses another variant. In both cases problems arise experimentally because of the presence of readily oxidizable forms of carbon that do not affect "immediate" fertility status. "0.77 is the recovery factor proposed by Walkley" states the SCS manual (USDA,1984). Research by numerous workers has demonstrated recovery from 44-92% with the Walkley-Black method, considerable variability indeed. The Zambian laboratory records reproducibility from about 9% -17%. These two points have considerable bearing on classification when a critical threshold value of say 0.6% is in use. "The organic carbon content (for a mollic horizon) is 2.5% or more if the colour requirement is waived..... Otherwise the organic carbon content is at lease 0.6% (1% organic matter)....." (USDA,1975). Conversion to organic matter is conventially dealt with by use of the factor of 1.724. This further complicates matters for it has been shown that this factor also has considerable variability. Other workers have demonstrated the rapid oxidation that is often associated with tropical conditions. In one study rapid changes in the organic carbon levels of A horizons from about 2% to less than 1% occurred in a few years of arable cultivation. A low equilibrium level of about 0.3% appeared to have been reached after 24 years. (Cheatle,1975). The three possible laboratory distorting factors can all be additive and therefore compound error. Even if accuracy can be shown changes as a result of management can induce change across the boundary used for classification.

Most laboratory analyses should normally be regarded as providing results demonstrating an order of magnitude rather than a precise value. The use of these properties mentioned and others at higher levels of classification with the several possibilities for marked variation does suggest an urgent need to investigate these issues thoroughly and effect appropriate revisions.

This outline of some problems to include the concept of results as orders of magnitude does pose certain difficulties for users of soil taxonomy. Yet most can probably be overcome with a flexible approach. A useful facet of soil taxonomy is that parts lean towards classification by sets. For example when the record indicates that X will possess one or more of the following properties. It may well be that substitution of critical values by ranges and class perception as an inclusive set with a number of properties no one of which will exclude, should be considered more fully in the investigation suggested.

Analyses in laboratories other than that of the soil conservation service.

"Most of the methods are described in enough detail that they can be reproduced in many laboratories without reference to other sources". This extract from the SCS Laboratory manual is

followed by-: "For some methods ..... an investigator may need .... to read more about ..... the technique of a method". Elsewhere the reader is referred to ASTM method D424 and for a method for boron to USDA handbook 60. On page 28 of the 1975 Soil Taxonomy is recorded a method for determining sodium adsorption ratio that is not listed in the SCS laboratory manual. Some modifications are indicated.

Presentations of two methods to three of our own staff as written in the manual with an instruction to follow the method did not produce good results. It has to be appreciated that in some situations are staff with relatively low educational background and limited experience and practical skill. For them the procedure must be written as a series of very detailed steps in very simple terms down to the last calculation and presentation of the results. The implicit inference of the SCS manual is that staff exist these trained to a high level of skill and well able to act entirely on their own initiative. Situations elsewhere can be very different. After visiting numerous laboratories in Africa and Asia Arnott (1985) pointed out that the Zambian laboratory had a progressive staff training programme and was one of the best equipped laboratories he had seen during a recent tour. Yet all our methods must be specified in detailed form to assure success for the limited range of work presently undertaken. Our equipment level provides for considerable capability but many of the requirements for soil taxonomy just cannot be met.

Anyone with experience of laboratory situations will readily point out that variations to procedure lead to differences in results. For example the use of large open type vessels for oxidation in organic carbon determinations as opposed to smaller narrow necked ones means that the reaction temperature to assure good recovery will not be reached. If a suspension for pH does not equilibrate fully in one case due to a shortened standing time there will be a difference between replicates. Almost any variation in a method leads to a different result. The manual must specify every detail of every procedure.

The instructions in the SCS manual are not always very precise but can be demanding. "Prepare dialysis membrane sacks from 5.5" cellulose casing (Visking company), using larger rubber bands to tie the bottoms". No doubt a range of strange objects could be produced for those with casing from Visking but what of those who have difficult or no access to the market of the U.S.A. and perhaps only very limited funds for use in the local market where many required goods are simply unavailable. Keeping equipment going is a major task where there is inadequate funding and no spare parts, even more so when there are no maintenance staff or those available have inadequate skill.

The SCS approach has been towards automated analyses and data processing. "Several (Radio-shack microcomputers) are interfaced with electronic balances and other analytical

instruments. (Data) are transferred to a central data terminal for processing by a main frame computer ..... Major instruments .....used to automate analyses are identified at the beginning of each section (of the laboratory manual)".

Table 9 provides a rough estimate of costs for purchasing major items of equipment mentioned in the SCS laboratory manual and necessary for the analytical work of soil taxonomy. Some equipment (air compressors for example) are not mentioned and there is no provision for minor equipment, labware, chemicals or the fabric and infrastructure of the laboratory.

Table 9 Estimation of purchase costs by section for some of the instruments in use within the Soil Survey Laboratory. USDA.

Section	Estimated cost U.S. Dollars .
Preparation	15,000
Chemical	270,000
Fabric related	18,000
Micromorphology	18,000
Mineralogy	78,000
Optical	9,000
Miscellaneous	15,000

	423,000

The total made available for capital and recurrent expenditure for Zambia's agricultural research branch in 1985 may approach 240,000 U.S. Dollars equivalent. Included is the Central Agricultural Research Station and all the numerous sub-stations. For soils research perhaps 10.000 U.S. dollars equivalent will come from the nations coffers. (AADR,1985). Things are difficult here and in many countries. While there are no figures directly comparable there is an image of stark contrast.

What is possible in some places is not always possible in others. Even if some similar equipment is available there may be problems of compatability, with computer systems for example.

In some cases the skills required are just not available even if the sophisticated apparatus is. Let us assume that a thin section is prepared by hand and a suitable microscope is to hand. In how many LDC countries are there staff with the skills and time to spend on determining whether or not the section reveals evidence in support of an argillic horizon. Also do these users have computers, back up support for them and skilled data processing staff? Do they have XRD, DTA and the staff skills for their operation, maintenance and data interpretation? In many cases the answer is negative. For many it is extremely difficult to maintain throughput for just a few methods. Can we

interested in soil taxonomy demonstrate useful cost benefits in relation to other priorities for equipment purchases, maintainance and staff training?

In the SCS laboratory manual are listed more than 200 methods, not all are requirements for soil taxonomy but many are. Few laboratories in the LDC's can cope with such a requirement. there are 15 methods for aluminium alone. How many of us could immediately produce a critical comparison of these, describe the differences in results expected and state the optimum uses in particular situations? There are almost certainly opportunities to reduce the size of the list.

At the same time there may be opportunities to simplify approaches and introduce straightforward but effective equipment. Bulk density and associated analyses with SARAN coated clods is one of those more precarious areas for some LDC users. A suitable extracting tool might be used to obtain volume or an infill procedure developed. Might oxidation with hydrogen peroxide replace loss on ignition to remove the requirement for expensive furnaces necessary for reasonable results? In such cases there might be a cost in terms of accuracy and or reproducibility but given other constraints this might be acceptable. Technology has to be appropriate for everyone if soil taxonomy is to become truly international.

There is a good deal to be done to develop these aspects of soil taxonomy to provide suitable low cost, simple but effective analytical operations that can be accomplished by the majority of laboratories most of the time.

It must also be realised that many laboratories have much more to deal with than analyses for soil taxonomy. For example there may be:-

Developmental work related to applied methodology.

Maintenance and staff training.

Research on such matters as soil testing, benchmark characterisation, other aspects of crop growth.

Provision of data for fertilizer and other advisory recommendations

Elucidation of crop problems

Herbage and other nutritional investigations.

These matters are important. In Zambia there has been a stages of laboratory development and nationwide some attention to fertilizer trials for advisory purposes. Yet the important work of developing analyses and calibrating them to crop trials is barely off the ground. There are reasons to extend this work

when a suitable balance must be preserved between these aspects and those of soil taxonomy. This must be recognised and every attention given to making full use of observable properties, minimising the analyses necessary and incorporating those that can be speedily and efficiently dealt with at low cost.

There is also a more general need to incorporate analyses even more strongly related to soil management than those presently in use for promotional benefits will accrue.

A demonstration can highlight some of these features and suggest that there is a road for investigation ahead where all can contribute.

Figure 1 illustrates in relation to the clay of selected alfisols, oxisols and ultisols in part A the additional phosphorous required to produce a soil solution of 0.2ppm and in part B an aspect of phosphate recovery. 0.2ppm is sometimes regarded when certain other conditions are satisfied as a suitable value for crop growth. Clearly an approach related to identifying retention and release of phosphate is strongly orientated towards soil management for agricultural purposes.

It must be emphasised that these are preliminary laboratory data for some proposed benchmark sites in Zambia and as yet unrelated to field conditions.

In part A of the figure there is indicated strong correlation between clay and phosphate retention but poor discrimination between soil orders. One alfisol with high retention is widely separated from other alfisols. It might be appropriate to class this separately from other alfisols to highlight the distinctive property. Would this be likely? Whatever if the attribute has validity it should be so separated.

Recovery of the retained phosphate will relate to the kinds and proportions of clay sized minerals present. Part B recording a view of recovery now provides a clear discrimination between the alfisols and the other two groups. The fact that many oxisols and ultisols have much in common is revealed by the clumping and mixing in the 40-47% recovery zone. A possible boundary ranged about 50% recovery is suggested. Now sigh and note that just one alfisol is across on the wrong side of the tracks.

This discrimination could also be identified by other means. X-ray diffraction studies would almost certainly identify different clay species dominant in the two groups. Yet in this case although the approach is somewhat time consuming it can be undertaken by a basic laboratory equipped with a shaker and a calorimeter of some kind. The possibility of establishing relationships through in depth characterisation with possibilities for extrapolation suggests strong support for this kind of activity.

It is emphasised that soil taxonomy must be dynamic and relate closely to manageable properties of soil systems that are of most utility. Also that the analytical approaches must in the main be such as can be handled by the majority of users.

It is also a purpose of the demonstration to suggest that the problems to today's soil taxonomy present a healthy challenge to all soil survey staff everywhere. Soil taxonomy is already an advanced system for classification and if we are to improve it further there is a special responsibility for us all. We are required to examine our data, process it, be innovatory and contribute to the development of soil classification by putting forward suggestions for modifications.

Concluding statement

For the benefit of taxonomy and its users the relative inadequacy of skills and materials for laboratory work in some locations has to be faced. Often organization and administration is unsatisfactory and there is little or no forward planning. All facilities may be very poor. Production breaks due to lack of spares or unavailability of skilled repair artisans are common. Funding is frequently inadequate and such monies as are made available are usually in a non-negotiable local currency where in the local market there are but few of the requirements. Staff are also not always well trained and the available skills place strict limits upon what can be achieved. All this may suggest that the creation of regional laboratories be considered. In this context a limited number of straightforward analyses might be dealt with locally. Confirmation and correlation of data together with the completion of more sophisticated work might be accomplished at the regional level. In Southern Africa one possible placement of a regional facility is within the framework of SADCC.

As a conclusion comes an appeal. There is an urgent need to investigate at an international level all methods and procedures to close the gap of difference between nations and to promote internal coherence. Refining the analytical component of soil taxonomy is a major task. For all users there is a need for method development, procedural alignment and improvements in quality control. There is a most important area to examine in order to provide a general most methodology whereby all can accomplish the necessary work. In the first instance the development of a forum through the setting up of an active international committee would seem a most important step. A workshop to permit the presentation of international views would enable this work to move forward rapidly. These steps are proposed.

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THE GEOLOGY OF ZAMBIA

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Introduction

It is practically impossible to give a detailed account of the geology of Zambia. Rather a generalised account will be given of the main geological units based on the Geological Map of Zambia, 1:1,000,000 (1974-5) and on inferred relationships between soil characteristics and associated rock types as studied during the systematic soil surveys. For a comprehensive account on geology of the country reference should be made to Reeve (1963), Swardt and Drysdall (1964) and Drysdall et al. (1972). A series of separate geological maps at different scale covering various parts of the country and accompanied by explanatory memoirs, mostly of Quarter degree sheets, is also available.

Little attempt will be made to distinguish and define lithostratigraphic units and the chronological sequences, but emphasis will more on rock-types and how they have affected soil formation and its distribution. As will become evident later in the discussion rock-types are therefore classified on the basis of their properties as soil parent materials which are generally grouped into igneous or metamorphic rocks, sedimentary rocks and unconsolidated materials. The influence of geology on soil formation becomes apparent when lithological information is compared with soils after quantitative chemical and mineralogical rocks are determined. However, the relationship becomes obscured when deeply weathered soils are considered and as such inferences are normally made.

The geological effects on soils are expressed in terms of grain size or texture which influences other soil properties such as CEC, drainage, moisture retention, etc. and the composition of the rock-types and their stage of weathering which play a fundamental role as relates to the supply and release of nutrients.

The Geology of Zambia

Geological surveying and mapping has been in existence for the past 35 years prior to which prosoecting for economically viable minerals formed the basis of all exploratory surveys. As early as the beginning of the century individual geologists and concession companies have had their rights granted by the British South Africa Company to carry out prospecting. It was through such prospecting that in 1902 Lead and Zinc deposits were found in Broken Hill (now Kabwe) and Copper deposits at Bwana Mkubwa. Between the world wars, however, little was done on exploratory and prospecting activity. During the early '20s Anglo-American Corporation and Rhodesian Selection Trust Limited and other concession companies started prospecting for minerals of

economic value and their findings were directed more in that line than on geological mapping and recognition of rock-types. The maps produced by such prospectors were therefore lithological with broad structural features. The compilation of such maps by a group of geologists (including J.A. Bancroft, T.D. Guernsey and B.B. Brock) co-ordinating the fieldwork produced five sheets (around the mid-40's) which formed the basis of the geological map of the country until the formation of the Northern Rhodesia Geological Survey in 1950. The main task of the then newly formed department was to map hitherto unsurveyed areas and revise the already mapped areas through fieldwork, photogeological interpretations, correlation, etc..

General

Zambia forms part of the great East and Central African plateau of ancient crystalline rocks consisting of sediments, lavas and intrusives mainly around eastern and south-eastern side of the country. These are the equivalents of the Basement Complex. In the south-west, west and north-west younger groups of sedimentary rocks overlie the elder granite (Katanga system) and Basement Complex. In the remaining parts of the country sediments of the Karroo system, and the Kalahari system together with recent alluvium are important.

The effects of repeated folding and metamorphism have altered the original of the sediments and associated intrusives and extrusives (Reeve, 1963). The first and main phase of such folding, referred to as the Lufilian orogeny (>600 m.y. ag), deformed the Katanga system containing pre-Cambrian and possibly paleozoic geosynclinal sediments (Drysdall et al, 1973). Such folds were accompanied by metamorphism though these phases are not easily distinguishable from the major phases which accompanied the Lufilian orogeny. The stratigraphy and structure of these ancient rocks are not therefore easily identified. Reeve (1964) and especially Drysdall et al (1973) have dealt with structural-stratigraphic zones at length. Various age determinations of the complex suggest gaps of millions of years between them. Reeve (1963) also notes that the granitic intrusion into the Basement Complex are more difficult to distinguish than in younger rocks.

In terms of age the younger sediments overlying the Katanga systems and alluvium were deposited in the periods ranging from the Upper Carboniferous, through the Jurassic and Tertiary to the recent.

Table 1 lists the major geological units, systems and rock-types together with the estimated geological period of their formation. Based on the areal extent and importance Zambia can be divided into six (6) main geological units listed below from the oldest to the most recent excepting for group six which consists of rocks of various ages.

1. Basement Complex - Pre-Kibaran, Kibaran & Muva
2. Katanga System
3. Karroo System
4. Kalahari System
5. Alluvium
6. Other rocks of various ages

Table 1. Geological periods with associated geological units and rock types

PERIOD	SYSTEM/GROUP	SERIES	ROCK TYPES
various ages probably older than Pre-Cambrian	others igneous rocks	-	Acidic (6a): Granite, syenite quartz-porphyry, feldspar-porphyry Basic (6b): Gabbro, diorite, basalt, carbonatite
Pre-Cambrian	Basement Complex	Pre-Kibaran	schist, gneiss, migmatites, meta-volcanics (1)
		Kibaran (and Muva)	quartzites, conglomorates, grits, flagstones, cherts, argillites, phyllite slates, shales and schists (2i)
Late Pre-Cambrian and Lower Paleozoic	Katanga	Kundelungu -arenaceous	Shales, tilloidal conglomerates, argillites, grits, sandstones
		-carbonaceous	carbonaceous shales, dolomites/argillites limestone (2ii)
Upper carboniferous to Jurassic	Karroo	-	lava (basalt), sand stone, grit, marl, mudstone (3)
Tertiary to Jurassic	Kalahari		sand, sandstone, limestone and silcrete (4)
	Alluvium	-	Alluvium (5)

Types and Soils

The diversity of rock types found in Zambia is of prime importance in understanding the nature and properties of the soils and consequently the potential of the soils for agricultural development. In many cases the differences between the major geological units is less important in terms of soil development than lithological variation within the geological unit.

Superimposed on the geology is the effect of the climate, in particular the rainfall. The higher rainfall in the north, in extreme cases twice as much as in the south, has with few exceptions resulted in a strong depletion of the bases in the northerly soils, independent of the parent material from which the soils have derived.

A clear example of this overriding influence of the rainfall are the soils derived from the carbonaceous facies of the Basement Complex and the Katanga system. In most cases these limestones, marls and dolomites weather into well drained deep red clayey soils. But in the north they belong to the haplustox (even acric in some instances), whereas in the south they develop into paleustults and paleustalfs. Nevertheless, the acidity of the limestone soils in the north is still less than that of surrounding soils situated over more acid parent materials.

Similarly, "sandveld" soils derived from acidic Basement Complex rocks tend to be highly leached with low pH values and mineral reserves in the north, but only moderately leached with reasonable mineral reserves in the south.

The effect of physiography on soil formation is relatively minor in Zambia when seen on a national scale. This is due to the subdued nature of the landscape. In exploratory mapping, therefore, geological subdivisions are made at a higher level than physiographic subdivisions.

The Basement Complex

The group is divided into the Pre-Kibaran and Kibaran (and/or Muva) system and includes meta-sedimentary, meta-volcanics and migmatites with some granites. The Pre-Kibaran (also referred to as undifferentiated Basement Complex) is the oldest and include mainly granitic-gneisses and migmatites with some granites, mica-schists and also pegmatite, amphibolites and talcose schists. It also includes some pre-upper Plateau series rocks of the Bangweulu Block, pre-Muva rocks of the Copperbelt, the granulite-migmatite, calc-silicate, amphibolite sequences sheathing the northern edges of the Mozambique belt and the quartzite-gneiss-migmatite sequences of the Sukusashi-Zambezi confluence area (Drysdall et al, 1973). The Hook and Mkushi granitic massifs are probably of pre-Kibaran but have been

extensively reconstituted and modified during Kibaran and later orogenies.

The Kibaran system includes the 'Muva system' of metasediments, migmatites and late porphyblastic gneisses, metavolcanic-marble-graphite-schist-pelite mignatite sequences and the upper plateau series of Drysdall et al. Compared to the above system the 'Muva' are younger and separated by a very marked unconformity (Reeve, 1963) and the degree of intensity of metamorphism. The psamruites of this group include quartzites (most common in the Muva group) or quartz-schist whereas pellites are largely shales, phyllites or mica-schists, hornblende-schists and gneisses.

The Basement Complex is best developed around the south-eastern part of the country bordering the Zambezi valley between Mazabuka and Livingstone, between Lusaka and Luangwa valley (Map 1). Isolated domes are common in the north-western part of the country.

The soils formed over Basement Complex are typically "sandveld" soils, i.e. medium to fine textured soils with a loamy sand to sandy loam topsoil which under undisturbed conditions can be up to 40cm thick, but usually is much thinner. The transition from topsoil to subsoil is normally fairly abrupt.

As Basement Complex both underlies large parts in the north and in the south of the country, the chemical characteristics of the soils derived from Basement Complex cannot be dissociated from the differences in climate, in particular from the depth and thus the leaching effect of the rainfall. pH ($CaCl_2$) values range from 4.2 in the north to 5.0 and higher in the south. Similarly, the CEC (clay) increases from 10 meq or less to 15 or more in southerly direction, while along the same line the base saturation increases from about 10% to over 30%. Thus the southerly sandveld soils are considered to be moderately leached, while their northern counterparts fall into the highly leached category, (paleustults and paleustalfs). The textural profile of sandveld soils gives them a low structural stability. This is borne out by the ease which with hardpans develop once brought under cultivation.

Pre-Katanga schists, which occur in close association with the Basement Complex, often have given rise to sandveld type of soils as well. However, in Northern Province this lithological unit is interwoven by numerous meta-quartzite ridges. This has resulted in a rather hilly landscape in which shallow soils over bedrock or laterite occur next to deeper soils. A striking feature of the soilscape is that in this kind of environment the reddest soils usually are situated at the foot of the ridges. Despite the coarse textured lithology of these hills the red soils, which vary in depth from moderately deep to very deep, are often surprisingly fine textured (fine loamy to clayey). Otherwise they exhibit the same highly leached character that is

common to most of the soils in northern Zambia (haplustox).

The soils derived from Hook granites are believed to be mostly shallow ustorthents, while the quartzites can be associated with deep highly leached soils (haplustox), fine loamy to clayey depending on the sandiness of the parent rock, normally with a sandy clay loam topsoil.

The Katanga System

The system includes all sedimentary rocks above the Muva and below the Karroo system. It incorporates the Kundelungu series (> 620 million years ago) and Mine series of Mendelsohn (1961) and includes sediments consisting mainly of ore deposits e.g. copper, zinc, lead, etc.. The 'Mine' series consists of a succession of conglomerates, quartzites, intercalated shales and dolomites (Lower Roan), argillites, shale, quartzite and dolomitic breccias of the upper Roan whereas the 'Mwashia' consists largely of sandstone, shale and interbedded quartzites. The Kundelungu series, which is the most extensive subunit of the Katanga system, included both arenaceous and carbonaceous facies consisting of sandstone, shale, siltstones, quartzites, arkoses and conglemerates, dolomite, carbonaceous shale and limestone. Though 1300 +/- 40 million years has been suggested as the lower limit of deposition of the Katanga system (Reeve 1963) there are considerable changes in lithology from one part of the country to another. Also, the degree to which the system has been subjected to metamorphism differs considerably at various locations.

The system is well represented and covers areas west of Copperbelt province from Chingola to North-western province as far as Mushima and Mumowa. Another area is a strip along and between the Bangweulu swamps and the Mpika-Kasama road up to Chambeshi river and the area south-west of Mpika.

The Kundelungu series are to a large extent made up of siltstones, sandstones and shales. These yield fine loamy to clayey soils, depending on the texture and the degree of metamorphism of the parent material. Clayey soils have usually a sandy clay to clay topsoil, while the fine loamy soils have a loamy sand to sandy loam topsoil (mainly haplustox and paleustult). The latter therefore resemble sandveld soils, although their transition from topsoil to subsoil is more gradual. Where the parent material has undergone some metamorphism, the silt content of the soils is normally high. This renders the soils erodible, which is reflected in their relatively shallow depth (often laterite within 2 m). This effect is particulary out-spoken in the north-western part of Zambia,

Soils over Kundelungu shales are as a rule very deep highly leached red clayey soils. They constitute the acric subgroups of the oxisols in North-western Province. An interesting soil occurs south of Minilunga, also in North-western Province.

Rejuvenation and/or protection against weathering by a Kalahari sand cover has resulted in a soil rich in bases, with a fairly high CEC and a pH of around 5.0. Unfortunately, these haplustalfs are also very erodible, which severely limits their agricultural value.

The Kundelungu carbonate rocks are very deep red clayey soils, highly leached in the north-western part of Zambia, but with a slightly higher pH than the surrounding oxisols. In the central part of Zambia, e.g. south of Kabwe, they are considerably less leached and give rise to haplustalf, with chromusterts in low lying and poorly drained positions.

The Karroo System

These sediments formed in the period from the Upper Carboniferous to the Jurassic, consist of lava (basalt), sandstone, grits, marl and mudstone with basal formations usually associated with coal measures. The Karroo system is well represented in the east, south-east and south of the country around Luangwa valley, mid-Zambezi valley, Luano valley, Gwembe valley, Lukusashi and Rufunsa valleys.

Remnants of Karroo lavas (mainly basalts) are confined to around Livingstone, the confluence of the Kafue and Zambezi rivers and Mwinilunga district.

The soils derived from Karroo include a wide range of soils due to the different physiographic settings which are controlled by this geological unit. Where it forms part of the escarpment the soils are dominantly shallow, but with pockets of deep soils in valley, deep base rich fine loamy and clayev soils dominate, while the high temperatures and low rainfall are responsible for a large proportion of soils with a high salt content in less well drained positions (haplustalf and natraqualf). The poorly drained heavy textured mopane soils, formed in sediments derived from residual soils over Karroo, mostly belong to the chromusterts.

The Kalahari System

The system formed from the Tertiary to recent periods is one of the major geological units covering the Western province of Zambia and western parts of North-western province. The sediments dominating this system and concealing almost all evidence of older rocks consists of strata of poorly consolidated red to white sandstone, thin limestone, unconsolidated wind-blown sands associated with consolidated sands and gravels cemented by iron oxides, lime and chalcedony giving rise to ferricrete, silcrete or calcrete.

A wide range of soils occur within this system depending on the differences in geology and drainage.

Soils formed in unconsolidated Kalahari sand deposits are mostly sandy, although in North-western province coarse loamy soils tend to dominate. Red iron rich and yellow phases occur side by side, the latter probably having been deferrated as can be induced from the presence of laterite banks within the deposits. They show otherwise very little profile development and are without exception all very leached and acid soils (quartzipsaments and paleustults). Podzolic features have developed in the sands around Mongu (tropohumod), while on the west bank of the Zambezi and elsewhere on a smaller scale (e.g. north-east of Mwinilunga) the groundwater level can rise close to the surface or even reach it during the rainy season or when the Zambezi is in flood (psammaquent, tropaquent and tropaquept); pH ($CaCl_2$) values in these soils are commonly less than 4.0.

Where the Kalahari sand cover thins out a wide range of transitional soils can be found, displaying a high degree of variation within short distances. These soils mostly belong to the haplustult and haplustox, and texturally range from coarse loamy to fine loamy.

Alluvium

These are recent sediments concealing older rocks. These have been deposited and are found around the Zambezi, middle Kafue, Busanga, Machili-Nanzhila, Bangweulu and Chambeshi river system. The system is characterised by seasonal waterlogging or flooding and relatively high water-tables.

Alluvial sediments are responsible for a wide range of soils in Zambia. The major alluvial systems include poorly drained heavy textured soils (chromustert and pellustert) like in the Kafue flats and more recent lighter textured soils (fluvaquent) as in the Zambezi floodplain. The major swamps are surrounded by coarse loamy and sandy soils in upland position (ustorthent and/or ustipsamment) and clayey flats around their fringes (tropaquept), while the swamps themselves contain permanently waterlogged soils rich in organic matter (haplaquoll).

Peaty soils occur in Zambia too, in particular in those Kalahari sand valleys that continuously receive water through seepage from adjoining uplands, but their extent is limited (medihemist).

Terrace soils are widespread, in particular along sections of the Kafue, but they often are not easily identifiable in the landscape as such. The Kafue terraces are heavy brown clays, mostly imperfectly drained, with a high pH and a good base status (haplustalf and ustochrept), while the terraces connected with the Kalahari system are fine loamy to coarse loamy with clear planosol features (albaqualf).

Others

This group encompasses lithological units of various ages but probably the majority are older than the pre-Katangan system. The 'Igneous' rocks group is the main geological unit consisting of acidic volcanics and metavolcanic rock-types such as granites, syenites, quartz-porphyry, and ryolites, the basic rock-types e.g. gabbro, diorite, basalt and dolerite and carbonatites and cale-silicate rocks.

The group includes the Luapula volcanics of crystalline porphry-ryolites and the Irumi-Rufunsa-Kafue volcanics of Drysolall et al (1973). The granites are abundant in the north, east and south-east of the country, carbonatites around Nkombwa Hill east of Isoka and Lower Rufunsa valley and meta-carbonates and calc-silicate rocks around Lusaka and Kafue areas.

The most important soil developed from undifferentiated lithological units are the soils derived from the limestone of the Lusaka plateau. These soils, which belong to the most productive agricultural soils of Zambia, are deep clayey red soils, with a nearly neutral reaction, a relatively high CEC clay of around 30 meg, and rich in bases (paleustalf).

Scattered occurrences of basalts and amphibolites are also covered by red clayey soils which, however, have less favourable characteristics than the soils derived from the Lusaka limestone. The effect of the rainfall is very outspoken again on these soils, with haplustox overlying the more northerly basalts and rhodustalf covering the southern basalts.

The large occurrence of granite and associated rocks covering substantial parts of the northeast of Zambia has given rise to a very uniform soil cover, again highly leached, with pH values of less than 4.5, a CEC clay of 10 to 15 meq and a base saturation between 20 and 30%. Together with a very similar texture profile (sandy loam fairly abruptly over a fine clayey control section) these soils are very much akin to the sandveld soils developed over gneiss. Considering the broadly similar mineral composition of many of the gneisses and granites in Zambia this shows that despite the equalizing effect of a long history of intensive weathering the influence of the parent material is to some extent still discernable, even on the chemical characteristics.

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A GEOMORPHIC LEGEND FOR ZAMBIA

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Introduction

Physiography is sometimes regarded as the integration of geomorphology, photogeography and soil science, but there is a general assumption that, in the study of landforms, 'physiography' is associated with a descriptive approach and 'geomorphology' with an interpretative analytical approach (Amer. Geol. Inst., 1972, p538). In view of the somewhat genetical, and therefore interpretative, nature of the legend presented in this paper, the use of the term 'physiography' has been avoided and the American term 'geomorphic' adopted for concise usage.

In the preparation of this document, most of the literature on geomorphology in Zambia has been reviewed; existing and old terminology were considered and used - where appropriate, and some new terms have been introduced. The legend has been developed through a progressive process of proposition, discussion, debate, field testing and refinement. Various approximations have been produced. The legend presented herein represents a consensus of opinion at the time of writing; but through use it is assumed that it can be refined further and improved. In particular, it is expected that geomorphic units in the fourth level of the legend, and eventually in the fifth level (if needed), will be agreed and defined in due course.

Aims and Objectives

Two major objectives of phase 2 of the NORAD-funded soil survey project in Zambia are to produce a new 1:1,000,000 scale exploratory soil map of the country, and to complete a range of systematic reconnaissance soil surveys of quarter degree sheets at 1:100,000 scale. A major input into the preparation of legends for these maps is likely to be a consideration of geomorphic units and their definition. Such units are, however, open to a wide range of definition at a variety of scales and, in the past, the failure to reconcile individual opinions within the Soil Survey Unit has been largely due to the fact that the scales at which some units have been defined have differed from survey to survey and from surveyor to surveyor. Several geomorphic legends for specific areas in Zambia have been prepared in the past by Soil Survey Unit staff (English 1982a, 1982b; Dalal-Clayton 1982a,1982b; Veldkamp 1982a, 1982b; Vikan 1982) but it has, so far, not proved possible to incorporate these into an acceptable national legend. There is also a clear need to standardise the use of geomorphic terms used by soil surveyors and others in site description, and to categorise and define the

range of geomorphic units to be found in Zambia.

The legend presented in this document seeks to achieve these requirements.

With two exceptions (viz.dambo and dilungu), the use of local terms or names has been avoided. The view has been taken that pure geomorphological terms will convey meaning more readily to those unfamiliar with the country.

The recognition and mapping of erosion surfaces (Dixey 1945, King 1962), whilst very useful for pure geomorphological studies, is a very time-consuming process. Older, more leached and weathered soils are often found on the older surfaces, but equally often essentially similar soils may be developed on different erosion surfaces.

Central to the process of developing a geomorphic legend for exploratory and systematic reconnaissance surveys is the need to recognise a hierarchy of pre-defined geomorphic units at specified scales bringing together previous legends into a single basic framework. The legend presented here adopts this approach and is hierarchical in structure. The rationale behind this structure is the recognition of the fact that Zambia comprises four macro (continental) geomorphic units (First Order Units) each of which can be divided into Second Order Units. The latter can be progressively subdivided into Third and Fourth Order Units and so on according to scale requirements and need. The more detailed lower order units are not included in the legend at this stage. They will need to be identified and defined in due course as the overall legend is applied and tested in the field.

Some units (e.g. floodplain, terrace, etc.) appear several times in one or more levels, but this is unavoidable in a hierarchical legend in which the higher order units have broad definition encompassing wide assemblages of landforms.

The hierarchical approach adopted, at least in the First to Third Orders of the legend, is to some extent equatable with the 'Land Systems' method of recognising composite landscape patterns which was inspired by Bourne (1931). Several groups of workers have used this approach (Christian and Stewart, 1968; Bawden and Stobbs, 1963; Becket and Webster, 1962; and Aitchison and Grant,1967) which recognises Land Systems intended for mapping at scales in the range 1:250,000 - 1:1,000,000. This approach has been used in Zambia in the Luangwa Valley (Astle et.al., 1969) and in the Northern and Luapula Provinces (Mansfield et.al.,1976). Elements from these studies were drawn upon in constructing the legend.

There are a number of geomorphological terms which are ambiguous and thus capable of interpretation in a variety of ways (e.g. pediment) and these have been avoided as far as possible. It is essential that only clearly defined terms be added to the

legend as it is developed.

Definitions of all the First to Third Order Units are included in this paper, and a glossary of local terms used in the definitions or text is provided.

The development of geomorphological studies in Zambia.

Before World War II the few studies of a geomorphological nature that were published either focused on the unique landscape of the Victoria Falls and its associated gorges (e.g. Lamplugh, 1907 Maufe, 1938), or else stemmed from general geological studies (e.g. Molyneux, 1909; Bancsroft and Pelletier, 1929; Murray-Hughes, 1929) or from studies being carried out to further the development of the country's copper resources (Guernsey, 1941). A notable publication was, however, made by the German geologist, Ackermann, who provided the first detailed study of dambos (Ackermann, 1936). He was much later to write on penitent rocks in this country (Ackermann, 1963).

The framework upon which much of our present knowledge of the geomorphology of Zambia has been developed was provided by the extensive pioneer studies of Frank Dixey. Amongst other things he was the first writer to attempt to provide a comprehensive account of the geomorphology of the country as a whole. In view of the relevance of Dixey's work to the Geomorphic Legend presented in this paper, and the extensive use made of it, together with Professor Lester King's scheme of planation surfaces, by later investigators in Zambia, an extended discussion of the work of these two workers seems appropriate here.

Dixey worked in the then Northern Rhodesia as Director of the Department of Water Development between 1939 and 1944 following 18 years of service with the Nyasaland Geological Survey (Anon, 1983). His work was temporarily interrupted during this period by war duties and his contribution to Zambian geomorphology is thus especially meritorious, particularly in view of the poorly developed communications of the time, the inadequate maps and the lack of comprehensive air photo coverage.

Dixey adopted a traditional Division approach, identifying in the landscape a series of uplifted peneplains which had been dated elsewhere by examination of their relationship to fossil-bearing deposits. His work in this country was a development of the studies he initiated in Malawi, and also benefitted from the studies of Veatch (1935) in the Congo (now Zaire river) Basin. Although he identified at least nine such surfaces, some are of limited extent or preserved essentially as unconformities beneath Karroo or Cretaceous deposits. Of the nine, six might be considered as of more than local importance:

Late Jurassic Peneplain
Vipya Peneplain (Late Cretaceous or early Tertiary)
5,100 ft Peneplain
Mid-Tertiary (Miocene) Peneplain
End-Tertiary Peneplain
Post-Tertiary Surfaces

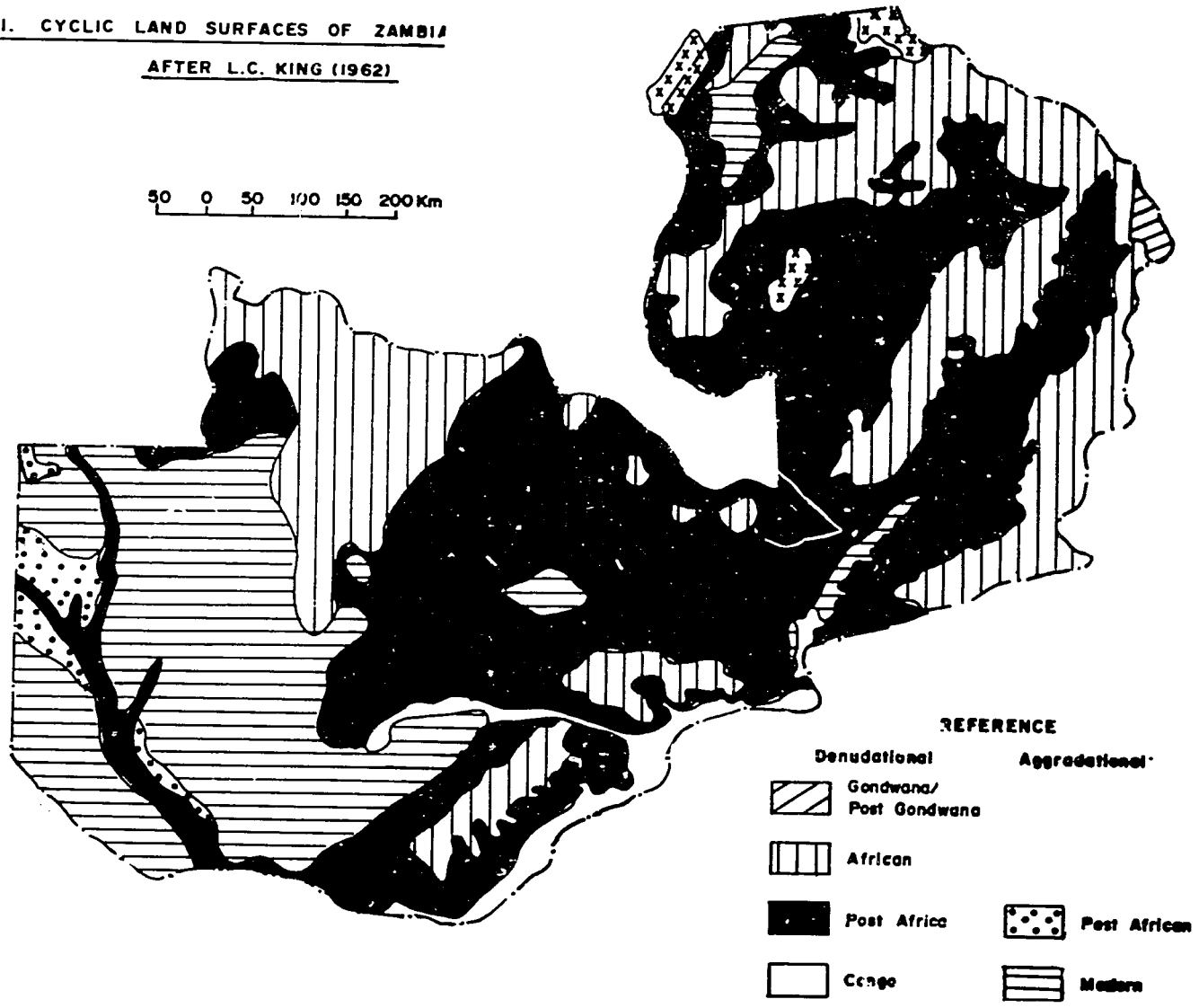
These surfaces are all of low relief (but with important contrasts in the degree of planation) and identification seems to have been greatly influenced by altitude. Development by processes of fluvial denudation involving down-wasting is implicit, whilst rejuvenation of the rivers, following uplift, led to the formation of newer surfaces at lower levels.

Dixey was particularly interested in the relationship between structural features and the planation surfaces. He considered the faulting which followed Karroo deposition especially important, later rift-faulting being controlled by these earlier structures which (e.g. in the area around Lake Tanganyika) have an influence on present-day topography. The most important phase of uplift seems to have occurred following the End-Tertiary surface. Dixey's major study on Zambia (1945) was unfortunately not illustrated by a map, although his study of the Zambezi-Congo watershed does contain a map showing the erosion surfaces of the watershed zone westward from the Pedicle. Further problems in the use of Dixey's detailed descriptive account result from his reference to places, the names of which have since changed, or are no longer of importance.

At about the time that Dixey was working in Northern Rhodesia, the South African geologist, Lester King, was developing a wholly new theory on the formation and development of the African landscape. His ideas were presented in an attractive textbook of geomorphology (1942; later editions, 1951, 1963) and have gained international recognition. King was the first to provide a map of the 'land surfaces' (equivalent to the 'erosion surfaces' of Dixey) of central and southern Africa, which first appeared in his textbook and which was later (King, 1962) refined and extended to include the whole of Africa. Fig. 1 is an expert from King's later map and shows the distribution of his erosional and depositional landsurfaces in Zambia. Although King travelled in this country, he is not known to have done any detailed fieldwork here and probably relied to some extent on the detail provided in Dixey's several publications. King has more recently restated his views on the geomorphology of the southern part of Africa (King, 1978).

FIGURE I. CYCLIC LAND SURFACES OF ZAMBIA

AFTER L.C. KING (1962)



There are two major differences between King and Dixey in their interpretation of the sequence of planation surfaces. Firstly, whereas Dixey accepted the traditional Division perspective, King was more innovative, although developing ideas which can be traced back to the German geomorphologist, Penck. Scarp retreat (i.e. parallel retreat of slopes) and pedimentation were key processes and King considered that pediments (pediplains/planation surfaces) once formed were little affected by denudational processes. He conceived of a staircase of such surfaces, headed by scarps, migrating inland following initiation at the coast: uplift would not stop scarp retreat and hence the headword development of all surfaces would continue. Thus the surface would be of a progressively younger age when traced inland. Higher surfaces would, however, eventually be consumed by the development of those at lower levels. The scarps might have been formed at the coast by monoclinal warping, the continental margin rising (partly isostatically) whilst deposition of sediments in the offshore zone would have caused down warping there.

Basic to King's theory is the notion that Africa once formed part of the super continent of Gondwanaland: King was a proponent of the theory of continental drift when it was a revolutionary theory unacceptable to the scientific establishment of the time. Thus the earlier 'landsurfaces' he identified as having formed when Africa comprised part of the supercontinent of Gondwanaland. The most significant of these formed a surface of extreme planation characterising the supercontinent immediately before it's disruption, and to this King gave the title 'Gondwana landsurface'. Disruption of the supercontinent (in the late Jurassic) was marked by a tectonic event which initiated the dissection of this smoothly planed surface. King also introduced the term 'cymatogeny' to describe a form of uplift which has a wave-like effect, thus accounting for the 'basin and swell' topography characteristic of Africa, as earlier identified by Arthur Holmes (1965).

Dixey did not accept these ideas of King. He restated his view (Dixey, 1955) by extending his central African work (based on studies in Zambia and Malawi) southwards into South Africa, and also by taking account of the work of Cahen and Lepersonne (1952). The latter workers had traced key planation surfaces inland from the coast and from the Congo Basin across the continental divide into Zambia. Unfortunately, like most of Dixey's earlier work this paper of 1955 lacks a map illustrating the location and extent of the surfaces described. Although King and Dixey have contrasting views on the origin, they were in general agreement in their identification of the various erosion/land surfaces, differing mainly in terms of the mechanisms of their formation and development. Dixey conceded that there is a role for parallel slope development, as in the case of hillslopes with resistant (e.g. lateritic) capping. But he continued to stress the paramount role of downwasting, which would result in declining slope angles once the resistant capping

had been consumed.

It is useful to compare the terminology of Dixey and King (see Table 1) and to underline some of the key differences between their schemes of landform developement. The equivalence of Dixey's Mid-Tertiary Peneplain ("the main peneplain of Northern Rhodesia" Dixey, 1945, p.19) and King's African landsurface ("this extra-ordinarily smooth planation (which) affords the datum that is most sought by geomorphologists": King, 1963, p.239) is clearest. The equivalence of Dixey's surfaces with King, Gondwana landsurface (developed before the break-up of the supercontinent) and the post-Gondwana landscape (initiated by the break-up is less certain. Dixey seems to identify more extensive remnants of these higher level surfaces and identifies more than two. King referred to these as 'multiphase aspects of the Gondwana surface' (due to local uplift), an explanation which was accepted by Dixey (1955, p277). Conversely, King's Post-African landscape is two-cycle, a distinction not drawn by Dixey in his End-Tertiary Peneplain. Both suggest a major phase of uplift at the end of the Pliocene - "strong cymatogeny" in King's terminology - which gave Africa much of its present day elevation (and hence relief), causing major incision of the rivers and waterfall development. Although the time lapse since this event is relatively slight, landscape development is seen by both as multiphase; King, for example, distinguishes between a higher Victoria Falls Cycle (which has proceeded inland as far as the falls) and a lower Congo Cycle which has extended little from the coast.

Table 1. Sequences of planation surfaces in Zambia.
(Dixey and King Compared)

DIXEY	KING
Late Jurassic Peneplain	Gondwana Landsurface
Vipya Peneplain (Late Cretaceous) 5100 ft peneplain	Post-Gondwana Landscape
Mid-Tertiary (Miocene) Peneplain	African Landsurface (Early Cainozoic)
End-Tertiary Peneplain	Post-African Landsurface (Late Cainozoic)
Post-Tertiary surfaces	Congo Landsurfaces (Quarternary)

King's views, which he has expanded (King, 1962) in a scheme of morphological evolution for all of the continents of the world, remain highly controversial. Although his scheme of land

surfaces is often made use of, paradoxically his model of landscape development does not form part of established scientific thinking. That there has not been the effective challenge of an alternative viewpoint can probably be attributed to the loss of interest in denudation chronology by the geomorphological community in recent years in favour of process studies. However, for an understanding of landforms on a macroscale, such as is required in the formulation of a national geomorphic legend and map, King's scheme offers the most useful framework. It is for this reason that his ideas, together with those of Frank Dixey, which are complimentary, have been given such a detailed examination.

King, and to a lesser extent Dixey wrote on topics at a macro scale. The same approach was adopted by Wellington (1955) in his textbook on the physical geography of southern Africa. Subsequent investigators have tended to concentrate on smaller areas. The institutional framework for study was also to change with the establishment in the early fifties of the Geological Survey Department and then, in the mid - sixties, the founding of the University of Zambia. The reports of the Geological Survey usually contain a short section of descriptive geomorphology (eg. Simpson et.al., 1963; Smith, 1963). In addition there have been occasional contributions on geomorphological topics in occasional papers and records (e.g. Bailey, 1955; Smith, 1966; Tavener-Smith, 1968) also published by the Geological Survey. In general the staff of the Geological Survey have shown a limited interest in the country's geomorphology. One notable exception was A.M.J. de Swardt (Director of the Survey, 1961-68) who focused his studies on rift faulting and its landscape expression (de Swardt, 1965) and on laterites (de Swardt, 1964). He identified two main laterites extensively developed through equatorial Africa, relating these to erosional episodes and climatic change. He also attempted to initiate a geomorphological study of Zambia by the Geological Survey Department (de Swardt, 1967), but this does not seem to have had any tangible result.

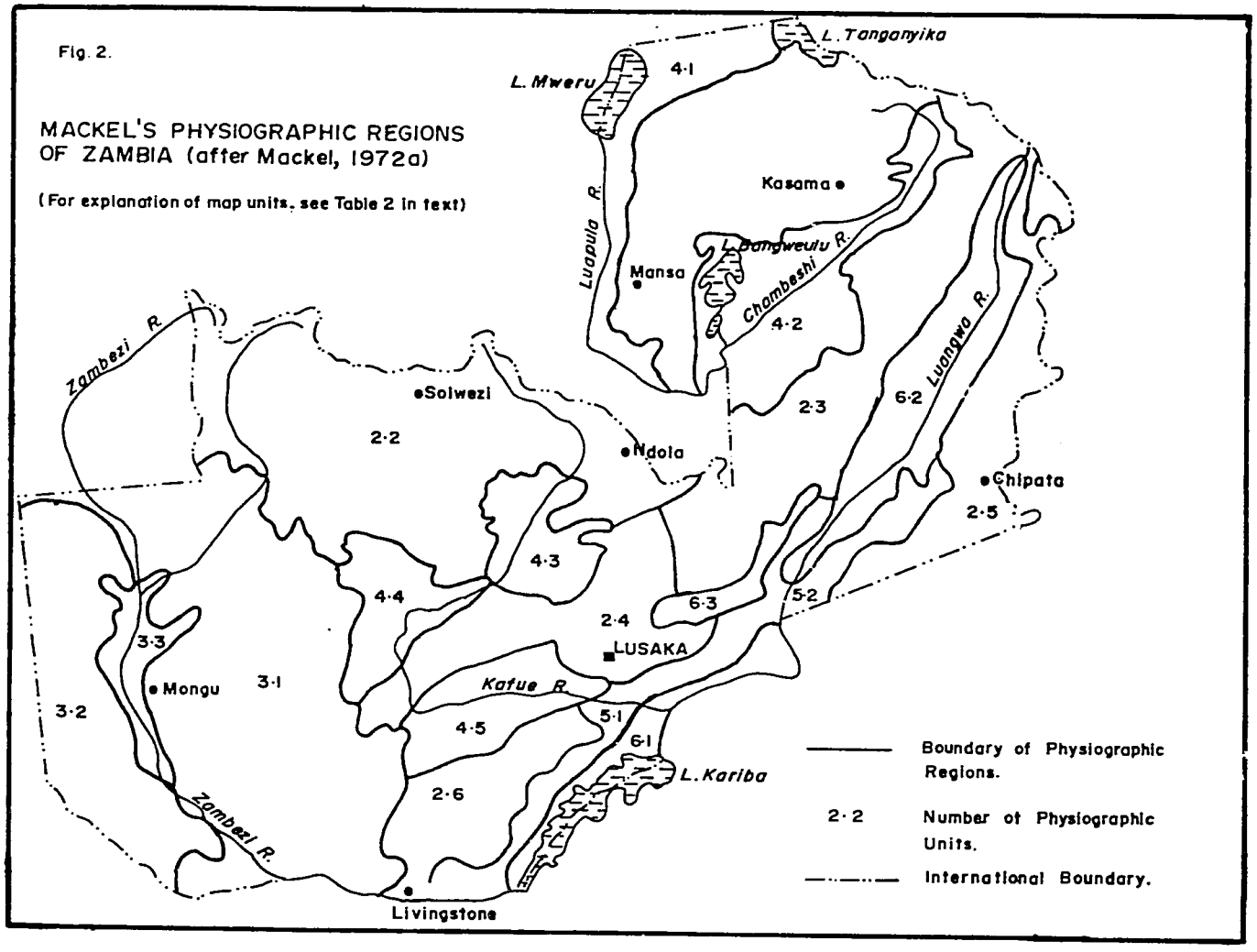
The Department of Geography at the University of Zambia, since the Universtity's foundation, has offered geomorphological courses at various levels. Departmental teaching staff have published on various aspects of the geomorphology of Zambia, most notably Rudiger Mackel, who carried out detailed studies on aspects of the geomorphology of the Kafue-Zambezi escarpment zone (Mackel, 1974). Other publications have dealt with topics such as dambo development (Mackel, 1974) and piping (Mackel, 1976), whilst a contribution of particular interest is his map of the physiographic regions of Zambia (Mackel, 1972), (Fig.2). This map uses a combination of geomorphic terms and local names (e.g. Kafue Basin, Luangwa Hill Country, Eastern Plateau), (Table 2).

A problem with the map is that the delimitation of some units is difficult in places, i.e. in the Kapiri Mposhi - Mkushi area where Mackel's North Western, North Eastern and Central Plateau merge imperceptibly.

Fig. 2.

MACKEL'S PHYSIOGRAPHIC REGIONS OF ZAMBIA (after Mackel, 1972a)

(For explanation of map units, see Table 2 in text)



Other UNZA staff who have contributed to the geomorphological literature include Archer (1968, 1972), Giardino (1973a, 1973b, 1973c) Pullan (1979), Turner (1979, 1984) and Williams (1975, 1982 and 1985).

Table 2. Mackel's physiographic units (to accompany Figure 2) (Mackel, 1972a)

1. High Mountain Region

2. Zambia Plateau Region
   - 2.1 Northern Plateau
   - 2.2 Northwestern Plateau
   - 2.3 Northeastern Plateau
   - 2.4 Central Plateau
   - 2.5 Eastern Plateau
   - 2.6 Southern Plateau

3. Barotse Plain Region
   - 3.1 Eastern Plain Region
   - 3.2 Western Sandplain Region
   - 3.3 Zambezi Floodplains

4. Lake and Swamp Basin Regions
   - 4.1 Northern Lake Basin Region (Mweru-Tanganyika Lake Region)
   - 4.2 Bangweulu-Chambeshi Basin
   - 4.3 Lukanga Basin
   - 4.4 Busange Basin
   - 4.5 Kafue Basin

5. Escarpment Regions
   - 5.1 Zambezi Hill Country
   - 5.2 Luangwa Hill Country

6. Valley Regions
   - 6.1 Mid-Zambezi Valley
   - 6.2 Luangwa Valley
   - 6.3 Lunsemfwa-Lukusashi Valley

The expansion and development of the Soil Survey Unit of the Department of Agriculture in the mid 1970s added a further impetus to the study of geomorphology. Out of necessity the study of soils requires an understanding of landforms and landscape processes. Many of the reports of the Soil Survey Unit contain sections of physiography, sometimes in some detail (Dalal-Clayton, 1980; English, in press). In addition the Land Use Planning Guide of the Department of Agriculture (Dept. of Agric., 1977) contains a useful map of the ecological regions of Zambia which is largely physiographic.

A number of major ecological and land resource surveys have been commissioned by the government during the last half century and, although incidental to the main purposes of the studies, have provided observations, and sometimes stimulated research, on the geomorphology of the country. Perhaps the most well known were the ecological surveys of Colin Trapnel carried out in the 1930s and early 1940s. The Report of the Ecological Survey of North-Western Rhodesia (Trapnell and Clothier, 1937) contains the first-known attempt to delimit what they termed 'Natural Regions', identifying between Northern and Southern Plateau Regions, the Kalahari Region, a Lower Valley Region (i.e. the mid-Zambezi trough) and an Upper Valley Region (the lower Kafue Basin); subdividing these further in terms of swamps and floodplain areas and soil types. It is worth noting that in this report it was already recognised that "physiographic factors are perhaps of the greatest importance in determining the distribution of soil and vegetation types'. The report on the survey of North-Eastern Rhodesia (Trapnell, Martin and Allan, 1943), although containing a detailed description of the 'physiography' does not contain a comparable map. Both of these reports contain geomorphological descriptions of then little known terrain which still remain valuable today.

Just after the Second World War, Professor Frank Debenham carried out investigations in the Bangweulu swamps which have a geomorphological content (Debenham, 1946, 1947, 1952), but with this notable exception the lake basins of Zambia are in general little known geomorphologically.

Carrying on the fine tradition of Trapnell, Verboom worked extensively on the ecology of the Western Province and provided a highly individual comment on aspects of the geomorphology of parts of that area (Verboom, 1974; Verboom and Brunt, 1970). The earlier ecological studies of Monica Cole concerned the relationships between landforms, soils and vegetation and showed that particular vegetation associations were indicative of particular geomorphological and pedological characteristics (Cole, 1963).

As earlier noted, the 'land systems' approach to resource analysis has been adopted in the east of the country. It was used first in the Luangwa Valley (Astle, et.al., 1969) and in the Northern and Luapula Provinces (Mansfield et.al.,1976). The data compiled on the landscapes of these areas comprise a valuable source of information for future investigations.
In the context of this publication, of particular interest is the attempt by Bruce King (geomorphologist attached to the team which assessed the land resources of the Northern and Luapula Provinces - Mansfield et.al., op.cit.) to identify physiographic regions by analysis of the relief and stream frequency of individual land systems, the result being shown in an R-F diagram of the 'land systems' (King, 1972).

The evidence for climatic change provided by landform assemblages and associated deposits has been of particular interest to archaeologists. Archaeological work in Zambia has been based in Livingstone (where the Rhodes-Livingstone Museum was established in 1934). Not surprisingly much effort has been expended in elucidating the cultural and environmental history of that area. Clark (1950) edited an important publication on a survey of the Stone Age cultures of the country, which has a strong focus on the Zambezi valley both up and downstream of the Falls, and there are contributions in this publication by Dixey (on the geology) and Bond (on the Kalahari sands) as well as a section by Clark himself on the recession of the falls through Batoka Gorge. This latter topic was returned to by Derricourt, also an archaeologist, in a more recent publication (Derricourt, 1976), whilst Bond (1964b) has made available a popular account of the evolution of the falls.

An understanding of climatic change in Zambia is vital to the elucidation of recent landscape history, and particularly in the Western Province where aeolian features, apparently out of harmony with the present climate, are an important element of the landscape. The availability of satellite imagery in the 1970s has permitted a new and synoptic approach to their study (Sterckx and de Ploey, 1973; Sterckx, 1974; Williams, 1982). The latter author has compiled the first map to show the location and main structures of the fossil dunefields and pan forms of western Zambia, whilst Thomas (1984) has more recently placed them in a broader regional setting.

Finally, it might be noted that geomorphologists are also using their skills to monitor the impact on the landscape of man's activities. The recent studies of Robinson (1978), Turner (1984), and Nugent (1983) fall into this category, whilst Stocking (1984) has indicated the role of the geomorphologist in Zambia in assessing the environmental impact of recent changes in agricultural practice.

An Introduction to the Geomorphology of Zambia

The greater part of Zambia is situated on the continental divide and constitutes a part of the Central African Plateau with an average elevation of 1200m (c.4000 ft) above mean sea level. The position of Zambia in relation to the prominent continental features of Southern Africa is shown in Figure 3.

The plateau is generally gently undulating and is broken only here and there by isolated hills or hill ranges composed of the more resistant rocks. According to Dixey (1945), this plateau is "actually a composite feature, built up of several separate erosion surfaces. A large part of it does represent the presumed Miocene peneplain, but there are many large and small remnants of older peneplains standing above it."

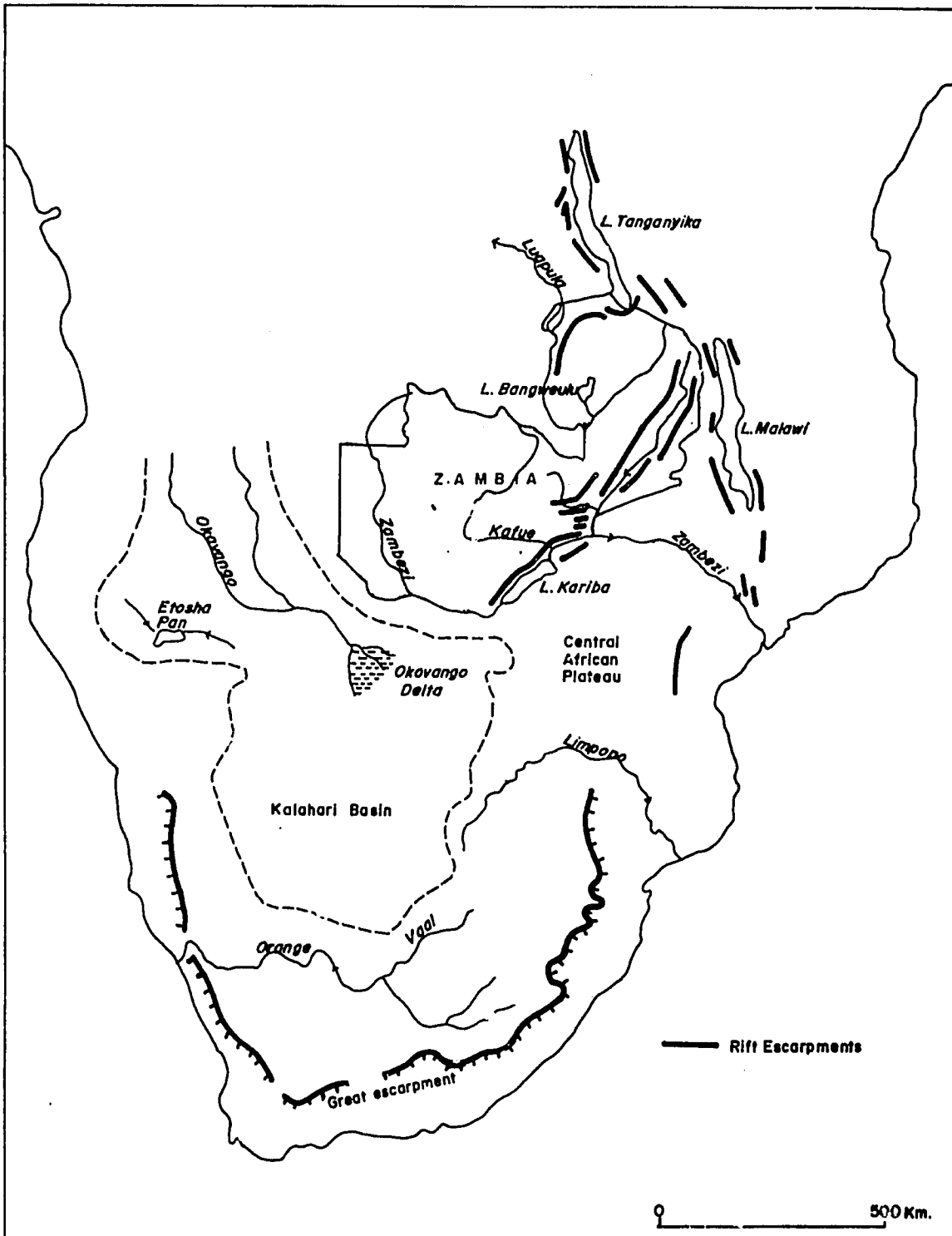


FIGURE 3.

DRAINAGE AND RIFT ZONES IN SOUTHERN AFRICA

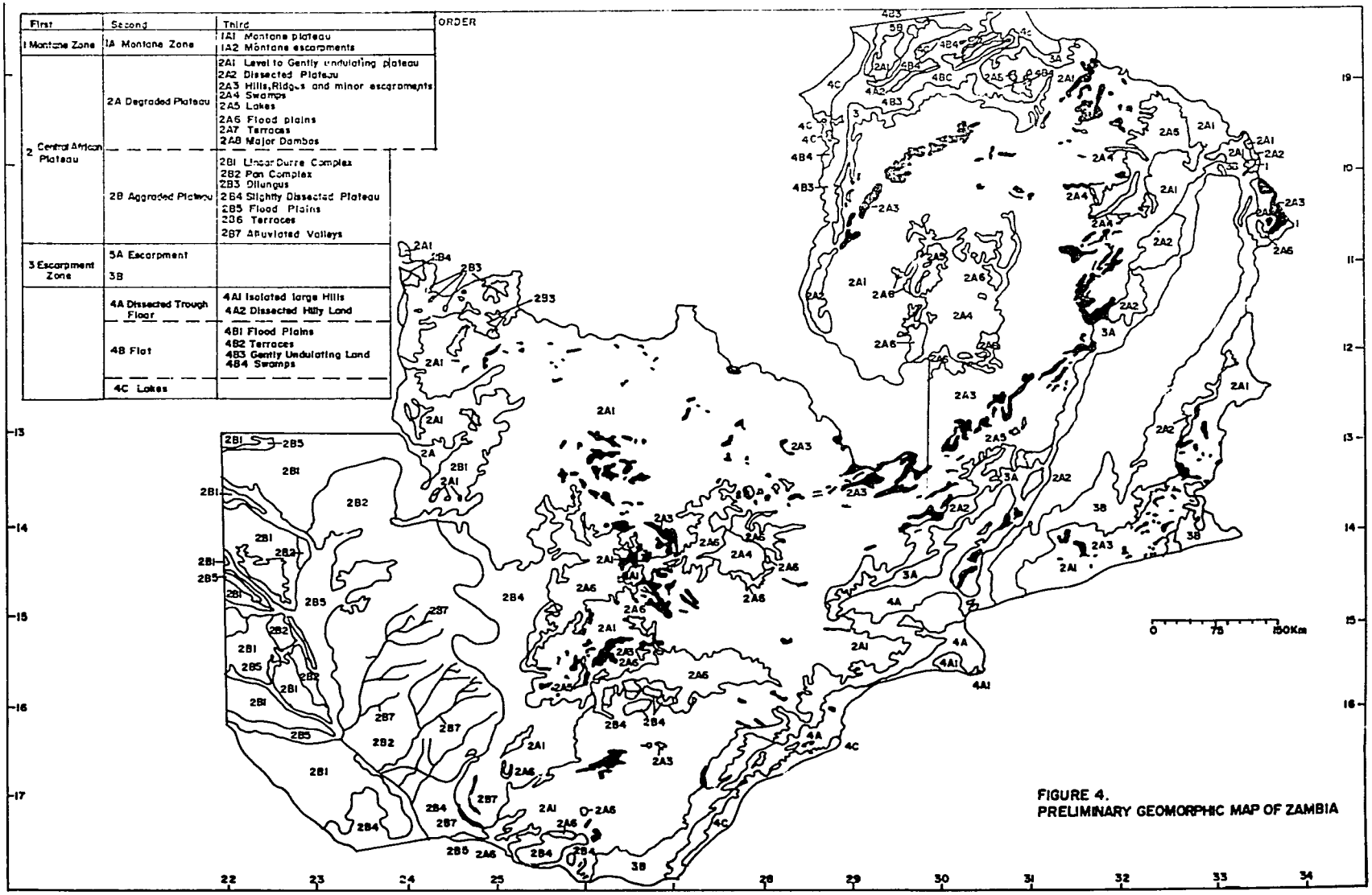
The highest parts of the plateau are found in Northern Province around Mporokoso, Mbala, Mpika and Tunduma; in Central Province around Serenje; and in North Western Province between Solwezi and Mwinilunga; where elevation exceeds 1525m (c.5000 ft) and in a few places 1650m (c.5500 ft). Dixey (1945) considers some of these higher areas to be remnants of the so-called Vipya peneplain of late Cretaceous or early Tertiary age, and Archer (1972) has postulated that they may correspond to the post Gondwana surface of King (1962) formed during the Cretaceous period. The remaining extensive areas of the Central African Plateau lie at elevations below 1525m (c. 5000 ft) and decrease in elevation towards the south and west.

Two subdivisions of the Central African Plateau are recognised in the legend (see Figure 4). Firstly, a Degraded Plateau which has resulted from cyclic processes of erosion over a long period of time on a relatively stable land mass; and secondly an Aggraded Plateau comprising sands of predominantly eolian origin.

The Degraded Plateau is found in all but the western parts of Zambia. Dixey (1945) considers much of it be part of the mid-Tertiary (Miocene) erosion surface.

A sequence of Degraded Plateau types may be distinguished. The most extensive is 'Level to Gently Undulating Plateau' with slopes rarely exceeding 3 - 5%. Interfluves are normally mantled by deeply weathered soils. This type occupies large tracts of country on the older 'erosion surfaces' on the watersheds between the main drainage systems. The latter have their headwaters in this type, usually taking the form of broad headed dambos. With increased proximity to the major river valleys there is usually a gradation into 'Undulating Plateau' with slopes in the range 3/5 - 8/12%. The interfluves are often occupied by shallow gravelly ridges. The drainage system takes the form of valley dambos or narrow stream valleys and the rivers are usually incised into the plateau. The 'Undulating Plateau' gives way, in those areas marginal to the Escarpment Zones bordering the Rift Troughs (see later), to 'Dissected Plateau' where slopes usually exceed 12% and are often very steep. This type is characterised by predominantly very shallow, stony or gravelly soils and fast flowing streams and rivers in usually v-shaped valleys. Dambos are normally absent but streams sometimes flow from seepage sites on the interfluves. Figure 5 illustrates the distribution of these main plateau types in an area near Chipata in the Eastern Province.

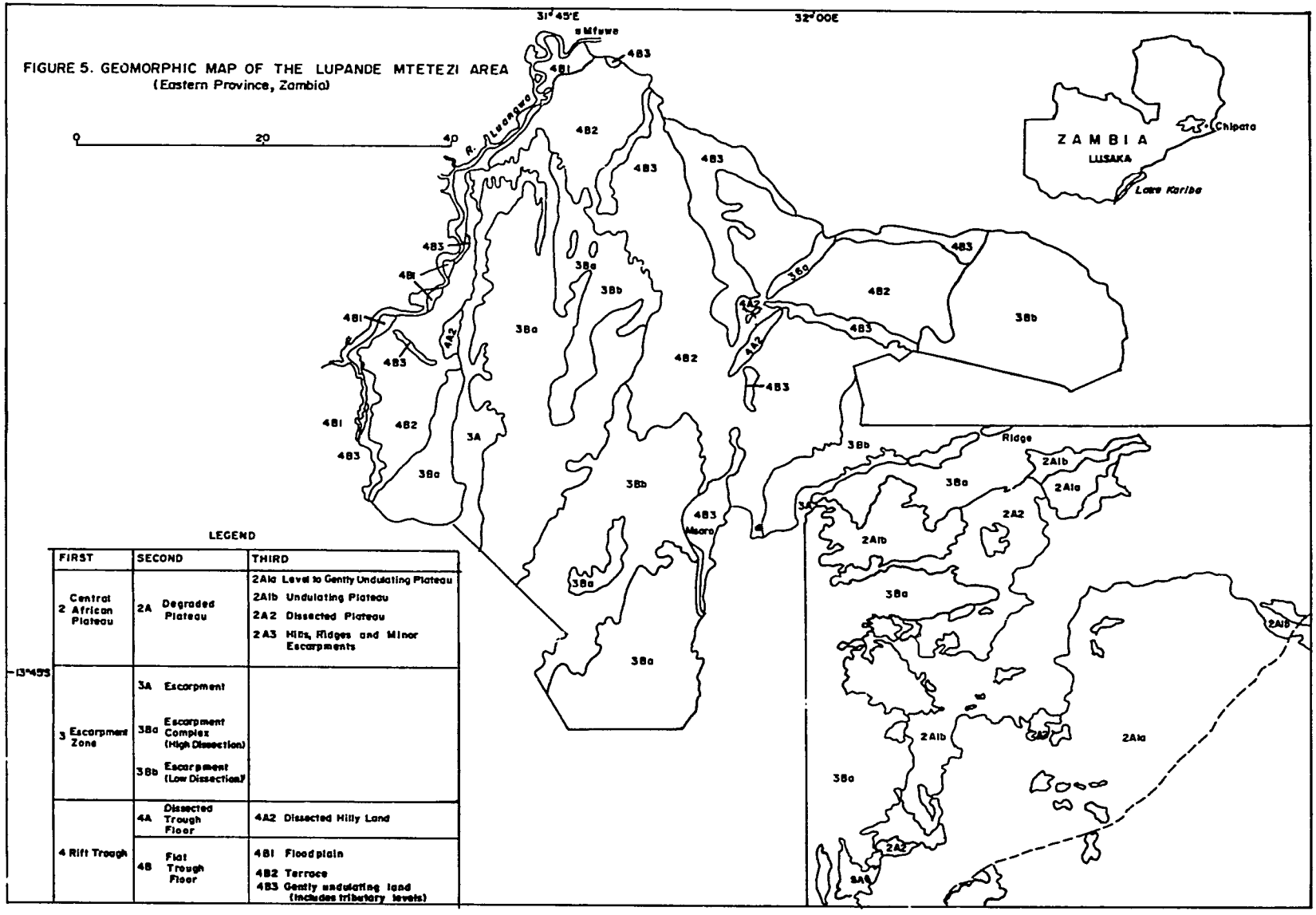
In a number of areas underlain by limestone, the 'Level to Gently Undulating Plateau' is characterised by karst features. Solution-lowered landscapes comprising sink holes and uvulas have been noted near Solwezi in North Western Province (Dalal-Clayton, 1982c; Arthurs, 1974) and similar landscapes are common near Mpongwe in the Copperbelt Province.



First	Second	Third
1 Montane Zone	1A Montane Zone	1A1 Montane plateau 1A2 Montane escarpments
2 Central African Plateau	2A Degraded Plateau	2A1 Level to Gently undulating plateau 2A2 Dissected Plateau 2A3 Hills, Ridges and minor escarpments 2A4 Swamps 2A5 Lakes 2A6 Flood plains 2A7 Terraces 2A8 Major Dambos
	2B Aggraded Plateau	2B1 Linear Dune Complex 2B2 Pan Complex 2B3 Dilungus 2B4 Slightly Dissected Plateau 2B5 Flood Plains 2B6 Terraces 2B7 Alluviated Valleys
3 Escarpment Zone	3A Escarpment 3B	
	4A Dissected Trough Floor	4A1 Isolated large Hills 4A2 Dissected Hilly Land
	4B Flat	4B1 Flood Plains 4B2 Terraces 4B3 Gently Undulating Land 4B4 Swamps
	4C Lakes	

FIGURE 4.
PRELIMINARY GEOMORPHIC MAP OF ZAMBIA

FIGURE 5. GEOMORPHIC MAP OF THE LUPANDE MTETEZI AREA
(Eastern Province, Zambia)



FIRST	SECOND	THIRD
2 Central African Plateau	2A Degraded Plateau	2A1a Level to Gently Undulating Plateau 2A1b Undulating Plateau 2A2 Dissected Plateau 2A3 Hills, Ridges and Minor Escarpments
3 Escarpment Zone	3A Escarpment	
	3Ba Escarpment Complex (High Dissection)	
	3Bb Escarpment (Low Dissection)	
4 Rift Trough	4A Dissected Trough Floor	4A2 Dissected Hilly Land
	4B Flat Trough Floor	4B1 Floodplain 4B2 Terrace 4B3 Gently undulating land (includes tributary levels)

The best known karst features are probably those located around Lusaka where both pinnacled and buried karst types are found (Williams, 1982). In these areas streams and valleys are generally absent and the drainage is indeterminate.

The main river systems of the Degraded Plateau discharge into either the Zaire (former Congo) or Zambezi rivers. The upwarped watershed between the latter two major African rivers follows the Zaire - Zambia border in the Copperbelt and North Western Provinces.

The Kafue river, which rises on the above mentioned watershed in the Copperbelt, flows with a low gradient generally south westwards. Extensive swamps occur along the river and its tributaries, notably the Busanga and Lukanga swamps, in downwarped depressions formed in the Pleistocene. At Iteshi Teshi the river turns sharply to the east and enters a vast floodplain - the Kafue Flats. To the east of Kafue town the floodplain ends as the river enters a gorge cut through a massif of ancient metamorphic rocks, through which it descends to its confluence with the Zambezi. Dams have been constructed in the Kafue Gorge and at Iteshi Teshi, forming lakes.

Most of eastern Zambia is drained by the Luangwa river and its main tributary, the Lunsemfwa. The former flows south eastwards with a steady but gradual flow, meandering in a Rift Trough to eventually join the Zambezi. There are few swamps along its course. The Lunsemfwa rises on the plateau near Mkushi and then flows southwards to fall steeply down the Muchinga Escarpment through the spectacular Wonder Gorge into a rift trough before discharging into the Luangwa.

The 'Degraded Plateau' is much more extensive to the north west of the Luangwa rift trough than to its south east, where it is restricted to the relatively narrow watershed between the Luangwa river to one side and the Zambezi river and Lake Malawi rift trough to the other. The Great East Road in the Eastern Province and the Chipata - Lundazi highway follow this watershed. The edge of the escarpment zone flanking the Zambezi trough to south is approximately marked by the Mozambique border, but is very conspicuous in the area to the south of Chipata.

To the north of the Zaire-Zambezi watershed in Northern Province, the Chambeshi flows south eastwards with a gentle gradient and is bordered by extensive floodplains. It flows into the Bangweulu swamps and is distributed across the swamps in an intricate channel system (some of which enter Lake Bangweulu itself) which appears to be a delta with close similarities to the delta of the Okovango river in Botswana where it discharges into the Okovango swamp. Old levees are clearly discernable along many of the channels within the Bangweulu swamps, and these now form a series of islands. Most of the smaller rivers arising on the surrounding plateau uplands drain internally into this swamp. The swamp and Chambeshi floodplain occupy downwarped

depressions also formed in the Pleistocene. The permanently flooded swamp is surrounded by a vast floodplain. Long beach ridges occur within Lake Bangweulu (i.e. Mbabala island) and along the western shore of the lake (i.e. Lifunge Pen).

The Luapula river flows from the south west corner of the Bangweulu swamps turning northwards to become incised. It flows over a series of falls before entering a broad rifted zone with swamps, where it eventually flows into Lake Mweru.

The second subdivision of the Central African Plateau, the Aggraded Plateau, comprises predominantly wind-blown desert sands up to 60m (c. 200 ft) thick in places (Kalahari Sands), and often overlying Karroo sediments.

The two-fold division of the Central African Plateau into 'Degraded' and 'Aggraded' plateau reflects the position of Zambia extending from the upwarp of the East African Rifted Zone in the east to the fringes of the Kalahari Basin in the west (see Figure 3). In the east, uplift stimulated erosional processes, transport of the resultant sediment being predominantly southwestwards (the formerly predominantly south west draining river system has since been disrupted by capture and diversion (de Swardt, 1967) into a vast inland drainage basin where the waters evaporated and thick sedimentary deposits accumulated. These deposits have subsequently been re-worked by wind. Thus, although predominantly aeolian in character, fluvial agencies have probably played a major role in concentrating the sediments.

A complex multigenetic origin for these surface sands has been postulated (Savory, 1963) and similar complex histories have been suggested for the related surface sands of Zimbabwe (Swift, 1961) and Botswana (Poldervaart, 1955). By contrast, Verboom (1974) has proposed an essentially alluvial or lacustrine origin for the sands, but this seems unlikely and underrates the importance of probable past changes in the areal extent of desert conditions (Williams, 1982). Williams (op.cit.), in reviewing these postulations concluded that "the deposits are polygenetic (although eolian characteristics predominate) and have formed diachronously rather than synchronously." The sands were probably deposited in the late Tertiary (possibly Pleistocene)-early Quaternary (Drysdall, et.al., 1972; Money, 1972) and cover most of Western Province and parts of North Western Province.

The Aggraded Plateau surface is a vast plain with an average elevation of 1000m (c.3300 ft) which is considered to represent the end-Tertiary (Pliocene) erosion surface of Dixey (1945).

To the west of the Zambezi the Aggraded Plateau is extremely flat forming vast plains comprising a complex of parallel dunes, individual units of which may extend for distances up to 50km (Williams, 1982), and inter-dune depressions which are waterlogged in the rainy season.

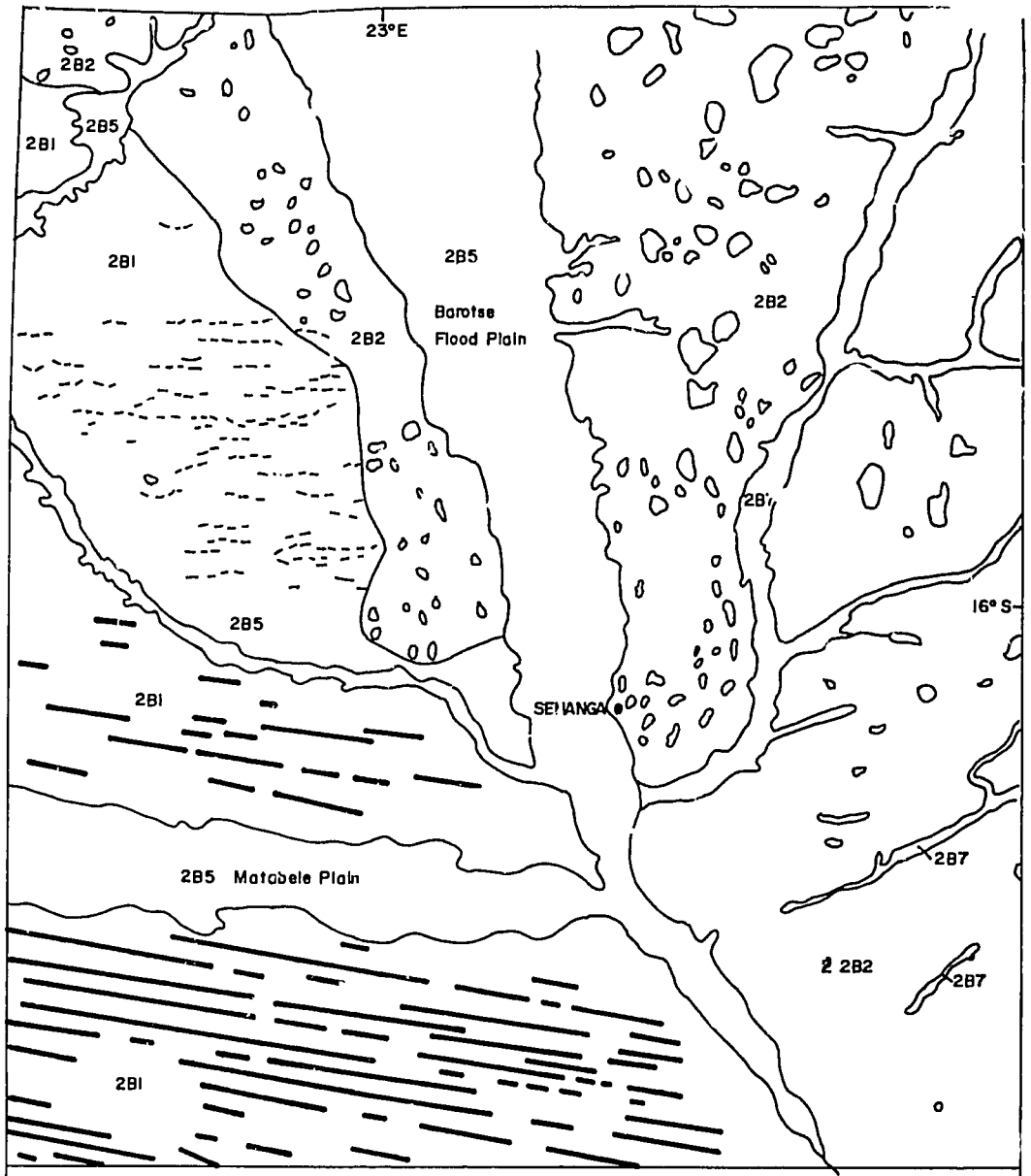


FIGURE 6. GEOMORPHIC MAP OF THE SENANGA AREA (Western Province, Zambia)

LEGEND

SECOND	THIRD	Order
2B Aggraded Plateau	2B1 Linear Dune Complex 2B2 Pan Complex 2B3 Flood plain 2B7 Alluviated Valley	

0 10 20 30 40 50Km.

Dune alignment
Other lineation
Pan

This 'Linear Dune Complex' (see Figure 6) gives way in the middle reaches of the upper Zambezi to an area of loose sands and slightly greater relief predominantly to the east of the river, where numerous depressions (pans), often circular or elliptical, characterise the interfluves. These pans may be permanently or seasonally flooded and vary between 2 - 20 sq.km in extent. Some are interconnected and integrated into the drainage pattern.

To the east, north east and south east of the 'Pan Complex the Aggraded Plateau rises gently towards the Degraded plateau and passes into a broad zone of 'Slightly Dissected Plateau' characterised by broad level interfluves comprising more compact and shallower sands, and somewhat incised valley dambos and broad flat bottomed river valleys.

Traversing the Aggraded Plateau are the long alluviated valleys of the tributaries of the Zambezi, some of which flow into the Barotse Plain - the alluvial floodplain of the upper Zambezi. These valleys are unusual in that they narrow near their confluences with the Zambezi at which point the alluvial deposits disappear. This suggests possible back-tilting of the land surface near the Zambezi. Another feature of these valleys which supports this possibility is that some of them make an abrupt turn to the south east in their lower courses to parallel the flow of the Zambezi.

To the south of the Barotse floodplain at Sioma, the Zambezi passes over the Ngonye Falls and a subsequent series of rapids until it turns abruptly eastwards to pass through a (probably) block faulted alluvial basin (the Sesheke Plain) on its way to the Victoria Falls.

The Barotse and Sesheke Plains are flooded annually, the former between February and June, the latter somewhat later. Extending from the Sesheke Plain north eastwards across the Machili basin, and from the Kafue Flats south westwards across the Nanzhila basin, are two plains developed on Karroo beds and characterised by poorly drained clays supporting mopane (Colophospermum mopane) trees. These areas appear to be former floodplains of rivers in the Zambezi and Kafue drainage systems (developed on the margins of the Kalahari sands) which formerly flowed south westwards into the Kalahari Basin and - as described above - have subsequently been disrupted and captured.

The highest parts of Zambia are located in the north east bordering Malawi where the Montane Zone exceeds 1850m (c. 6000 ft). The highest point in the country lies at an elevation of 2164m (7097 ft) at a point on the Malawi border. This Montane Zone comprises both Montane Plateau (the Nyika Plateau) and the narrow linear summits of the nearby Mafinga Hills and Makutu Mountains; and Montane Escarpment comprising the steep slopes flanking the Nyika Plateau and the precipitous flanks of the above hills and mountains. The Montane Plateau is believed by

Archer (1972) to be part of King's (1962) Gondwana surface - a remnant of the original surface of the ancient super-continent of Gondwanaland before the present continents drifted apart - formed in the Jurassic period. Dixey (1945) records that the late Jurassic peneplain is represented on the Montane Plateau areas.

In the east and south east of Zambia the continuity of the Central African Plateau is interrupted by a series of relatively deep Rift Troughs (see Figures 3,7 and 8). They are flanked by faulted Escarpment Zones comprising both steep Escarpments and broader areas of Escarpment Complex comprising deeply dissected rocky hill land.

The most prominent of the rift troughs are the Luangwa Valley and middle Zambezi valley. These are not considered to be true rift valleys since they are hinged along their south-eastern escarpments. As a result the north-western escarpments (particulary the Muchinga escarpment, which is about 600m, c.2000 ft, high) are much more precipitous than those to the south east. The south eastern flank of the Luangwa Valley, although not obviously a faulted boundary and having more subdued topography, does sharply demarcate the boundary between the Basement Complex rocks of the Central African Plateau and the much younger Karroo sediments of the valley floor.

The Luangwa Valley extends 560 km from north east to south west. In its lower reaches it converges with the middle Zambezi rift trough, part of which is occupied by the man-made Lake Kariba. Below the gorge in which the Kariba Dam is constructed, a floodplain occupies the rift trough as far as Mpata gorge. Associated with the Luangwa valley are a number of subsidiary rift troughs including the Lunsemfwa, Rufunsa, and almost parallel Lukusashi river valley.

In northern Zambia, the Sumbu - Lake Chisi rift zone is thought to be a direct extension of the "Western Rift" of the East African rift system (Mackel, 1974c) in which Lake Tanganyika is located, and consists of a belt of predominantly parallel spectacular faults (e.g. Kalaye and Kashile escarpments). Lakes Mweru and Mweru-Wantipa and their associated swamps and floodplains are located in a fault trough in this area. The Luapula river flows northwards into this rift trough around the Mambilima Falls. South of this point the river is not considered to be in a rift trough, although the eastern flank of the Luapula valley is marked by scarp slopes.

The Kafue Flats in the lower Kafue valley comprise recent alluvial sediments much of which now form the extensive floodplain of the Kafue river which is shallowly flooded annually. However, the Flats probably overly an unexcavated fault trough. According to de Swardt (1965), Karroo sediments largely underlay the more recent alluvium, and the Flats are bounded by major faults.

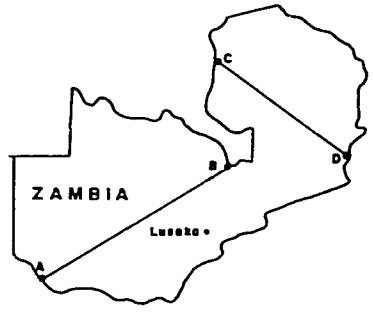


FIGURE 7. CROSS SECTION OF ZAMBIA (A — B)

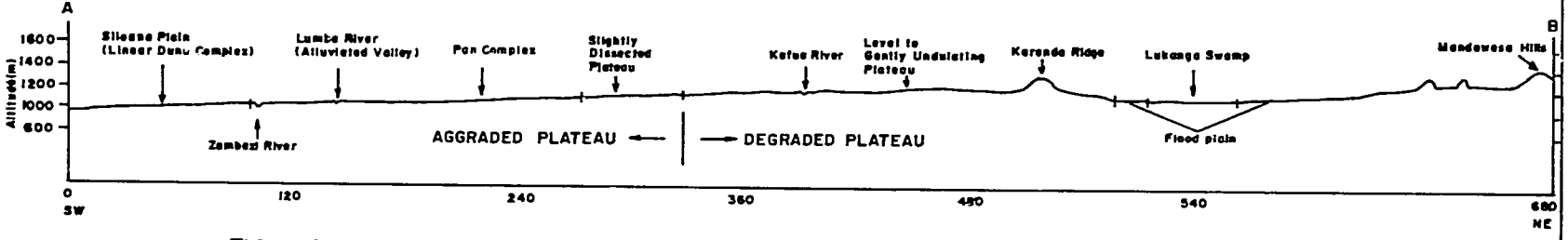
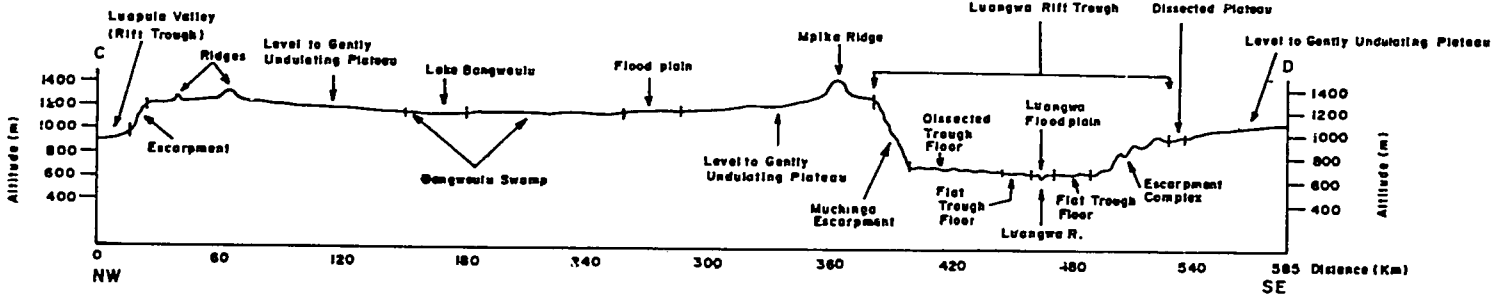


FIGURE 8 CROSS SECTION OF ZAMBIA (C — D)



There is also evidence that the Zambezi valley above Victoria Falls owes much to rift and block faulting phenomena. The alluvial basin near the confluence of the Chobe and Zambezi rivers to the east of Sesheke (the Sesheke Plain) is probably block faulted and may be related to similar structures in the lower Kafue Basin. Further north, around Mongu, block-faulted structures are suggested by Landsat imagery, accounting for the marked linearity of the scarps flanking the Zambezi floodplain.

The main faulting that initiated the Luangwa and middle Zambezi rift trough system occurred during the Karroo period (Barr and Brown, 1986), but the Lake Tanganyika rift trough is, by contrast, of more recent age, probably late-Tertiary (Archer, 1972). Faulting on the flanks of the Mweru - Mweru Wantipa trough took place in Cainozoic times (Anderson and Unrug, 1983) and probably throughout the Holocene (de Swardt, 1965), and Mackel (1974c) records that faulting in the area is still active.

The Legend

The legend outlined in this section deals with the First, Second and Third Order geomorphic units. These are shown in Table 3, whilst Figure 4 illustrates the distribution of the First and Second Order units, and some Third Order units.

1. Montane Zone (Also 1A)

This unit consists of land at an elevation generally in excess of 1850m (c.600 ft). It includes the rolling Montane Plateau surface of the Nyika Plateau and the narrow montane summits of the Mafinga Hills and Makutu Mountains. It also encompasses Montane Escarpments which include the precipitous western margin of the Nyika Plateau and the steep flanks of the above hills and mountains.

1A1. Montane Plateau

Those parts of the Montane Zone, usually at an elevation in excess of 2000m (c.6500 ft) which are characterised mainly by rolling open grasslands and by deeply incised stream valleys, with patches of relict montane forest, and seasonal swamps in low lying areas. Slope vary between 0 - 40%, but are 0 - 5% on the higher peaks of the Nyika Plateau, and on the narrow summits of the Mafinga Hills and Makutu Mountains which are included in this unit. Granitic outcrops, particularly tors, are common.

1A2. Montane Escarpment

The steep slopes marking the western margin of the Nyika Plateau and the precipitous flanks of the Mafinga Hills and Makutu Mountains, all of which are dissected by deep ravines. The elevation of the foot of these escarpment areas is variable and in some places falls to around 1500m (c.5000 ft).

Table 3: The Geomorphic Legend

FIRST	SECOND	THIRD
1:5,000,000 <----------> Approx. 1:1,000,000		
1. Montane Zone	1A. Montane Zone	1A1. Montane Plateau 1A2. Montane Escarpment
2. Central African Plateau	2A. Degraded Plateau	2A1. Level to Undulating Plateau 2A2. Dissected Plateau 2A3. Hills, Ridges, Minor Escarpments 2A4. Swamps 2A5. Lakes 2A6. Floodplains 2A7. Terraces 2A8. Major Dambos
	2B. Aggraded Plateau	2B1. Linear Dune Complex 2B2. Pan Complex 2B3. Dilungus 2B4. Slightly Dissected Pla'eau 2B5. Floodplains 2B6. Terraces 2B7. Alluviated Valleys
3. Escarpment Zone	3A. Escarpment	
	3B. Escarpment Complex	
4. Rift Trough	4A. Dissected Trough Floor	4A1. Isolated Large Hills 4A2. Dissected Hilly Land
	4B. Flat Trough Floor	4B1. Floodplains 4B2. Terraces 4B3. Gently Undulating Land 4B4. Swamps
	4C. Lakes	

2. Central African Plateau

The macro geomorphic unit of level or mainly level land, elevated in the continental interior and distinguished from the coastal lowlands from which (in many areas) it is separated by great escarpments. The plateau is traversed by rivers and, in places, by hill ranges. In the east the plateau is associated with upwarped areas of the East African Rifted Zone, whilst in the west it encompasses the extensive internally draining

Kalahari Basin. In Zambia the highest parts of this plateau are located in the extreme north and north west where elevation exceeds 1525m (c.5000 ft). There is a steady fall in elevation to the Zambezi river in the south west and south to an altitude of 600m (v.2000 ft) or less. In general the plateau is gently undulating and rather monotonous, broken only here and there in the eastern half of the country by isolated hills or hill ranges composed of the more resistant rocks. The plateau is subdivided into two major subunits; Degraded Plateau and Aggraded Plateau.

2A. Degraded Plateau

Those parts of the Central African Plateau where planation has been and remains the dominant landforming influence. These areas are traversed by a network of rivers, streams and dambos of varying drainage density. Relief is level to gently undulating where drainage density is low, and more pronounced where drainage density is high. Included in this unit are the isolated hills and ridges of the more resistant rocks (usually quartzitic) which rise above the general plateau surface, minor escarpments (not associated with rift troughs), swamps and lakes which occupy depressions, and floodplains.

2A1. Level to Undulating Plateau

Those parts of the Degraded Plateau surface characterised by level to undulating topography, usually having a dendritic drainage pattern of dambos and streams separated by level or broadly convex interfluves. Slopes rarely exceed 5% in level to gently undulating plateau areas, but may range between 3/5-8/12% in undulating areas where streams are more incised. Included in this unit are the footslopes (often comprising colluvial material) found at the foot of hills and ridges (slopes normally between 5 - 12%).

2A2. Dissected Plateau

Those parts of the Degraded Plateau surface characterised by strongly dissected topography, having a dense drainage pattern with incised, relatively steep-sided, stream valleys. Broad head dambos are mainly absent. Interfluves are generally narrow and often shallow, gravelly or rocky. This unit often occurs towards the margin of the Central African Plateau where it is transitional to the Escarpment Zone.

2A3. Hills, Ridges and Minor Escarpments

This unit comprises isolated hills (including domed inselbergs and large tors), linear ridges and hill ranges standing above the adjacent land surface and normally comprising resistant rocks with steep slopes (25 - 100 %) covered with shallow, loose (often sandy) soils, stones and rock outcrops. At the foot of the hills or ridges there is usually a zone where colluvial material has accumulated (examples: Chainama Hills near

Lusaka, Mphangwe Hill near Katete). Also included in this unit are minor escarpments (not associated with rift troughs) on the plateau surface (e.g. at Solwezi State Farm).

2A4. Swamps

Large flat depressions (usually at least 10 sq km in extent) in which the surface is permanently saturated with water and is usually overgrown with vegetation (papyrus and reeds). (Examples: Bangweulu, Lukanga and Busanga swamps).

2A5. Lakes

Large (at least 10sq km) permanent bodies of water, entirely surrounded by land, the depth of water away from the shore normally exceeding 2m (e.g. Lake Bangweulu). Lakes included in this unit may be man-made (e.g Mulungushi, Mita Hills and Iteshi Teshi dams).

2A6. Floodplains

Low-lying, level areas adjacent to rivers or swamps which are seasonally flooded due to a rise in river level or to impeded run-off. Included in this unit are oxbow lakes, flood channels, abandoned channels, and fluvial deposits such as levees, point bar deposits, back plains and sand bars. (Examples: Kafue Flats, Chambeshi floodplain).

2A7. Terraces

Level areas adjacent to river channels, lakes or floodplains, from which they are sometimes separated by an abrupt slope. They are not seasonally flooded and represent abandoned (or former) floodplains. (Example: Extensive areas adjacent to the Luangwa River in the Luangwa Valley).

2A8. Major Dambos

Low-lying, shallow, generally treeless, linear depressions, at least 1.5 km wide, which are seasonally waterlogged, and which may or may not contain drainage channels. Parts of some major dambos are sometimes permanently waterlogged, and although strictly swamps, are included in this unit.

2B. Aggraded Plateau

That part of the Central African Plateau comprising semi-consolidated or unconsolidated deep sands (Kalahari sands). This surface is characterised by extensive, level to very gently undulating plains with generally widely spaced drainage lines, and areas where complexes of dunes and pans (some containing small lakes) predominate. This surface is restricted to Western Province and parts of North Western Province. Also included in this unit are the floodplains and associated terraces of the

upper Zambezi river, and the associated tributary alluviated valleys.

2B1. Linear Dune Complex

Those parts of the Aggraded Plateau Surface found mainly to the west of the Zambezi river and characterised by parallel dunes (mainly in an ESE - WNW direction) extending for distances up to 50km (Williams, 1982) and separated by inter-dune depressions. The dunes are generally 1.5 - 2 km wide and the inter-crystal spacing is approximately 3 km (Williams, op.cit.). Relative relief is 0 - 5 m.

2B2. Pan Complex

Those parts of the Aggraded Plateau, predominantly (although not entirely) restricted to the eastern side of the Zambezi river, and characterised by numerous depressions, often circular or elliptical, occurring on the interfluves. The depressions may be permanently or seasonally flooded. The size of the pan depressions varies between 2 - 20 sq km and some (particularly near Mongu) are interconnected and integrated into the drainage pattern (Williams, 1982).

2B3. Dilungus (see Glossary for explanation of origin)

Large (usually at least 10 sq km) non linear, mainly treeless, seasonally waterlogged areas found in the northern part of Mwinilunga District. Two main types are distinguished:- (A): Those Dilungus having low relief, commonly traversed by perennial streams. Some of the larger ones contain east-west aligned dunes. (B): Those Dilungus which occur either on (flat) interfluves not surrounded by Kalahari sands, or extending between drainage lines and interfulve upper slopes (0 - 5% slopes).

2B4. Slightly Dissected Plateau

Those parts of the Aggraded Plateau with a sub-dendritic to sub-parallel drainage pattern, with level to slightly covex interfluves, and a relative relief of 5 - 50 m (c.15 - 150 ft). Slopes vary between 0 - 8% but are mainly less than 1%. Drainage lines comprise both narrow valley dambos and broader flat-bottomed valleys. Also included are minor escarpments bordering floodplains, isolated dunes and isolated pans.

2B5. Floodplains

Low-lying, mainly level areas adjacent to rivers which are seasonally flooded due to a rise in river level. Included in this unit are river courses, oxbow lakes, flood channels, and fluvial deposits such as levees, point bar deposits, back plains and sand bars. (Examples: Zambezi floodplain; Luena Flats).

2B6. Terraces

Level areas adjacent to river channels, lakes or floodplains, from which they are usually separated by an abrupt slope. They are not seasonally flooded and represent abandoned (or former) floodplains.

2B7. Alluviated Valleys

Incised valleys, filled with alluvial sediments. They are characteristically flat bottomed and do not flood annually. They are located exclusively to the east of the Zambezi river in areas lacking linear dunes.

3. Escarpment Zone

A zone transitional between the Central African Plateau and the major rift troughs, characterised by steep escarpments and by a complex of dissected rock hill land.

3A. Escarpment

A linear, abrupt, steep slope terminating the elevated surface of the Central African Plateau, formed mainly (in Zambia) by major faulting and modified by subsequent erosional processes. (Example: Muchinga escarpment).

3B. Escarpment Complex

A broad zone comprising deeply dissected rocky hill land, v-shaped valleys and gorges, forming a complex descent from plateau to rift trough. The whole zone is one of active erosion and is cut by perennial and ephemeral streams and rivers.
(Example: The area between Chipata and the Luangwa Valley). It is possible to distinguish between those areas of Escarpment Complex which are characterised by a relatively high degree of dissection and those which have a low degree of dissection. This distinction is made in Figure 5.

4. Rift Troughs

This unit is confined to the floors of those large valleys which have been formed mainly by the sinking of land surfaces between two roughly parallel faults or by the uplift of surrounding blocks of land. The faulting in some places (e.g. the eastern flank of the Luangwa Valley) is not always particularly obvious. In Zambia the elevation of the trough floors is generally below 650 m (2132 ft), the lowest point being 325 m (1030 ft) at the confluence of the Luangwa and Zambezi rivers. (Examples: Luangwa, Luano, Sumbu - Lake Chis, and Lake Tanganyika troughs).

4A. Dissected Trough Floor

Areas comprising (A) isolated large hills which are outliers of the Central African Plateau, and (B) dissected hilly land underlain by Karroo sediments.

4A1 Isolated Large Hills

Outlying hills of the Central African Plateau which rise to an elevation normally in excess of 700 m (c.3000 ft) and have a relative relief of 200 - 300 m (c.650 - 1000 ft). (Examples: Kililangoma and Kasafu hills in Luano valley).

4A2. Dissected Hilly Land

Areas underlain mainly by relatively soft Karroo sediments with generally moderate relief (30 - 120 m ; 100 - 400 ft and comprising a complex of cuestas, homoclinal ridges and hills (some isolated), together with some flat plateau areas, dambos, footslopes and fans along the base of the escarpments. Davison (1981) describes this unit as being characterised by many ephemeral streams and by shallow stony or rocky soils, and represents areas where active erosion of Karroo sediments is still taking place. It usually commences at the foot of the escarpments and extends towards the trough centres to varying extents.

4B. Flat Trough Floor

This unit comprises (A) alluvial areas including floodplains and broad alluvial terraces, (B) flat to very gently undulating, non-dissected land underlain by Karroo sediments, and (C) swamps.

4B1. Floodplain

A strip of relatively flat land adjacent to a river channel, formed from river sediments and subject to frequent (usually annual) flooding. Included in this unit are river courses, oxbow lakes, flood channels abandoned channels, backplains and sand bars.

4B2. Terraces

Flat or very gently sloping plains with widely spaced drainage lines, abandoned following river incision into former floodplains, and modified (in some places) by the accumulation of colluvium from the Dissected Trough Floor. This unit is subjected to infrequent flooding.

4b3. Gently Undulating Land

Those areas of the Flat Trough Floor underlain by Karroo sediments and which are non-dissected or very weakly dissected. They are characterised by very gently undulating topography with

both low and convex interfluves, river and stream channels, shallow (concave or flat) valleys and dambos.

4B4. Swamps

Large flat depressions (usually at least 10 sq km in extent) in which the surface is permanently saturated with water and is usually overgrown with vegetation (papyrus and reeds). (Example: Mweru Wantipa swamp).

4C. Lakes

Large (at least 100 sq km) permanent bodies of water, entirely surrounded by land. (Examples: L. Tanganyika, L. Mweru Wantipa, L. Kariba (man made).

Glossary of Terms

Note: This glossary provides definitions or explanations of those somewhat local geomorphological terms used in the text (Ed).

Central African Plateau

The continental geomorphic unit of level or mainly level land at an average elevation of 1200 m (c.4000 ft) which extends through much of the central African region. It is characteristically traversed by rivers and the smoothness is occasionally interrupted by ridges and hill areas which rise above its surface. The plateau is bordered by escarpments and interrupted by rift troughs.

Dambo

Dambos are a characteristic feature of the level to gently undulating plateau areas of Zambia and surrounding Central African countries. The term 'dambo' is a widely used Bantu expression, employed by local populations to indicate a variety of seasonally wet grass-covered and treeless areas such as floodplains or valley floors. It was first used in scientific literature by Ackermann (1936) to describe "periodically inundated grass covered depressions on the headwater end of a drainage system in a region of dry forest or bush vegetation". A variety of definitions exist for 'dambo' and these have been discussed in detail by Mackel (1974a) and more recently by Whitlow (1984).

In Zimbabwe they are known as vleis (an Afrikaans word meaning marsh or swamp) and this term appears frequently in the older literature on Zambia. The standard definition of vlei, provided by Rattray et.al. (1953), states that a vlei is "a low-lying, gently sloping treeless tract of country which is seasonally waterlogged by seepage from the surrounding high ground assisted by rainfall and which frequently contains the

natural drainage channel for the removal of excess run-off from the surrounding high ground". However, Whitlow (1984) has recently proposed to drop the term 'vlei' in Zimbabwe in favour of 'dambo', particularly in view of the increasing use and acceptance of the latter term amongst scientists, especially those in earth sciences and related fields.

The new Penguin Dictionary of Physical Geography (Whittow, 1984) describes 'dambo' as "a shallow streamless depression at the headwaters of a drainage system, in which no actual channel can be identified. The term has been specifically applied to phenomena in tropical Africa but it has been widely recognised (under different names) in other parts of the world outside the tropics."

However, in Zambia dambos often carry a drainage channel and the following definition is used in this Geomorphic Legend. " A low-lying, shallow, generally treeless, linear depression, which is seasonally waterlogged and which may or may not contain a drainage channel".

Dilungu

A vernacular (Lunda) term for large, non linear, mainly treeless, seasonally waterlogged areas found in the northern part of Mwinilunga District and in neighbouring Zaire. Two main types are distinguished and defined in detail as Unit 2B3.

Sterckz and de Ploey (1973) record that this term is also used across the border in Zaire to describe "monotonous steppic grasslands which cover the very flat plains on the divides and during the wet season become marshy".

Trapnell et.al. (1937) called these features 'watershed dambos', but this term is likely to be misleading now that the term dambo has become an accepted term for linear seasonally water logged depressions.

Dilungus differ from the pans of Western Province in that they are relatively shallow and underlain by sheet laterite, are much larger in size, and are not characteristically circular or elliptical.

Gondwanaland

The name given by A. Wegener to the hypothetical southern hemisphere 'super-continent' consisting of South America, Africa, Madagascar, India, Arabia, Malaya and the East Indies, New Guinea, Australia and Antarctica, prior to its break up under the forces causing 'continental drift'. It corresponds to 'Laurasia' in the northern hemisphere (Whitten and Brooks, 1973).

The two 'super-continents' together formed Pangaea, the hypothetical enormous primeval land mass, surrounded by a

hypothetical sea known as Panthalassa

Kalahari Sands

A term given to the deep sands which mantle most of the Western Province and parts of the North Western Province. These have been subject to eolian re-working and are predominantly aeolian in character at present, but concentration as a result of river transportation in the first instance seems likely.

They often overlie Karroo Sediments and are up to 60 m (c.200 ft) thick in places. As the name suggests, the Kalahari sands are considered to have once formed part of a vast desert, of which the present Kalahari desert of Botswana and Namibia is a remnant. The term 'Barotse sands' is sometimes used synonymously for Kalahari sands, after Barotseland - the former name of Western Province.

Kopje

An Afrikaans term used synonymously with inselberg, and particularly with and to.

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THE AGROCLIMATE OF ZAMBIA

M.R. Muchinda and O.C. Spaargaren

Introduction

Soil characteristics are mainly due to climatic factors, livging organisms, parent rock material, time, and topography. The climatic factor is the most important, for not only does it influence the nature of weathering of the underlying rock but also the topography, the vegetation on the soil and the living organisms in the soil. The two most important features of climate are rainfall and temperature. In Zambia the decisive climatic factor is rainfall which has affected the degree of soil weathering and leaching. In Southern Zambia where the mean annual rainfall (see Fig. 1) is under 800mm these processes are slower than in the rainier north and northwest where rainfall exceeds 1,400mm (Mackel, 1971)

Temperature affects the rate of weathering, the weathering being more rapid with higher temperatures. The microclimate as observed from weather stations is closely related to the microclimate of the soil of a given region. Soil temperature in particular plays an important part in crop growth and nutrient uptake. It may be a crucial factor in the survival and efficiency of rhizobial inoculations of legumes, for instance. The rate of soil chemical and biological processes such as organic matter decay depends on soil temperature. ater soil temperatures and soil moisture and their implication for Soil Taxonomy classification will be discussed in more detail.

Closely related to effects on the infiltration capacities of various soils is the rainfall intensity. Rainfall intensity generally varies with the altitude, the lower altitudes having a higher intensity. The higher the intensity the greater will be the erosive power of the rain and in most tropical countries, including Zambia, rainfall intensities exceeding 25mm/hr are not uncommon. This is particularly true of the low drier areas where the vegetative cover tends to be sparse and although the rainfall is low, the intensity is high, resulting in soil erosion.

Zambia's Agroclimate

On the basis of rainfall and temperature patterns, the year can de divided into 3 distinct seasons:

(a) a cool and dry season (April - August)
(b) a hot and dry season (September - October)
(c) a warm and wet season (November - March)

Fig. 1

REPUBLIC OF ZAMBIA
MEAN ANNUAL PRECIPITATION
FOR THE PERIOD 1940—1970

In accordance with local practice the entire period (April-Oct.) of the dry season is referred to as the Irrigation Season and the warm and wet season (November - March) as the rainy season. The rainy season is the main crop growing season.

In Zambia, the mean annual temperatures fall within the range 18-22deg C except in the major river valleys, notably Zambezi, Luangwa and Luapula where they may be higher.

The mean maximum temperature during the warmest part of the year (October) does not exceed 35deg.C and the absolute maximum temperature is normally below 40deg.C. The mean monthly minimum temperature during the coolest months, June and July varies between 3.0 - 12.3deg.C. Frost (ground frost) occurs during the months of May, June, July and August but it is primarily confined to the region west of longitude 29deg.E, particularly on the poor heat retaining Kalahari sands of the Southwestern region (Hutchinson, 1974). (see Fig.2).

During the dry season there is little cloud cover and bright sunshine is usually in excess of 8 hours per day. It often falls to half this value during the rainy season. Daily relative humidities in July range from 60 to 80% in the early morning and from 20 - 40% in the afternoon except in the vicinity of lakes and permanent swamps where the values are higher. On an annual basis the mean relative humidity varies between 55% in the drier southern and southwestern parts of the country to 72% in the north. The wind during the dry season is predominantly from the east throughout the country but during the rainy season northeasterlies and northwesterlies also prevail; windspeeds are generally light except during gusts often associated with thunderstorms.

Rainfall

It has been noted from Fig. 1 that the mean annual rainfall is considerably higher in the north and northwest of Zambia (about 1400mm), decreasing to about half this value in the south and southwestern parts of the country. The rainy season normally begins in November and tapers off at the end of March. The dependability of seasonal rainfall in Zambia has been analyzed at the 70% probability level, but the mapping of these values is complicated by variations in the length of the wet season from place to place and in the length of the growing season required by various crops (Veldkamp et.al., 1984)

The mean annual rainfall (P) shown in Fig. 1 has a dependable rainfall of only 500 - 1100mm and the variation of crop yields about the mean therefore tends to be much greater than it is in the temperate areas for instance.

FIG. 2

AVERAGE NUMBER OF DAYS OF FROST PER YEAR

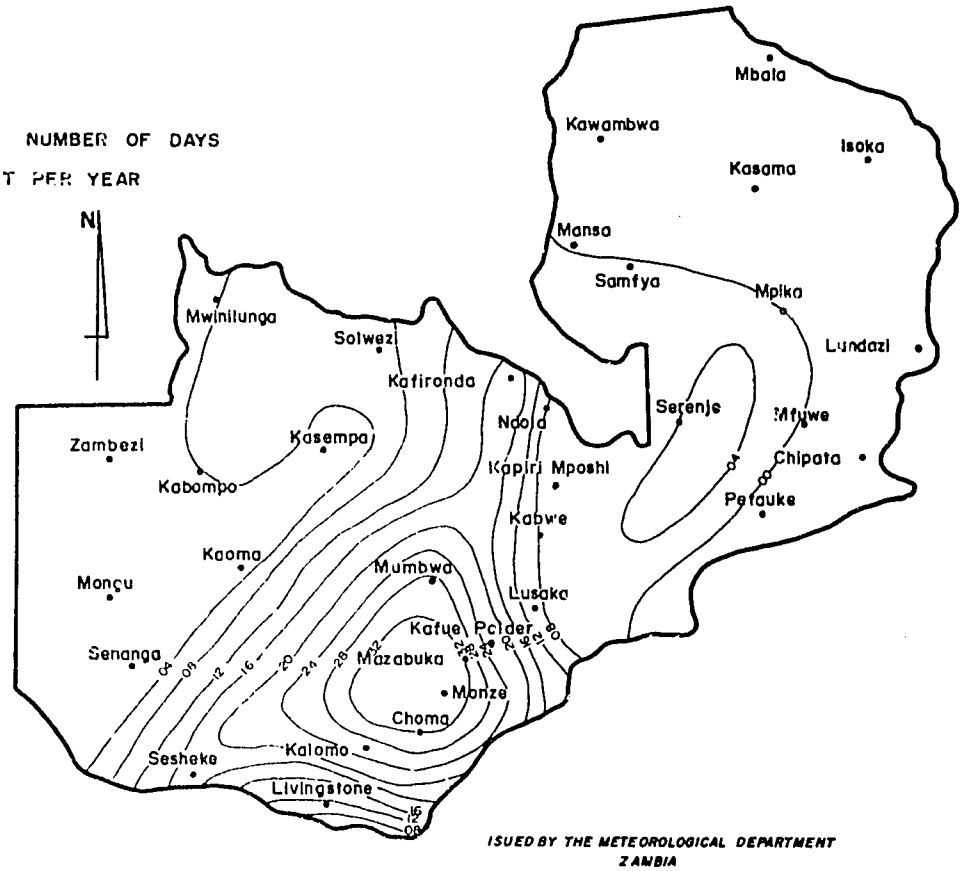
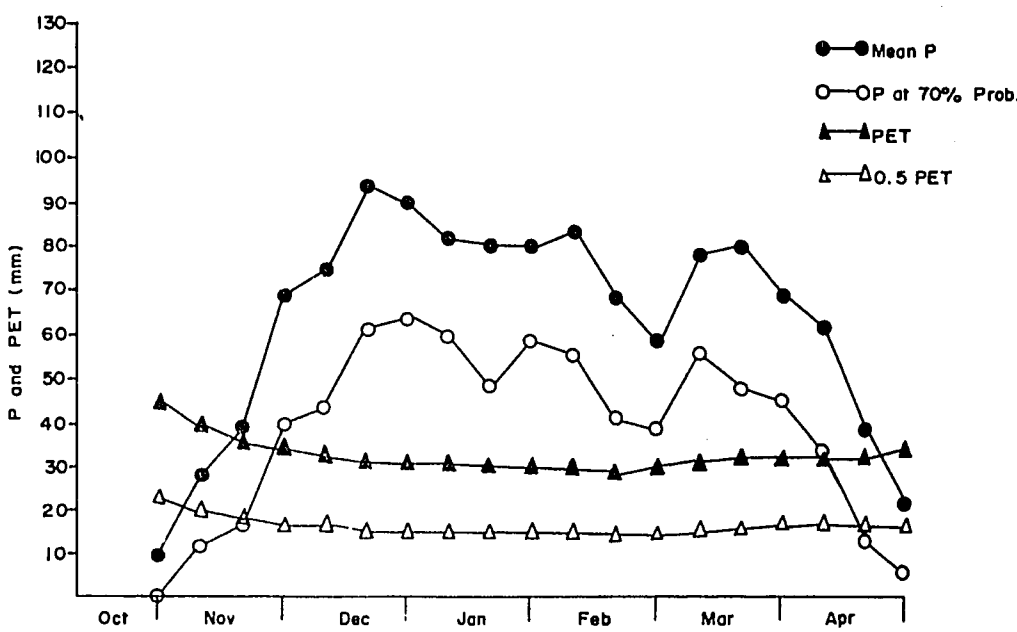


FIG.3 Water balance diagram for Mbala



Just as it is important to assess dependable or reliable rainfall, it is also useful to determine the reliable length of the growing season. Veldkamp et.al. (1984) included soil moisture storage capacity in the determination of the length of the growing season for 29 stations by taking half of the estimated available water holding capacity of the soil up to 1.0m depth and to divide this value by the potential evapotranspiration (PET) at 70% probability. Based on this information and on dependable rainfall, the length of the growing season in Zambia ranges from 85 - 190 days.

The starting decade of the growing season in Zambia based on the $P \geq 0.5$ PET assumption, varies from the first decade of November in the north and northwest to the second decade of December further south. However it has been observed that farmers in the Southern Province tend to plant earlier, on the first good rains (Veldkamp, personal communication). The rainfall stability and reliability in most areas of Zambia is very good (Muchinda, 1985) except in the Southeastern and extreme Southern parts of Southern Province, the southwestern parts of Western Province and along major river valleys - these areas often suffer from dry spells (particularly on lighter soils) during the crop growing season and the rainfall (70% prob.) rarely exceeds or does not exceed potential evapotranspiration (PET). This is clear from Figs. 3,4 and 5 which serve to illustrate the different water balances from the wetter north, the intermediate central region, and the drier south, respectively.

Zambia's Pedoclimate

Two pedoclimatological elements are used extensively in soil Taxonomy: the soil moisture regime and the soil temperature regime.

The soil moisture regime is a function of the precipitation, the groundwater behaviour and flooding. Where groundwater or flooding does not play a role, soils in Zambia have an ustic soil moisture regime, according to the following description in soil Taxonomy (1975. p. 56): "If the mean annual soil temperature is 22deg.C. or higher or if the mean summer and winter soil temperatures differ by less than 5deg.C. at a depth of 50cm (these temperature requirements apply to the whole of Zambia) the soil moisture control section in an ustic moisture regime is dry in some or all parts for 90 or more cumulative days in most years. But the moisture control section is moist in some part for more than 180 cumulative days, or it is continuously moist in some parts for at least 90 consecutive days". This latter provision applies to Zambia during the rainy season.

Consequently most upland soils in this country fall in the Ustox, Ustalf, Ustult, Ustert and Ustoll suborders or in the Ustochrept, Ustropept, Ustifluvent, Ustorthent and Ustipsamment great groups.

FIG. 4 Water balance diagram for Mt. Mukulu

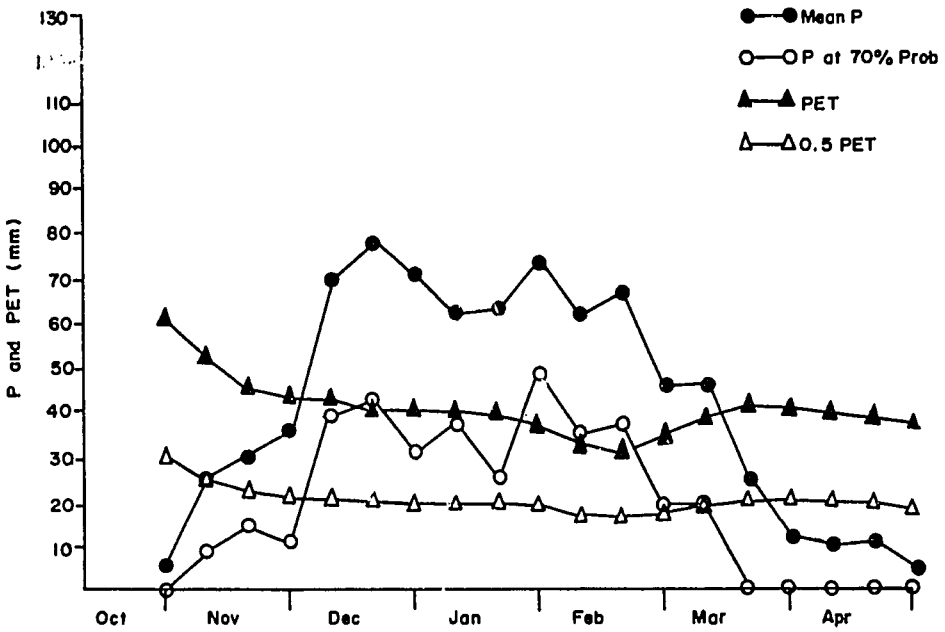
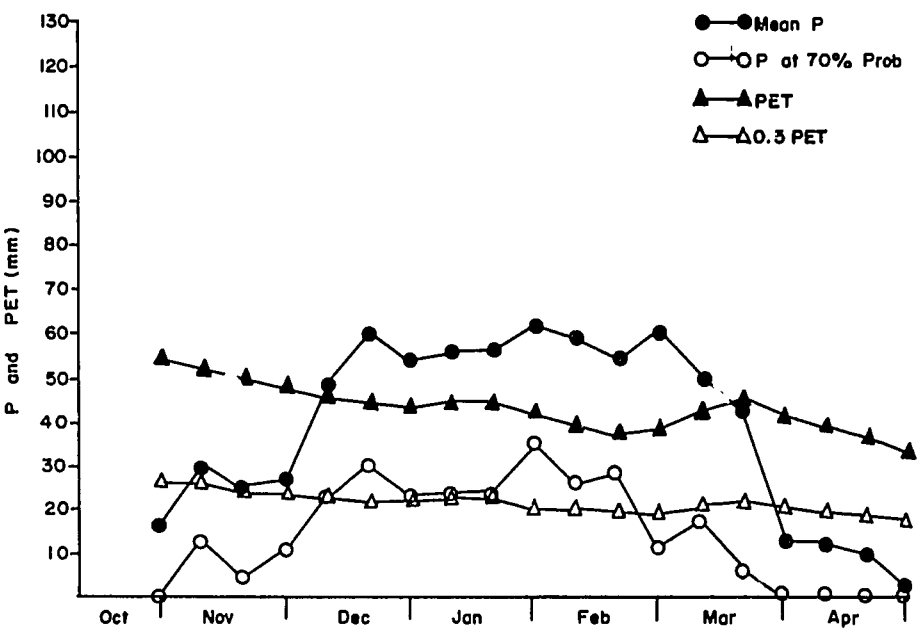


FIG. 5 Water balance diagram for Sesheke



Where groundwater plays a role or where lands are flooded aquic and udic soil moisture regimes occur. Soils in which the groundwater reaches a level of 10 - 30 cm below the surface for at least a couple of days, are aquic suborders. Therefore soils in floodplains and dambos frequently classify as Aquents, Aquepts, Aqualfs, Aquults of Aquolls.

Udic moisture regimes in Zambia are rare and are also related to the presence of groundwater. If the groundwater is so deep that the capillary fringe does not reach the surface (required for the aquic moisture regime), but sufficiently shallow to keep the soil moisture contol section moist throughout by capillary action for at least 27C days in most years, the soil has an udic moisture regime. These kind of soils, which often classify as aquic subgroups, occur in seepage zones along wet dambos, along high river banks and possibly also in dambos and river plains with a semi-deep, not much fluctuating groundwater level. The "udic" character of the soil often shows by brighter colours as compared to the more pale "aquic" colours. Although not extensive, these soils are agriculturally important as they can be cultivated throughout the year without irrigation.

Possibly aridc or torric soil moisture regimes occur locally in the extreme south of the country. From climatic point of view the erratic rainfall with significant dry spells during the rainy season contributes to this possibility. The soil moisture control section in soils with a low water holding capacity may then be "never moist in some or all parts for as long as 90 consecutive days when the soil temperature at a depth of 50 cm is above 8deg. C.", while the soil moisture control section is "dry in all parts more than half the time (cumulative) that the soil temperature at a depth of 59 cm is above 5deg. C.".

Consequently we may expect in the extreme south of the country locally the occurrence of Aridisols.

Three "official" soil temperature regimes occur: isothermic, isohyperthermic and hyperthermic. The isothermic soil temperature regime occurs around Solwezi in Northwestern Province and on the Nyika Plateau. Of these Solwezi is marginally isothermic, with a mean annual soil temperature close to 22deg. C.

In Southern Province, the southern part of Western Province and Lusaka Province, except the plateau around Lusaka, a hyperthermic soil temperature regime prevails.

The rest of the country has an isohyperthermic soil temperature regime.

Special areas are the large valleys, the Luangwa, Gwembe and Luapula Valley. The scarce data of these areas give mean annual soil temperatures well over 28deg.C. This 28deg C limit seems to be an important boundary. Above it conditions become marginal

for crops like maize, soybean and potato and tree crops like apples and peaches, while these high temperatures become optimal for cotton, banana and pineapple.

The 28deg.C has also been found in Venezuela to be an important ecological boundary. Therefore the large valleys are separated in Zambia and soils there are regarded as having a "megathermic" soil temperature regime, following proposals made by the Venezuelans.

As far as we have data now, the southern part of Luangwa Valley and the Gwembe Valley appear to have a "megathermic" soil temperature regime, while the northern part of the Luangwa Valley and the Luapula Valley appear to be "isomegathermic". So in Zambia the following soil temperature regimes are distinguished (see also fig. 6):

Hyperthermic	22-28deg.C MAST Difference MSST and MWST more than 5deg C	Southern Province, Lusaka Province (except the plateau around Lusaka), southern part of Western Province
Megathermic	more than 28deg.C Difference MSST and MWST more than 5deg.C	southern part of Luangwa Valley and Gwembe Valley
Isothermic	15-22deg.C MAST Difference MSST and MWST less than 5deg. C	Areas around Solwezi and the Nyika Plateau. Solwezi area is marginally isothermic
Sohyperthermic	22-28deg.C MAST Difference MSST and MWST less than 5deg. C	Rest of the country except Luapula Valley and the northern part of Luangwa Valley
Isomegathermic	more than 28deg.C Difference MSST and MWST less than 5deg. C.	Luapula Valley and the northern part of Luangwa Valley

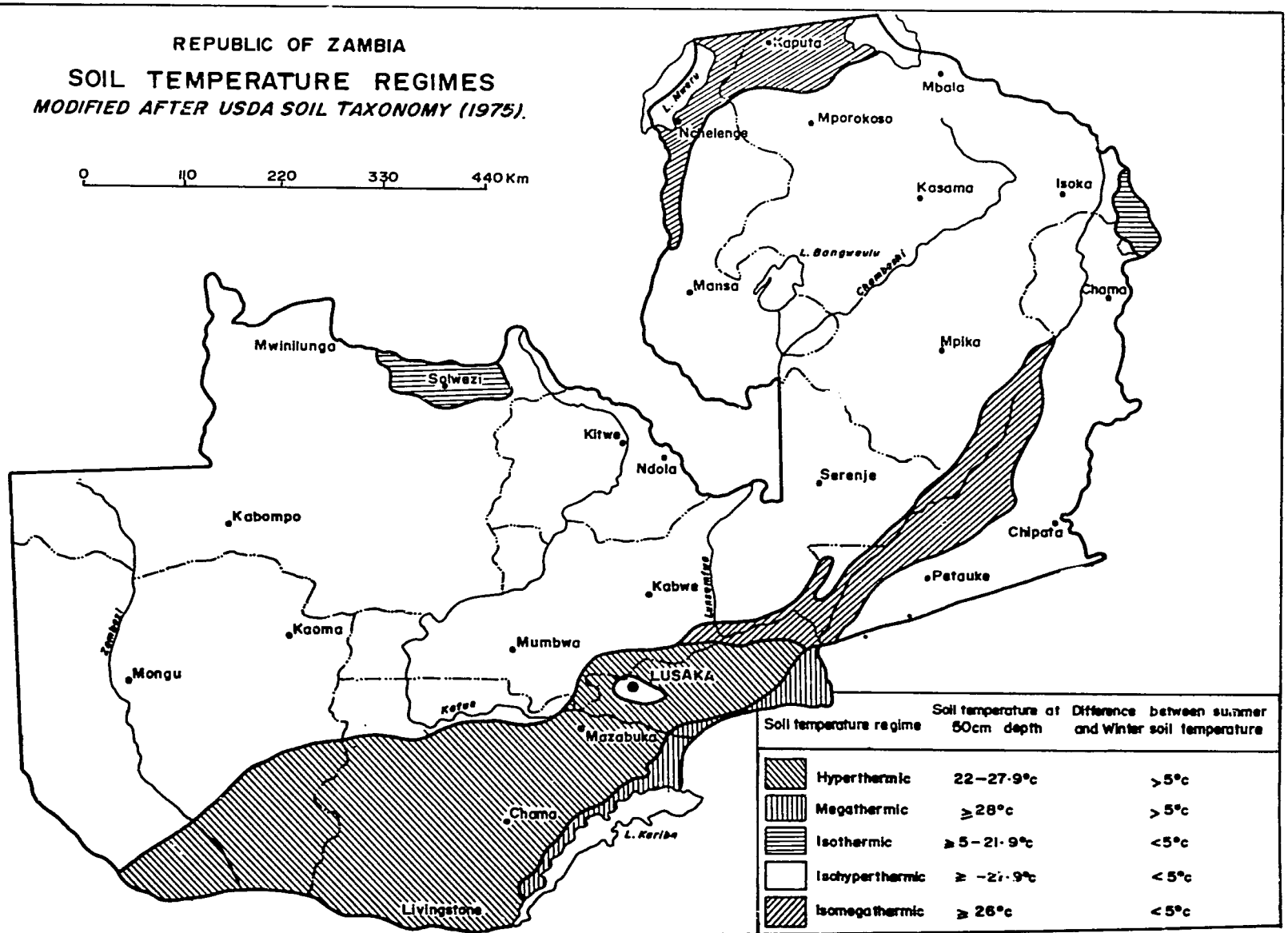
These temperature regimes are valid only for moderately well or better drained soils. In imperfectly and poorer drained soils the soil temperature fluctuations are dampened by the water. Imperfectly drained soils are included as these are wet at least during the summer months, which means that the mean summer soil temperature is lowered by some 2deg. C. As in the hyperthermic and megathermic areas the difference between the mean summer and mean winter soil temperature does not exceed 7deg. C, the imperfectly and poorer drained soils can be regarded as having isohyperthermic and isomegathermic soil temperature regimes in the respective areas.

Fig. 6.

REPUBLIC OF ZAMBIA

SOIL TEMPERATURE REGIMES

MODIFIED AFTER USDA SOIL TAXONOMY (1975).



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THE VEGETATION OF ZAMBIA

F.K.M. Shalwindi

Introduction

Vegetation Studies started during the colonial days in the 1930's. Trapnell and Clothier carried out studies on soils, vegetation and agricultural systems of the Western half of Zambia (by then known as North-Western Rhodesia). Their field investigations were undertaken during the period 1932 to 1934. The original report on their work was published in 1937 and the second edition was printed in 1957. From 1937 to 1940 Trapnell carried out investigations on the same subject in the Eastern half of Zambia (North-Eastern Rhodesia). The first report on his work was published in 1943 and this was reprinted in 1953. accompanying the two reports is the Vegetation-Soil Map of Zambia (Northern-Rhodesia) printed in 1962.

Astle (1963) studied the grass cover of the Chambeshi Flood Plains in Northern Province. Fanshawe (1969) carried out observations and studies on the vegetation of Zambia. Verboom (1960-63), 1964, 1970-72) surveyed the grasslands of Eastern, Western, Southern, and Central Provinces of Zambia. Ferreira and Shalwindi (1975) studied the Vegetation of Mbala Ranch, Northern Province and assessed its value as grazings. Heery (1976-79) studied the vegetation of Dambos around Choma in Southern Province. Jeanes (1985) carried out botanical surveys in Senanga District (West of the Zambezi River) in Western Province.

Information used in the preparation of this paper has been gathered from published sources which include the reports mentioned above. In this paper, the physical environment is discussed and this is followed by a general account of the vegetation of Zambia. For details on the vegetation see Fanshawe (1969), Trapnell (1953) and Trapnell/Clothier (1957). However, it should be pointed out that these workers used different approaches in their studies. Fanshawe in studying and classifying the vegetation used the physiognomic approach. Trapnell and clothier used the phyto-sociological method (plant associations). It should be noted that some of the botanical names used in Trapnell and Trapnell/Clothier reports are out of date. For example:- Afrormosia angolensis is now called Pericopsis angolensis.

Only the physiognomic types which are commonly known are described in this paper. A general map of the vegetation of Zambia is attached hereto (see figure 3).

Location, Area, Relief, Soils and climate.

Zambia lies roughly between latitudes 8deg. 15' and 18deg. 7' south of the equator. The country is surrounded by eight neighbors and these are Zaire, Tanzania, Malawi, Mozambique,

Zimbabwe, Botswana, Namibia and Angola.

The total geographical areas of Zambia is 75.26 million hectares. Total land area amounts to 74.34 million hectares. The area covered by water bodies (lakes, Swamps and Rivers) is about 0.92 million hectares (See Land Utilization table - figure 4).

Zambia's relief is made up of a series of gently undulating to flat plateaux and these are broken by hills here and there. The lowest ground is found at the confluence of the Luangwa and the Zambezi Rivers. It is 325 metres high - above sea level. the highest point is found near the border with Malawi to the North-Eastern side of the country. It is 2,164 metres high (see figure 1).

The bulk part of Western Province is covered by infertile sands of the Kalahari type. This soil type has little organic matter. The base exchange capacity is extremely low. They are acidic in nature.

Sodium affected mopane soils are found in the Zambezi, Luangwa and Lunsemfwa Valleys. Areas covered by fertile alluvial soils are found along rivers.

The Southern and Eastern plateaux, and the main plateau area which extends from Kabwe (Central Province) to Isoka (Northern Province) have similar soils. The soils are shallow, fine textured, structureless and are poor in nutrients and the humus content is low. Soil pH in the Northern half of the country is lower than that of the southern half.

In the Lake Basin areas of Northern and Luapula Provinces are found sandy soils. These are acid and infertile.

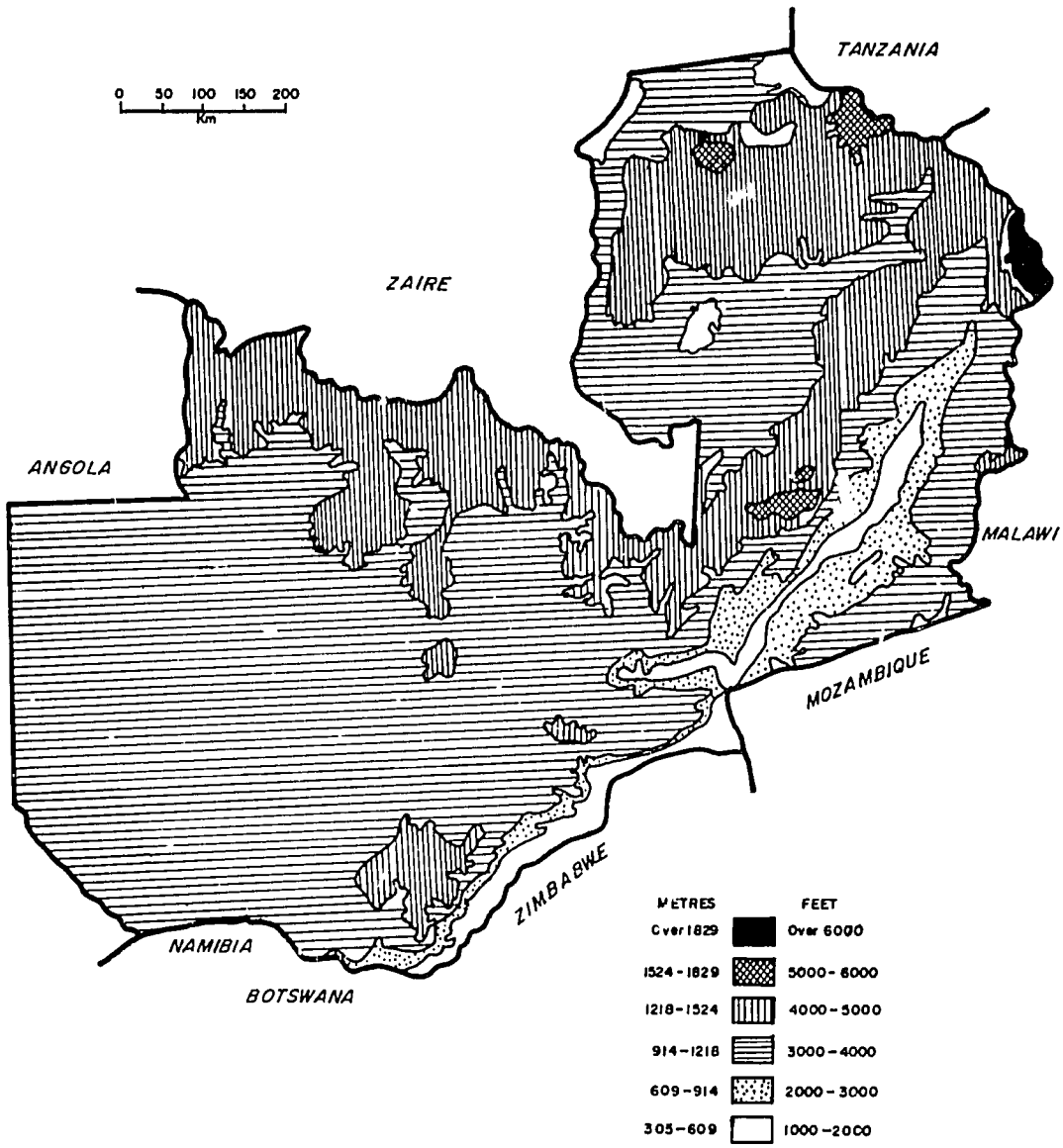
Parts of Southern, Central and Lusaka Provinces are occupied by clays and heavy sandy clays. These soils have a higher base exchange capacity. Similar soils are found in Eastern Province.

Zambia has a tropical type of climate. The rainy season starts in November and ends in April. This is followed by a dry winter until August and then a hot dry season sets in which lasts about two and half months. The southern half of the country receives less rainfall than the Northern half. Annual rainfall totals in the south range from 635mm to 1,015mm and in the north they range from 1,015mm to 1,520mm (fig 2).

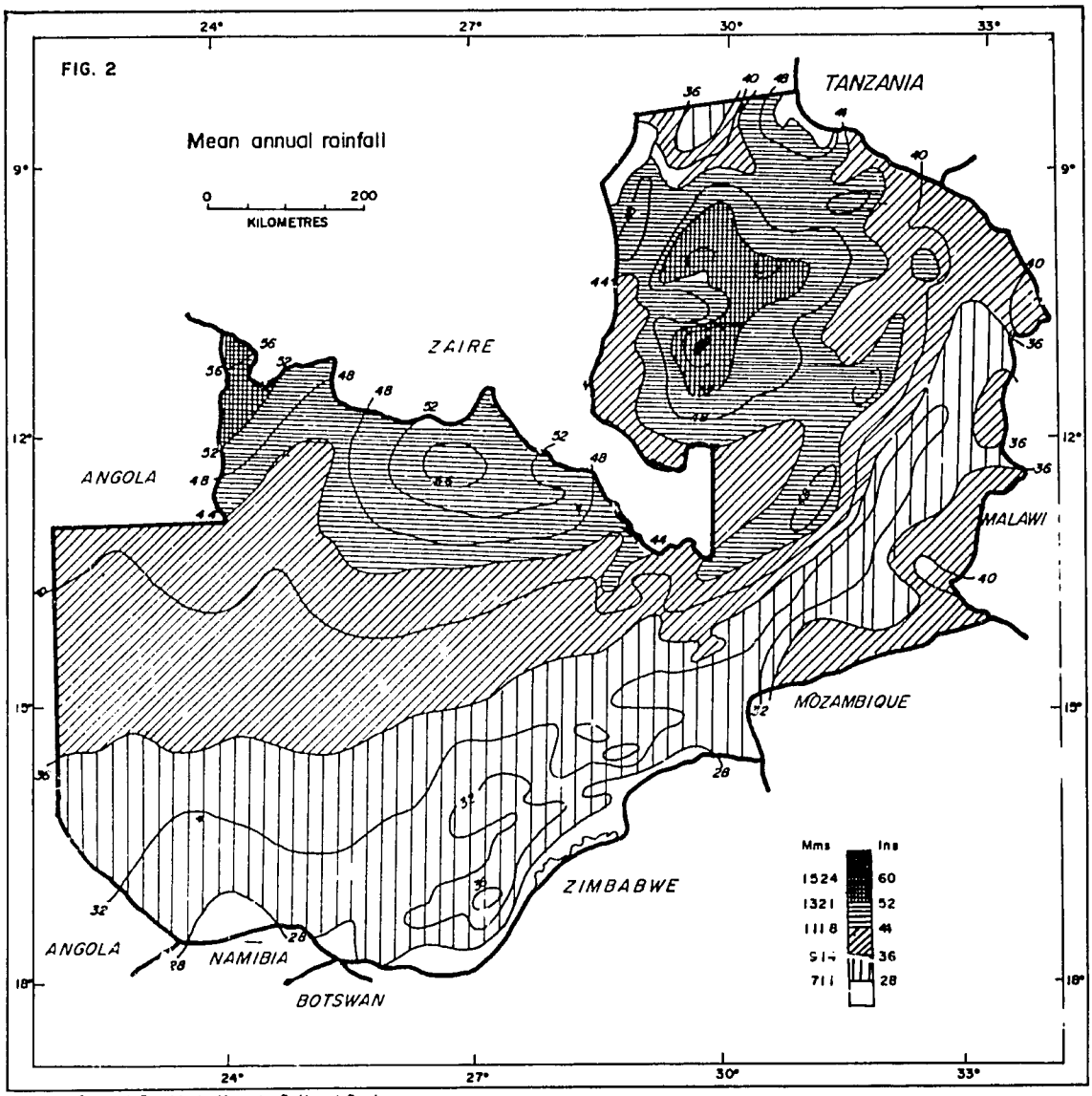
July is the coldest month (16deg.C). Air frosts have been recorded in May, June, July and August. October is the hottest month with mean daily maximums reaching 30deg.C.

FIG. 1

RELIEF



Source: Zambia in Maps by D Hywel Davies.



Source : Zambia in Maps by D. Hywel Davies

Vegetation.

The vegetation of Zambia comprises woodlands, forests and grasslands. Some woodlands have dense tree cover and others are open or parklike. Woodlands with dense tree cover have more or less closed canopy and the grass cover is sparse and this is due to insufficient sunlight made available to the ground. Open woodlands have unclosed canopy and the grass grows luxuriantly. Forests are characterized by the presence of thickets in the understorey. The canopy is mostly closed and the grass cover is very sparse. Grasslands in Zambia are associated with areas of poor drainage and these are dambos, swamps and flood plains.

Man through agricultural activities, burning and cutting trees indiscriminately has contributed to the destruction or degradation of the indigenous vegetation. Because of this it was found necessary to establish Protected Forest Areas where people are not allowed to settle or cut trees. Some woodlands and forests have been preserved to meet the future need for wood and for soil and water conservation purposes. " A good vegetational cover is the best and cheapest form of soil conservation. A protecting plant canopy prevents splash erosion and rain water will be absorbed instead of running off over the surface". The area covered by natural vegetation under protection amounts to 7.09 million hectares (see table 1).

Table 1. Land Utilization Types ('000 ha)

Total Geographical Area	75,260
Total Land Area	74,338
Total Land Available for Agriculture	42,657
Protected Forests	7,090
National Parks	5,943
Escarpments and Hill Country	7,310
Seasonally Flooded Areas and Swamps	10,439
Municipalities and Townships	899
Land Under Water Bodies	922

Woodlands.

About 50% of Zambia is covered by Miombo woodlands. The Miombo woodlands is a two storey vegetation type characterized by species of Brachystegia, Julbernardia and Isoberlinia. Marquesia trees are a component of Miombo woodlands in high rainfall areas.

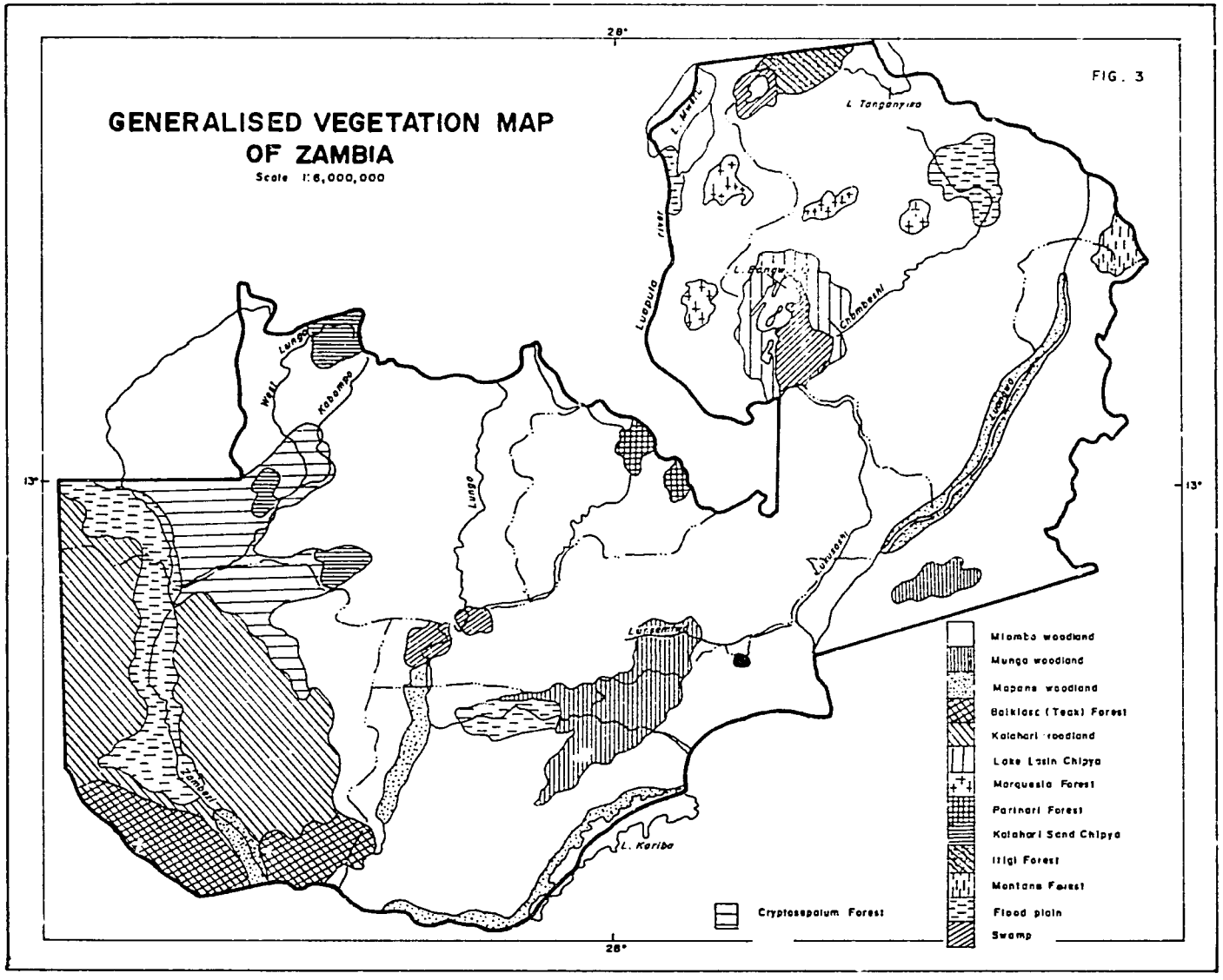


FIG. 3
GENERALISED VEGETATION MAP OF ZAMBIA
Scale 1:6,000,000
28°
13°
L. Tanganyika
L. Mweru
Luapula river
L. Bangweulu
Chambeshi
Kafue
Lungue
Lungue
Kabompo
Zambezi
Luangwa
Luangwa
L. Kariba
Miombo woodland
Munga woodland
Mopane woodland
Baikiaea (Teak) Forest
Kalahari woodland
Lake Basin Chipya
Marquesia Forest
Parinari Forest
Kalahari Sand Chipya
Itigi Forest
Montane Forest
Flood plain
Swamp
Cryptosepalum Forest

The Miombo vegetation generally is associated with areas occupied by soils which are poor in nutrients and in some places they are shallow. The plateaux, some valleys and part of the Kalahari sandy country, are covered by Miombo vegetation. Escarpment zones and other hilly ranges are also mantled by Miombo vegetation.

In higher rainfall areas (Northern Zambia) evergreen thickets are common in Miombo woodlands. Fanshawe (1969) suggests that at one time the Miombo woodlands with evergreen thickets were covered by dry evergreen forests. Trials undertaken by the Forestry Department on the Copperbelt have shown that when an evergreen thicket is destroyed the area is encroached by Miombo vegetation. This process is reversible. On the same area if the Miombo vegetation is removed an evergreen forest will develop.

In the hot river valleys of the Luangwa, Kafue and Zambezi we find Mopane woodlands on areas occupied by alkaline alluvial soils. Mopane woodland has one storey with an open canopy. It is dominated by Colophospermum Mopane. This tree thrives well on Sodium affected clay soils. It is browsed by Elephants in the Luangwa and Kafue National Parks.

Munga woodlands dominated by species of Acacia, Combretum, and Terminalia occur mainly in Southern, Central, and Eastern Provinces. Munga vegetation is two storeyed and is parklike. Usually grasses in this vegetation type are tall and dense. In Southern Province, Munga vegetation is common in Mazabuka and Monze Districts. Nakambala Sugar Estate (Mazabuka), the home of Zambia Sugar, was once under Munga woodland. This vegetation type covers large areas of the main agricultural Lands in the Provinces mentioned above. Munga vegetation is used by agriculturists as an indicator of good arable land. Munga vegetation usually occurs on flat land. In some places strips of Munga vegetation thrive along rivers and streams. The Munga soils in texture vary from clays to sand clays and have a high base exchange capacity.

A large area of Western Province is covered by Kalahari woodland. This vegetation type does not include the Miombo / Kalahari woodland, the dry deciduous and evergreen forests found in the western part of the country. The Kalahari woodland being discussed here is characterized by species of Guibourtia, Burkea, Erythrophleum, and Diplorynchus. Burkea, Guibourtia, and Erythrophleam are fire hardy species. This woodland is said to have been derived from the destruction of the dry deciduous Baikiaea (Teak) forest. Relics of Bikiaea can be seen here and there. Kalahari woodland vegetation thrives on infertile sands of the Kalahari type. These soils have little organic matter, they are acidic in nature and the base exchange capacity is extremely low. In Western Province, on the Kalahari sands, the overall crop development potential is relatively low.

Forests

To the southern part of western province in Senanga and Sesheke districts and also in Kalomo district (Southern Province) we find Baikiaea (Teak) dry deciduous forests. Baikiaea dry deciduous forest has two storeys and the canopy layer is mostly closed. Characteristic trees are Baikiaea and Pterocarpus. Baikiaea is economically valuable. It is used for making furniture. Baikiaea forest thrives well on Kalahari sands due to adequate moisture held at depth all year round.

Dry evergreen Crytosepalum forest occurs in Kaoma, Mongu, and Zambezi districts in Western Province. This forest type also covers parts of Mwinilunga and Kabompo districts in North-Western Province. The frequent trees are Cryptosepalum and Guibourtia species. This forest flourishes on Kalahari sands which retain a considerable amou. of moisture at depth throughout the year. Destruction of this vegetation type leads to the development of Kalahari Sand Ghipya vegetation.

In North-Western province parts of Kasempa, Mwinilunga and Kabompo are mantled by Kalahari Sand Chipya. This is an evergreen vegetation type. The sands on which it occurs retain moisture at depth for a longer time. The canopy trees are Burkea, Combretum, Erythrophleum, Guibourtia and Acacia species. Cryptosepalum is present also in this vegetation type. Tall grasses are found in this Chipya vegetation.

Between Lakes Tanganyika and Mweru Wantipa in Northern Province we find the Itigi forest characterised by Bussea massaiensis, Diospyros mweroensis and Baphia massaiensis. This is a two storeyed forest. The Itigi forest thrives on shallow soils underlain by stones or gravel. It is a dry deciduous forest. Destruction of this forest type leads to the development of Lake Basin Chipya type of vegetation.

Parts of Kawambwa, Luwingu and Kasama districts in Luapula and Northern Provinces respectively are covered by Marquesia Forest. This is a dry evergreen forest in which the frequent canopy trees are Marquesia macroura, Anisophyllea pomifera, and Syzygium guineense. Complete removal of the canopy trees leads to the encroachment of fire resistant Chipya tree species. Marquesia occurs in higher rainfall areas. It is a rain forest tree.

Dry evergreen Parinari forest is found in Central Province Serenje district and on the Copperbelt. Canopy dominants are Parinari ecelsa and Syzygium guineense.

Throughout Zambia are found Riparian Forests. A Riparian forest is a three storeyed vegetation type with a closed evergreen canopy layer. These forests occur around lakes and along rivers. They thrive on alluvial soils. The characteristic tree species are Diospyros mespiliformis, Khaya nyassica and

Syzygium cordatum.

Swamp forests occur in the higher rainfall areas. They are found in North-Western Province, the north eastern part of Central province, and some parts of Northern Province. These forests are three storeyed with closed canopy layer and are characterized by species of Syzygium, Mitragyna stipulata and Ilex mitis. The forest floor is mostly bare.

Swamp forests are confined to zones of seepage occupied by peaty soils around stream heads and to sites covered by alluvial sandy clays where rivers discharge their water into lakes.

The area which is at an altitude between 2,150 to 2,164 metres-above sea level on the Nyika plateau to the north-eastern part of the country carry Montane type of vegetation. The Montane forest found here is three storeyed and has a closed evergreen canopy layer. Some of th abundant trees found in this forest type are Parinari excelsa, Trichilia prieuriana, Myrica salicifolia, Podocarpus milanjianus, and species of Anigeria. Epiphytic ferns occur frequently in this vegetation type. Soils which are found on the Nyika plateau mainly are well drained sandy clays. Frosts of 10-20deg.C have been recorded. These occur between the period May to October.

Lake basin Chipya type of vegetation occurs on the Copperbelt, in the northern parts of Mkushi and Serenje districts - Central province. In Luapula province it covers areas around Lake Mweru and Lake Bangweulu. Some valleys within Luapula province are mantled by Chipya type of vegetation. In Northern province Chipya vegetation occurs in the Chamheshi valley and around Lake Bangweulu.

Chipya is a "Bemba" term and this refers to vegetation in which various trees grow mixed in very tall grass (Trapnell 1953). This vegetation type is three storeyed with an open canopy. It is composed of deciduous and evergreen trees. The characteristic tree species are afzelia quanzensis, Erythrophleum africanum, Pericopsis angolenis, Albizzia antunesia, Acacia albida, and Parinari curatellifolia. According to Trapnell (1953), the presence of evergreen thickets is an indication that areas mantled by Chipya vegetation may at one time been covered by evergreen vegetation. It is said that destruction of the evergreen forests by fire led to the development of Chipya vegetation. This vegetation type can be identified by the presence of Tall grass which belong to the genus Hyparrhenia, and also by the presence of Aframomum biauriculatum (Ginger) and Pteridium agulinum a fern. Soils observed in Chipya vegetation are loams, clay/loams, sandy loams and sandy soils.

Termitaria

Termitaria occur throughout the country in areas where the soil is not pure sand. Before a termite mound can be formed the

soils should have at least 10 per cent clay plus silt (Fanshawe 1969). Soils found on termite mounds have a high amount of clay and silt. These soils are more fertile than woodland soils. Mounds are utilized agriculturally, people grow crops on them during the rainy season.

Termitaria vegetation is found in the following vegetation types:-

i) Munga woodland
ii) Mopane woodland
iii) Miombo woodland
iv) Kalahari woodland
v) and Riparian forest.

Plant species generally found on termite mounds are Diospyros mespiliformis, Combretum, Dalbergia, Ficus, Ziziphus, Vitex, Popowia obovata, Asparagus racemoous, and Strychnos potatorum.

Grasslands

About 20% of Zambia is covered by grasslands (Perera 1980). There are three types of grasslands in Zambia and these are Swamps, Floodplains and Dambos.

Swamps are areas inundated by water. They are more or less permanently waterlogged or flooded. Good examples of these wetlands are the Bangweulu, Busanga and Lukanga swamps. Swamp vegetation is composed of Sedges and grasses. The characteristic sedge species is Cyperus papyrus and the grass species are Echinochlos pyramidalis, Vossia cuspidata, Leersia hexandra, and Phragmites connunis. Another herbaceous plant associated with swampy areas is Typha Latifolia. Peaty soils are found in swampy areas.

Floodplains are extensive grasslands found in the meander belt of rivers. A feature of these grassland areas is the presence of lagoons, abandoned river channels, ox-bow lakes and levees. Good examples of these grassland areas are the Zambezi floodplains, Kafue flats, and the Chambeshi flood plain. Some of the grasses found in flood plains are Panicum repens, Acroceras macrum, Echinochloa pyramidalis (and other species of Echinocloa), Imperata cylindrica, Vossia cupidata, Themeda triandra, Cynodon dactylon, Chloris gayana, Setaria spp, and Hyparrhenia spp. Flood plains are mainly occupied by alluvial soils.

Dambos are found on the plateaux. These are headwater grasslands. They are shallow linear depressions which do get waterlogged seasonally by runoff and seepage water from the surrounding higher ground. Verboom (1970) classified dambos into three categories - sweet intermediate and sour dambos. His classification system is based on soil pH and vegetation.

Sweet dambos occur mainly in the southern half of the country. Sweet dambo soils are underlain by lime rich rocks and have a pH higher than 6.5. The characteristic grass species found in such dambos are Acroceras macrum, Paspalum commersonii, Echinochloa pyramidalis, Setaria spp., Sporobolus spicatus, and Hemarthria altissima. There is an abundance of herbaceous legumes in Sweet Dambos. Some of the herbaceous legumes associated with these dambos are Teramnus gillettii, Alysicarpus rugosus, and Aeschynomene indicus. The presence of Acacia trees on the margins is a feature of sweet dambos.

Intermediate dambos have soils which developed from mixed sediments with pH between 5.5 and 6.5. The vegetation found in such dambos is a mixture between sweet and sour dambo plant species.

Sour dambos are common in the northern half of the country which receives heavier rainfall. The soil pH in these dambos falls below 5.5. In the southern half of the country they occur over granites and basement complex rocks. The main grasses found in sour dambos are Andropogon eucomus, Monocymbium cereciiforme, Elyoneurus argentens, Hyparrhenia bracteata, Aristida atroviolacea, Loudetia simplex and Trachypogon spicatus. Descodium salicifolium is the associated legume.

The three categories of dambos are grazed by cattle during the dry season, but the best grazings are to be found on sweet dambos. The seepage areas of all the three categories of dambos are suitable for rice growing, but good yields are obtained on the less sour dambos.

Dambos are natural water reservoirs. They absorb water during the rainy season and release it slowly during the dry season. Had it not been for the presence of dambos in the upper parts of the catchment areas many of our small rivers and streams would be dry before the end of the dry season. The organic peaty soils found in dambos are the main sponges through which water is collected and retained. Overcultivation and overgrazing leads to the drying up of dambos.

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SOILS OF ZAMBIA

R.N. Magai

Natural environment.

Zambia lies between 8 deg. S and 18 deg. S and has a climate affected by the altitude of its land surface, its continental position within Central and Southern Africa and the absence of high mountain ranges. The pronounced seasonal climate is characteristic of the savannah regions of Africa.

Most of Zambia lies over 1000 metres above sea level and therefore experiences lower temperatures compared with areas of similar latitudes. The mean annual temperatures are between about 18 - 24deg C. Monthly means range between 14-17deg.C in June - July and 22-26deg.C in September to October. Due to its flatness, it can generally be stated that the temperature shows little variation over the country, with the exception of the hottest valleys like the Luangwa and Gwembe.

The soil temperature regime for most of the country is isohyperthermic. In the south a hyperthermic soil temperature prevails while high altitude areas experience an isothermic soil temperature regime.

The annual rainfall exceeds 1400 mm in the extreme north of the North - Western Province and the west of the Northern Province the rainfall gradient shows a marked decrease southward to less than 700 mm along the southern portion of the country. Most of the Western, southern Central and Eastern Provinces have annual total below 1000 mm. The area north of the 1000 mm isohyet is general known as the "high rainfall zone."

Dominant soil moisture regimes are ustic and to a minor extent aquic in valleys and dambos. Locally udic soil moisture regimes occur depending on groundwater behaviour and seepage, while isolated in the low rainfall zone soils may have an aridic soil moisture regime which is isolated to low soil moisture storage capacity, low infiltration rates and the erratic character of the rainfall.

Zambia is underlain by ancient Archean rocks, which constitute the basement complex and consist mainly of metamorphosed gneisses, schists, quartzites, limestones and shales, with intrusive granites. Western Province is occupied by a mantle of sands known as the Kalahari formation. Biotite rich gneisses are found in the south east of the Eastern Province, passing into more acidic gneisses, schists and quartzites of the basement complex in the north. The youngest rock formations, the Karroo sediments, are found in major valleys which have escaped removal by denudation. Recent alluvium occurs widely on the upper Zambezi flood plain, the Kafue flats, in the Luangwa valley and in the Bangweulu and Lukanga swamps.

It is believed that regardless of long - continued weathering in areas where annual precipitation is less than 1000 mm, the influence of parent material becomes more apparent. There is a close relationship between the soil and underlying rock or parent material, particularly with regard to soil texture, colour, structure and other morphological features.

Soils

It has been established that Zambia contains all ten soil orders, although in varying extents. The 1983 soil map of Zambia (scale 1:2,500,000) has been used to estimate the occurrence of soil orders and soil-families of Soil Taxonomy. Table 1 shows the extent of soil orders:

Table 1. Extent of Soil orders in Zambia.

Entisol	25%	Vertisol	7%
Inceptisol	24%	Spodosol	3%
Oxisol	15%	Mollisol	< 1%
Ultisol	15%	Aridisol	< 1%
Alfisol	10%	Histosol	< 1%

Entisols are one of the largest orders. They are soils that have slight development or have not developed horizons, other than perhaps the darkening of the topsoil by organic matter or the bleaching of sand grains. Their physical properties are determined largely by the parent material. These are generally soils in young alluvium (sedimentary) silicious sands or rocky hill slopes.

The commonly occurring suborders of Entisols are the non-wet sandy soils subjected to movement by wind if dry enough - the Psamments. The widely spread soil family in the suborder is the ustic Quartzipsamment, acid isohyperthermic, found in Western and North western Provinces. These soils are formed in the Kalahari sand cover.

In the floodplains occur soils formed on sediments, the fluvents and the wet entisols, the Aquents.

Also occurring in Zambia are Entisols that are developed on youthful erosional geomorphic surfaces - the orthents. They typically occur on surfaces subject to erosion rather than deposition.

Inceptisols are relatively young soils in which the parent material has been sufficiently altered by weathering, or by other soil forming processes, to have lost its original structure, but which has not been sufficiently altered by leaching or accumulation of clay, iron or humus to warrant recognition in an order of more developed soils.

Inceptisols are the second largest order. The most widespread soil family belong to the Lithic ustropept, loamy-clayey-skeletal, mixed iso (hyper)thermic, as found on the hill ranges bordering the major valleys and on isolated hill ranges on the plateau. These soils have hardly been studied in detail.

Less widespread but still common subgroups are the Acric or Typic tropaquepts, which constitued some dambo soils with either a loamy or clayey texture, and occur in low lying areas or depressions that are usually seasonally water-logged, appearing everywhere on the plateau.

Oxisols form the third largest order. This order contains intensively weathered soils on old land surfaces. They are characterized by low silica / sesquioxide ratios, low cation exchange capacities, low activity of clays and low content of weatherable minerals.

Oxisols in Zambia occur on a variety of physiographic positions and are also developed on a variety of parent materials. Most of them are found on plateau, gently dissected older peneplains and non-dissected or erosional plains.

The ultic Haplustox, loamy - clayey, kaolinitic, isohyper-thermic is most widespread soil family. These soils are formed on acid metamorphic and sedimentary rocks. Next in line is the Typic Haplustox, mostly kaolinitic, but probably in North-Western and Northern Provinces is found on sedimentary rocks. Other important great soil groups are the Acrustox and the haplohumox..

The new proposal for establishing a kandic - taxa would drastically reduce the extent of oxisols by as much as 60% as most soils will classify as Kandiustults. The new percentages of oxisol and utisol would then be 6 and 24% respectively.

Ultisols are soils in which a significant amount of clay has been leached from the topsoil into the subsoil but which, unlike alfisols, have been strongly leached of bases. The presence of an argillic horizon, a low base status in the lower part of the soil is characteristic of the order.

The oxic haplustult forms a major soil type in the Central and Southern Provinces where they are locally known as "sandveldt" soils.

On the northern plateau oxic paleustult prevails interspaced with oxic haplustult and utic haplustox.

Other ultisols in Zambia are various Aquults and the Tropohumults of the Nyika Plateau.

Alfisols are characterized by prominent horizons of aluviation and illuviation. These are the soils in which a significant amount of clay has been leached from the topsoil into the subsoil

but which have not been strongly leached of bases.

Examples of Alfisols occurring in Zambia are oxic Haplustalf, loamy-fine, kaolinitic, isohyperthermic and Typic paleustalf, fine, mixed, isohyperthermic.

These soils occur in the southern and eastern parts of the country. The Typic Paleustalfs are probably the most productive soils in Zambia. The other haplustalfs are mainly found in the Southern Province.

Another important Alfisol is the Tropaqualf, mainly occurring on the large river floodplains for instance of the Zambezi.

Vertisols are heavy, strongly-cracking, clay-textured, usually dark-coloured and often containing lime concretions at some depth in the subsoil. They occur in hot climate in lower laying areas in medium and low rainfall zones. (less than 1000 mm).

They develop from a wide range of parent materials, but are commonly derived from calearous rocks. Vertisols are also typically developed on alluvial material in flat land areas or depressions.

Typic Pellustert, fine mixed isohyperthermic and Typic chromustert, fine, mixed, isohyperthermic are the most commonly occurring families.

Spodosols are soils developed in sandy to loamy material and are extremely acid soils in which the humus and/or iron and/or aluminum have been leached from the topsoil (leaving bleached sand behind), and deposited to form a darker or browner layer in the subsoil. The occurrence of these soils is confined to the kalahari sands in the western and North-Western Provinces. In Zambia Spodosols are formed in materials almost devoid of iron and they belong mainly to the Typic and Arenic Tropohumods.

Mollisols are soils which have a mollic epipedon and are relatively unleached with thick dark coloured humus rich, friable topsoil. They cover a very limited area and are therefore hardly known. Ustolls occur to a limited area extent in Lusaka, Southern and Eastern provinces, often in association with oxic Paleustalfs and Typic Pellusterts.

Dominant Mollisols in Zambia belong to the Argiustoll great group.

Aridisols are very rare in Zambia. Only recently one of the driest parts near Luangwa may classify as Aridisol.

Histosols are comprised of soils derived primarily from organic parent material. They are classified according to defined states of decomposition and are recognised for organic materials. Their

occurrence in Zambia is confined to swamps, lakes, dambos and riverplains constituting a poorly drained environment. Most classify as Tropohemist, with torric and typic subgroups. The soils are of limited coverage and under utilized for agriculture production.

Table 2. Occurrence of soil families in Zambia

Wide spread (10-20%)	Ustic Quartzipsamment, acid (iso)hyperthermic uncoated; ultic haplustox, loamy-clayey, kaolinitic isohyperthermic; lithic ustropept, clayey-skeletal, mixed, (iso)hyperthermic, oxic Paleustult, clayey, kaolinitic, isohyperthermic
very common (5-10%)	Acric/Typic Tropquept, loam, kaolinitic, isohyperthermic; oxic Haplustult, clayey, kaolinitic, (iso)hyperthermic; Typic Haplustox, clayey, kaolinitic, isohyperthermic.
common (1-5%)	oxic Haplustalf loamy/fine kaolinitic, hyperthermic humic psammaquent, siliceous, acid isohyperthermic Ultic Haplustox, fine-loamy, siliceous (iso)hyperthermic, Typic chromustert, fine, mixed isohyperthermic; Typic Tropaquent, sand/loamy, siliceous isohyperthermic.

LAND-USE PLANNING IN ZAMBIA

J.B. Mutelo

Introduction

Land use planning is a conscious process that helps decision makers decide how to use an area of land. It brings together land use objectives, ways of using the land, and natural resources so that the needs are satisfied as fully as possible without damaging the land.

Land use planning is done mainly for two reasons: firstly, it aims at making efficient use of the land by matching land uses to areas where those land uses are most productive and least damaging to the natural resources. Secondly, it aims at achieving desired objectives which will also give increased production while at the same time protecting the natural resources.

The development of agricultural land use planning in Zambia: a historical perspective.

Agricultural land use planning in Zambia evolved mainly from the need for soil conservation effort in the European farming lands in the 1940's. In 1950, the Natural Resources Board was set up along with the creation of the intensive conservation areas (I.C.A.). This was the first stage in the development of organized agricultural land use planning. Although I.C.A.s were geographical units which centred on soil conservation, elements of land use planning based on soil conservation were included in the development of the farming lands. In all there were 12 I.C.A.s created within the first year and these covered most of European farmed-land along the then only line of rail from Livingstone to Ndola.

In 1959, the Ministry of African Agriculture was created and this led to the extension of Regional Conservation Planning into African areas. The Regional Plans aimed at instituting conservation in both African and European areas. In the African sector, Regional Planning was supervised by the Natural Resources Board through an African Affairs Committee and the Government provided the funds.

During the colonial era, agricultural land use planning was an important aspect in the development of agricultural lands in the country.

" The conservation of natural resources, particularly land and water resources, is of paramount importance to the people of Northern Rhodesia and to the national economy of the country as a whole. The object of Regional Conservation Planning is to ensure the protection of these resources and, at the same time, to plan their wise utilization "(Planning Course, Department of

Agriculture 1964).

Regional Planning was replaced by Catchment Conservation Planning in 1965. Catchment Conservation Planning was evolved as a method of instituting basic development in rural areas while at the same time carrying out conservation work. Conservation work included dam and weir construction, and the construction of surface drainage channels. Recent plans have included soil surveys and road construction and the areas involved are of the order of 100 to 200 square kilometers, preferably on a catchment area of a river.

Since independence to the present day, land use planning activities have also included farm planning, settlement and small production schemes planning, feasibility studies and surveys of agricultural projects.

Present Agricultural Land-use in Zambia

The current land use system is derived from the former colonial regime which had three distinct categories: crown land which is now referred to as stateland with freehold, trust land and reserve lands which are now commonly referred to as traditional land apart from such lands as national parks which were also included in trust lands. Most of the stateland areas are found along the "old" line of rail which stretches from Livingstone to the Copperbelt, some areas in Eastern and Central Provinces, and some areas around Mbala and Mwinilunga. Traditional land forms most of rural Zambia.

Stateland areas are characterised by commercial farming and there are approximately 1,000 to 1,500 commercial farms, whereas subsistence agriculture is predominantly found in traditional lands where there are approximately 600,000 to 700,000 family farmers. Subsistence agriculture is greatly varied ranging from the "Chitemene" system to improved hoe and ox-cultivation on a permanent basis

Organisation of agricultural land use planning in Zambia.

The Land-Use Branch of the Department of Agriculture is the main institution engaged in the organization and implementation of agricultural land use plans in the country through some of its specialised sections, namely: Land Use Planning, Ecology, Irrigation, Farm Management, Soil Survey, Agricultural Engineering and Land Development Services. Some of these sections are not directly involved in the land use planning processes, but their role is supportive in nature such as the Soil Survey Section.

The Branch is headed by an Assistant Director of Agriculture who is at the Departmental Headquarters; then there are Provincial and in some areas District offices. These are the people who carry out the physical planning work. Policy issues

come from the top and trickle downwards as shown below. Some plans, ideals, problems and solutions come from the bottom upwards.

LAND USE BRANCH
H.Q.
\
PROVINCIAL OFFICES
\
DISTRICT OFFICES
\
FARMS-FARMERS

Most of agricultural land use planning that takes place in the country is carried out on ad-hoc basis. Thus, the planning is carried out only when need arises. There are a few cases where vast areas like Mkushi West farm block (1977-78) and Lukulu North Project (1980-85) have been systematically planned.

At this point it is necessary to mention that the areas that are usually planned are mainly those that are in the commercial farming areas (stateland), settlement schemes, and other agricultural projects. On traditional lands, there is hardly any land use planning that takes place. Thus agricultural land use planning is biased towards areas under commercial agriculture. Efforts are being made to plan the proper use of non-stateland areas where the vast majority of Zambians live.

Basic Techniques

In order to systematically plan for the proper use of any piece of land, some basic and structured techniques are used by all surveyors and planners in Zambia.

Positions and heights of earth's features including topography, soils, land use etc are measured and delineated on maps. A whole range of equipment such as chains, compasses, augers etc., are used to conduct field surveys. Surveying is used in land-use planning work for traverse contour surveys, field and block demarcation and furrow lay-outs.

A significant amount of planning is done as a desk study using remote sensing technique such as the use of aerial photographs and satellite imagery. Air photo interpretation techniques are used to deduct and record information from an air photograph. Satellite imagery interpretation is one means of carrying out ultra rapid reconnaissance surveys of a region particulary when used on scales of 1:1000,000. Satellite imagery cannot be used for land use planning at village level or on a large scale, because it does not contain sufficient detail.

Aerial photography used in Zambia is usually at a scale of 1:30,000. For most land use planning aerial photography provides the main source of information on soils, topography, vegetation and the settlement pattern. The ability to extract this information accurately from aerial photographs is vital for land use planning.

In nearly all cases remote sensing techniques have to be supplemented by spot checks on the ground.

In order to produce a good land-use plan of an area data on climate, vegetation, soils and settlement is collected by means of a field survey. The use of aerial photographs has already been mentioned.

A natural resource survey in the field consists of a detailed recording of information at a number of pre-determined sites which are usually located on the ground by a grid survey. The most detailed information is on the soil since this is the most important local factor for land-use planning. Such equipment as soil auger, abney level, Munsell soil colour guide and a plastic wash bottles are used to obtain soil information which is recorded on a standard format.

Types of Agricultural Lands

To optimise planning and management of agricultural lands in Zambia, it is necessary to classify in general terms these lands as follows:

Rainfed Agriculture Lands

The vast majority of agricultural lands in Zambia is rainfed. These lands are characterised by various types of cultivation systems ranging from permanent and modern high energy input commercial farming technology to shifting cultivation, low level technology producing negative marketable surpluses. These lands suffer from aridity in the south and excessive water and high soil acidity problems in the north.

Since rainfed lands rarely receive the right amount of rainfall at the right time, it is important to protect them from the effects of aridity as well as wetness.

It is important to have proper land-shapes and to construct appropriate contour-bunds which will retain maximum amount of moisture under dry conditions. The design of water drains should be such that it prevents soil loss under high rainfall conditions. Good agricultural lands threatened by wind erosion must in addition be protected by windbreaks.

Due to population pressure many rainfed agricultural lands which were classified as unsuitable for cultivation because of slope, soil depth ect. are being ploughed. These lands require

special attention if they are to sustain long term production.

Irrigated Agricultural Lands

The Department of Agriculture has identified some agricultural lands with a high irrigation potential. There are 10 million ha of irrigable land in Zambia. To date only 20,000 ha is irrigated. The main sources of irrigation water are rivers (Zambezi, Kafue, Luangwa, Chambeshi and their tributaries), Lakes (Kariba, Mweru, Tanganyika,' Bangweulu etc), dams, wells and boreholes.

Most irrigated land is furrow or surface irrigated. These lands require proper design and levelling to be effective. A few, and mainly wheat growers, use overhead sprinkler irrigation systems which requires more than basic technology and relies on imported machinery and spare parts which are not readily available.

In all cases appropriate drainage systems have to be included to carry excess water from irrigated farmlands, safely.

It should be noted, however, that most irrigable agricultural lands are also rainfed from November to April each season, particularly in Northern Zambia.

Dambos, Swamps, flats and Floodplains

These are Zambia's wetlands which are characterised by poor drainage and are usually covered by various grasses. In terms of agricultural land-use potential dambos and floodplains are used for grazing and growing water resistant crops such as rice, during high moisture levels, and other crops such as maize during dry periods usually under irrigation.

Swamps are used principally for fishing and grazing in their periphery. Efforts are being made to maximise agricultural production from these wetlands by improving pastures, water and soil management to increase crop and livestock production.

Forestry and other protected lands

These are several potentially high agricultural lands which consists of Game Reserves, Protected Forest and other areas of historical significance. These lands may not be used for agricultural production, but it is necessary to plan the best use of them to minimise soil erosion and decertification. Land-use planning for these areas require a National Multi-sectoral and Multidisciplinary approach to achieve their desired objectives.

It may be appropriate to state that deforestation alone has reached an alarming proportion in Zambia due to very high demand for charcoal and fuel wood from mainly peri-urban communities. The protection of running natural and the expansion of planted

forests plantations are concerns for a land-use planner in Zambia to-day.

An Approach to Land-use Planning in Zambia

The present trend in agricultural production shows that agricultural land-use will be intensified to the extent that more land will be cultivated. This necessitates the formulation of a systematic agricultural land-use planning approach which will be guided by:

a) Emphasise on self help and direct maximum attention to the small-scale farmer.
b) Implementation of government policy will in future be increasingly decentralised to district level.
c) Land capability classification shall continue to be the technical vehicle for land-use planning.
d) Planning land at the farm or regional level can only occur within a National land allocation policy. The division of land into Stateland and 'Reserve and Trust lands is largely historical but continues to confuse everything connected with land developments giving rise to unsatisfactory land settlements and allocations.

In order to rationalise the various options for the use of a given piece of land under existing financial, human, political, economic and natural constraints, there is an urgent need to set up a functional national body to promote intergrated thinking and action on all aspects of land-use in Zambia. The body should not be merely a co-ordinating agency, but should have within itself adequate technical and economic expertise to formulate land-use plans.

The body should be mandated to approach various national or international agencies to fill up data gaps.

There is a need to establish river valley catchment development authorities on a priority basis. These catchments, if properly planned, hold tremendous potential for agricultural production and employment generation. It is worth noting that most world civilisations have taken place in river catchments.

The multiplicity of agencies involved in "land-use" should be reduced and a unified system of land management should be introduced.

The Central Statistical Office should be involved in collecting and processing data pertaining to land-sue in Zambia.

There is currently and sadly zero land-use expertise at district level. This produces problems in implementing land-use programmes at district and sub-district levels.

The constraints in land-use for Zambia vary from region to

region. Each region should examine critically and identify the physical, social-economic and other constraints to evolve specific policy measures required. It would be desirable to examine these for each-climatic region of the country.

Wetlands act as flood absorbers and maintain aquatic flora and fauna, hence the reclamation of these lands may only be resorted to after understanding the ecological consequences of such actions.

Land development and other cultivation techniques use a lot of energy. In view of the energy crisis more attention be paid to the development of a technology which uses less energy in land development such as the possibility of increased use of solar energy directly or indirectly through biomass. Land use on privately owned land cannot be influenced by mere legislation. This problem has to be tackled through price policies, incentives and other mechanisms.

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LAND EVALUATION METHODOLOGY OF THE ZAMBIA SOIL SURVEY UNIT

Cuulu Kalima and W.J. Veldkamp

Introduction

Land evaluation in Zambia has basically developed through three most important stages. The period 1948-1960 was the period in which land evaluation was carried out at very rapid recconnaisance level using easily recognizable soil and environmental characteristics as a way of identifying the most suitable land for colonial settlements. The period 1960-1970 marks a period in which a consolidated land evaluation methodology, in the modern sense, was developed as a way of guarding the fertile land settled on by colonial farmers (so called crown land) against degradation especially due to water erosion. The third period covering 1970 to date is a period in which the quickly changing needs of production nave entered the Zambian evaluation methodology into the international arena of comprehensive land evaluation systems in which land utilization types have to be specified and their requirements identified before these are further matched or compared with land qualities to arrive at suitability. In the attempt to develop a modern land evaluation methodology Zambia has benefited a lot from the FAO frame-work for land evaluation (1978) and its land evaluation guidelines for rainfed agriculture (1984). Other systems such as the fertility capability classification system (Sanchez et.al. 1982) have contributed greatly to the Zambian land evaluation methodology.

This paper is an attempt at outlining and explaining the land evaluation methodology that is being developed in Zambia. The paper will also attempt to outline the system that is presently used in Zambia, the Land Use Branch Land Capability system (LUB).

The present land capability system

The LUB (Land Use Branch) land capability system (Conex 1963) is the system that is currently used in Zambia for land evaluation purposes. The system uses a limitation approach to land evaluation reminiscent of the USDA system (Klingebield and Montgomery 1961). In this system optimum use of arable land is the starting point and the value of the land is estimated by certain limitations that are supposed to decrease the optimum use of the land. That is to say the value of a tract of land decreases with an increased number of limitations. As the value decreases crop production is ruled out and the land is ultimately recommended for grazing.

Unlike other limitation approach systems that are meant for general land appraisal the LUB land capability system defines, identifies and is directed to the evaluation of certain land-utilization types. The LUB land capability system was tailored to evaluate the suitability of land for rainfed, medium and large scale commercial farming for maize (Zea mays) and tobacco (Nicotiana tobacum). Soybeans (Glycine max), sunflower (Heleanthus annus) and groundnuts (Arachys hypogea) are taken as minor crops. The structure of the system is shown in table 1.

Table 1: A diagrammatic representation of the land capability classification procedure of Zambia (Kalima C. 1983)

ORDER	CATEGORY CLASS		SUB CLASS	UNIT
S	Good	S1	S2s	S2mt
	arable		S2m	S2me
C	land	C1	S2t	S2mw
	Unsuitable			
U	land	Uw	No subclass	No unit

Orders 'C' and 'S' basically indicate whether the top soil is clayey or sandy. Class CI and SI indicate good arable land, sub classes (C3s or S2s with one suffix letter indicate good moderately good arable land. Sub classes C3s or S3s indicate poor arable land.

After indicating the capability of the land as indicated in table 1 the system proceeds to give crop suitabilities by comparing the crop requirements to land characteristics (Brammer 173). In effect a C1 class soil may not necessarily be suitable to all crops. According to table 2 class 1 is the most suitable and class 4 the least suitable.

The problems of the land capability system.

The disadvantages of the LUB system far out weigh the advantages. Kalima (1983) has outlined the disadvantages of the LUB system the most important of which are:

(a) The land capability classification and crop suitability classification are not expressed in the same values and can therefore not be matched confidently (c.f. table 1 and 2).

(b) The criteria for land capability classification are only related to the production of maize and tobacco at high-input management.

(c) The land capability classification does not express the interaction of many land characteristics in determining land suitability. The most limiting single characteristic always determines the suitability class regardless as to whether other limiting characteristics may also have a direct influence on crop growth or performance. Chemical soil fertility characteristics are not taken into consideration.

(d) The criteria for down-grading a piece of land are not well defined in the sense that they are not qualified. The qualification should as much as possible be defined. The defined qualification should show and verify the impact of a criteria on the growing conditions of particular crops.

(e) Lastly, the socio-economic aspects which together form a very important land use resource factor are not considered.

Table 2. An example of the Zambian crop suitability classification (Kalima 1983).

LUB LAND CLASS	RAINFED										IRRIGATED							
	Maize	Cassava	Bean	Sorghum	Finger millet	Groundnut	Sweet potato	Beans	Soybean	Tobacco	Potato	Tomato	Sweet potato	Wheat	Beans	Cotton	Rice	Pineapple
C1	1	2	1	2	1	2	1	1	1	3	1	1	2	1	1	1	1	2
C2s	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2
C2w	1	2	1	2	1	2	1	1	1	3	1	1	2	2	1	3	3	2
C3w	3	3	3	3	3	4	4	3	3	3	3	3	3	3	3	4	4	2
S1	2	1	1	2	1	1	2	2	2	1	1	1	2	2	1	1	1	1
S2w	2	2	1	2	2	1	1	2	2	3	1	1	2	2	1	3	3	1
S3w	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	4	4	2
Gw	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Land evaluation methodology of the Soil Survey Unit

Several attempts have been made by the soil survey unit (SSU) at developing a land evaluation methodology that would give a better land performance predictability than the LUB system. Mumba and Heilmann (1978) in reviewing the LUB system made the first attempt at modernizing the LUB system according to the framework for land evaluation (FAO, 1976). They made recommendations aimed at bringing the LUB system more in line with FAO framework. Bunyolo et.al. (1982) used the framework to make a rating for the land quality "soil moisture storage and climatic conditions". In this publication the concept of agro-ecological zones was first used in land evaluation in Zambia.

The Methodology

The soil survey land evaluation methodology is based on the FAO (1976) framework for land evaluation. The main emphasis has been to develop a system that translates land resource data into straight forward crop suitabilities and to outline to the user which crops are expected to grow reasonably well in a given environment. To achieve this several land qualities related to plant growth are rated and converted into land suitabilities for the most important crops using the matching process. The system follows the two stage approach of the FAO framework. Unlike in the parallel approach, a separate socio-economic evaluation will be carried out at a later stage. In the case of the soil survey unit it is envisaged that socio-economic factors will be included only when they can be mapped, described and rated, according to crop requirements, in terms similar to those of the physical factors. The separation of the physical factors from the economic factors will provide the SSU land evaluation methodology with a constant physical base, which can be re-evaluated with changed or changing social-economic conditions.

In this system, therefore, land qualities are considered to be more or less constant with time apart from annual dynamics.

Land Utilization Types

Land utilization types are only defined in a crude way. In other words the land utilization types are only defined using a single characteristic instead of defining them in a complex way using several characteristics or attributes. This has been necessitated by the scale at which resource surveys are carried out. Soil surveys and other land inventory studies carried out by the soil survey unit are at exploratory and reconnaissance level (1:50,000 and smaller). Land evaluation executed using data from such surveys can only give a rough indication of which crops can grow well. Identification of land utilization types in a complex way, using attributes like produce, capital, farm power, employment, farm sizes, technical know-how, etc. is not deemed necessary at this level.

Although the Soil Survey Unit's foremost task is to carry out small scale surveys in order to cover the whole country they are also assigned ad hoc tasks. These are usually farm surveys carried out at semi-detailed and detailed levels. In view of this, extensions have been made to the land evaluation methodology. The extensions inc'ude the identification of more land qualities and more detailed definitions of the land utilization attributes. At semi-detailed and detailed levels two complex attributes are used to define each land utilization type. These complex attributes are: (a) high inputs (b) low inputs, in relation to the production of a certain crop. The high input attribute is more of an optimistic criteria while the low input attribute is more of a pessimistic criteria. Table 3 outlines the main component characteristics of these attributes.

Table 3. Land utilization types and their attributes and attribute characteristics

ATTRIBUTES	LAND UTILISATION TYPE	
	Low input	High input
Soil degredation	X	X
Manual labour	X	X
Low level of fertilizer	X	X
Maintenance liming	X	X
Crop rotation		X
Water management		X
Ripping		X
Micro nutrient application		X
Flood protection		X
Drainage		X
Soil conservation		X
Mechanised labour		X
Recommended fertilizers		X
Reclamation/critical liming		X

Land Qualities

In the SSU land evaluation methodology the effect of land and climate on crop performance are considered on the basis of land qualities as defined by FAO (1976) and Beek and Bennema (1972). Mutual independence is assumed between the different land qualities but characteristics used to identify one land quality can be used in identifying another. The relevant land qualities used in the system are a product of an interaction between several characteristics. The important land qualities (and sub land qualities) for rainfed agriculture are listed in table 4. In a case where a compound land quality is considered the several characteristics in it are pooled together by summation or multiplicative methods to realise the final rating. There are two groups of land qualities, those related to soil conditions and those related to climatic conditions which are represented by agro-climatic zones. The rating of the climatic land qualities to produce agro-ecological zones is described by Veldkamp (1985). The most limiting climatic land quality is used

to arrive at the final suitability class by comparing it or matching it with the most limiting soil land quality.

Agro-ecological zonation (map 1) (climatic land qualities)

As already mentioned the basis of the soil survey land evaluation methodology is land resource data taking into consideration environmental factors. Environmental factors mainly deal with climatic conditions that are related to crop production. The severity of climatic limitations on crop production differs from area to area. The severity can best be expressed in the "growing period" concept as defined by the FAO Agro-ecological zones project (FAO), 1973). The first attempt at using the FAO approach was done by Bunyolo et. al. (1982). Velokamp et.al. (1985) determined and rated the climatic parameters (land qualities) following the FAO system to produced agro-ecological zones. The length of the growing season and the occurance of drought were determined on a 70% probability level using minimum expected rainfall in a 10 day period in 7 year out of 10 years. Land evaluation is then carried out and recommendations given according to the most limiting climatic land quality in each agro-climatic zone.

Rating and matching

The rating of land qualities in the SSU land evaluation methodology is expressed in either qualitative terms (i.e. low, moderate, high, good, bad) or quantitative terms (i.e. 1,2,3,4). The value given, either qualitative or quantitative, expresses the importance of a certain class limit within one land evaluation factor or attribute in relation to production. Usually a single way is followed in rating a land quality. However a complex way is followed when a land quality is affected by several characteristics.

The land quality rating depends on knowledge of the effect of certain soil and climatic conditions on crop growth.

In determining the best way of rating a land quality this knowledge is used to formulate a weighing scale depending on how the land quality influences the suitability for a certain form of land use. The general principle is that one or more land qualities weighted according to the weighing scale are the most limiting and therefore determine the suitability class (under defined management conditions).

Table 4. Land sub-qualities for rainfed agriculture

Crop			
1.	Total radiation *	14b.	Calcium carbonate/ sulphate
2.	Temperature*	14c.	Manganese toxicity
3a.1	Length growing season*		
3a.2	Total moisture*	14d.	Iron toxicity
3b.	Critical periods*	14e.	Acid sulphate condition
3c.	Drought hazard*	15a.	High humidity/pests, disease incidence*
4.	Oxygen availability	26.	Ease of puddling
5a.	Nutrient reserves		
5a.2	Phosphate fixation		
5a.3	Calcium		
5a.4	Magnesium		
5a.5	Potassium		
5a.6	Ca/Mg ratio		
5a.7	Ca/K ratio		
5b.	Boron deficiency		
5c.	Copper deficiency		
5d.	Iron deficiency	Management	
5e.	Manganese deficiency	16.	Soil workability
5f.	Molybdenum deficiency	17.	Potential for mechanization
5g.	Sulphur deficiency	18a	Land preparation
5h.	Zinc deficiency	18b	Vegetation clearance
6.	Nutrient retention		
7.	Rooting conditions		
8.	Germination/establishment		
9.	Low air humidity*	23a.	Existing accessibility
		Conservation	
11a.	Flood hazard	24a.	Water erosion hazard
12a.	Frost*	24b.	Wind erosion hazard
12b.	Wind*		
12c.	Hail*	25a.	physical soil degradation
13a.	Salinity		
13b.	Alkalinity	25b.	Chemical soil degradation
14a.	Aluminium taxocity		
		25c.	Biological soil degradation

* Land sub-qualities related to climate

At this stage in the evaluation, four (4) suitability classes (1-4) are recognised. These are not the final suitability classes. The best class (class 1) is sub-divided into 1a and 1b, bringing the number of suitability classes recognised to five (5). This is done to enable the evaluator to

include, in the assessment of highly table class land qualities whose influence on the suitability are uncertain and can only be predicted in a poor way. By classifying a suitability mapping unit into class 1b the evaluator can make the end users aware of certain poorly defined deficiencies and constraints that may be encountered in that unit. The effect of the sub-division (i.e. 1a, 1b) on the final suitability classes is usually minor.

The final suitability class is arrived at by matching the climatic land qualities with the land utilization climatic requirements on one hand and the soil land qualities with the land utilization soil requirements on the other. In diagram 1 the matching process is illustrated.

Diagram 1. Showing mechanical dynamics of the Soil Survey Unit's land evaluation methodology

```
Rating of climatic LQ                    Rating of soil LQ
        :                                        :
        :                                        :
Rating of LUT requirements               Rating of LUT requirements
   for climacic LQ                          for soil LQ
        :                                        :
        :                                        :
     Matching                                 Matching
   Climatic LQ                              Soil LQ
       vs                                       vs
 LUT climatic req.                        LUT soil req.
        :                                        :
        :                                        :
        :------------- Matching ----------:
                        1 vs 2
                          :
                          :
                          :
                Crop Suitability class
```

Matching to arrive at the final suitability class is facilitated and made possible by expressing the relationship between climate/land utilization type and soil/land utilisation type in similar preliminary suitability classes (i.e. 1a, 1b 2, 3 and 4). The final suitability classes are a product of the comparison of the soil/land utilisation type preliminary suitability classes on one axis and the climate/ land utilisation type preliminary suitability classes on the other axis as shown in table 6. Seven (7) final suitability classes are recognised (I, II,III,IV,V,VI,VII) and these are described in table 7.

Table 6. Final suitability classes as a combination of Climatic and soil suitability classes

Increasing Soil Constraints	Increasing Climatic Constraints: 1a	1b	2	3	4
1a	I	I	II	V	VI
1b	I	I	II	V	VI
2	II	II	II	V	VI
3	III	III	III	V	VII
4	IV	IV	IV	VII	VII

Future developments and problems

Several problems have been encountered in the development of this system some of which have long been solved. The problems and future development may be outlined at follows.

1. The methodology has not yet solved the question of critical values for suitability class limits. More information is required on crop requirements.

2. The influence of management and the characterization of land utilisation types has to be well defined. The effects of agricultural inputs and other agriculture practices have to be taken into consideration.

3. Although the methodology tries to use and follow simple calculations, the evaluator often finds himself having to deal with an incredibly large number of such calculations.Computerization of the system is therefore one of the next problems to be tackled.

4. The SSU methodology has brought with it several changes with regard to presentation of result. Training is therefore required for the extension staff so that they can get well versed with these system. The presentation has to be carefully explained the end users too.

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THE ROLE OF SOIL CLASSIFICATION IN TECHNOLOGY TRANSFER

S.W. Buol and H.P. Denton

One of the major purposes of the study and classification of soils has always been to facilitate the transfer of information about use and management of soil-related technologies from one location to other locations with similar soils. Bartelli (1978) lists a large number of technologies for which interpretative classifications of soil mapping units in soil surveys have been used to transfer information in localized areas. Among these are selection and yields of crops. Reclamation practices, irrigation practices, waste disposal systems, road building, and urban development. Modern soil survey of the U.S. National Cooperative Soil Survey (NCSS) make interpretations regarding transfer of more than 50 practices, ranging from yields of crops to use as a medium for uncoated steel pipe (Tant. 1982).

Most of these technologies are fairly simple, involving the transfer within a localized area of a few practices that make up only a small part of total technological systems. Documented transfers of complex technological systems from one geographical area across long distances to another based on soils have been rare. Methods for documenting technology transfer have not been generally formalized and tested.

In transfer of complex technological systems, those related to agriculture and forestry are of the most interest due to the importance of soil inputs in these technologies. They constitued the largest use of soils in terms of area, and there is strong interest in increasing food, fibre, and fuel production in lesser developed countries through transfer of advanced production technologies.

Increased production of food, fibre, and fuel in the lesser developed countries will require development of technological systems suited to the climatic, social, economic, and soil conditions existing there. This will require experimentation under these conditions. Many of these countries are small and lacking in the resources needed for developing technologies on their own (Beinroth et al,.1980). If technology developed under similar conditions in other locations could be successfully transferred, much time and expense could be saved, and production more rapidly increased. Since soil characteristics are a major part of agrotechnological systems, the use of soil classification units as a vehicle for technology transfer between widely separated areas seems possible. The U.S. system of soil taxonomy, because of its quantitative limits and its explicit consideration of climate as well as soil properties in classification, has been identified as being well suited for this purpose (Beinroth et al., 1980).

Role of soils in Transfer of Complex Agrotechnological Systems

Inputs provided by the soil are one part of very complex agrotechnological systems. In addition to other agronomic and environmental factors, a large number of economic and social factors make up the total technological framework within which agricultural and forestry practices are applied. The importance of soil characteristics varies according to the overall character of the technological complex. In many low input agricultural systems, initial soil properties may almost solely determine success or failure. In high input system, many initial soil characteristics can be modified, and soil conditions may be a lesser part of the overall technological system (Simonson, 1955). Even here, however, certain soil conditions may become limiting with existing economic constraints.

The potential usefulness of soil classification systems for transfer of technology depends on the relative importance of soil derived inputs in the technological system, the availability of other inputs, and the degree to which soil limitations can be corrected by substitution of other inputs such as capital or energy. Failure to consider the other economic, social, agronomic, and environmental inputs when attempting to transfer technology by means of soil characteristics could be disastrous. On the other hand, attempts to transfer agrotechnology without consideration of soil characteristics can be equally disastrous.

Transfer of agrotechnology based on soil classification units assumes that all other parts of the total system are controlled or are measured and considered in transfer. Such transfer can only be successful to the extent that the soil classification provides a measure of most of the variability between locations. If other important inputs in the system vary between location, similarity of soil classification units will not result in successful transfer. If all other inputs are essentially the same, then transfer based on soil classification is feasible. In evaluating the success of transfer attempts over a short period of time, seasonal variations in weather must also be considered. Weather conditions in a given year can completely obscure any long-term response to a given technology.

Generally, transfer of agrotechnology based on soil classification have focused on one practice or a relatively small group of practices within more extensive overall technological systems. The rest of the technology has been assumed to be in place, and soil characteristics have been the only major variable other than short-run climate, which was often measured and evaluated in transfer. For example, the application supplemental growing season irrigation to corn (Zea mays L) on a fine-loamy siliceous, thermic Typic Paleudult soil in eastern North Carolina might be expected to increase yields from 6000 to 9000 kg/ha as an average over a period of years. Transfer of this technology to similar soils elsewhere assumes availability of N and P fertilizer, lime, knowledgeable farmers, responsive varieties,

timeliness of operations and other important, often difficult to measure factors. Only if these conditions are met will quantitative transfer be successful.

Attempts are now being made to transfer packages of agricultural technology between locations in lesser developed countries based on soil classification units. This method of transfer has been little tested. Methods of transfer have not been formalized, and are based on soil science experience rather than hard data. It has been assumed these transfers will work, but there has been little research to document this. Perhaps in part this is because it is an empirical procedure, seeking merely to discover what will work, and not the underlying principles. Scientists are usually interested in more intensive study of basic relationships in agronomic systems.

Soil Classifications Systems used in Transfer of Technology

Natural soil classification systems, such as the U.S. system of soil taxonomy attempt to divide soils into groups based on naturally occurring assemblages of properties (Soil Survey Staff. 1975). Groups are based on known genetic relationships, often without reference to any particular use. The result is a large number of relatively homogeneous groups about which many statements can be made with regard to properties and behaviour (Cline. 1949: Orvedal and Edwards. 1941). The natural classification serves as a system to catalogue as much as possible of the known information about soil properties and their interrelationships.

Technical classification systems are developed for the purpose of making statements about one particular use, or at most a very few uses. Thus, they use as class criteria only a few properties of greatest importance to a particular use (Buol et al,. 1980: Cline. 1949: Orvedal and Edwards, 1941). In these classifications there is no concern about the relationships among properties or about other potential uses. Technical classification systems have many fewer classes than natural systems, and are simpler to apply and use. Such technical classifications have often been used in the past for transferring simple technology. They may also be used in the more complex transfer of components of agrotechnological systems.

A natural classification system catalogues as much information on as many properties as possible, and most properties needed in setting up technical classification systems can be determined directly or inferred from natural classification units. Thus, technical classification units can be derived by combining classes at the lowest level in a natural classification system. One of the great values of a natural classification system such as the U.S. system of soil taxonomy is the large amount of information it can convey, making possible the derivation of large numbers of technical classification systems from the single comprehensive classification. The

complimentary relationship of natural and technical systems is analogous to the relationship within a large library. The stacks of the library are the natural classification system for all the available information. Such special use facilities as the reserve room, documents section, and map room are the technical classification designed for the needs of specific users.

A problem with this concept is that although a natural classification system is based on many properties, no system can possibly consider all soil properties. For some uses, properties that are not considered in the natural classification and therefore cannot be reliably inferred may be of great importance. It may be necessary to measure and consider these other soil properties in developing classifications for specific uses. Of particular interest in the transfer of agrotechnology are surface soil or plow layer characteristics. Surface soil characteristics are not generally used as criteria in the U.S. system of soil taxonomy. This has been identified as a problem in transferring agrotechnology, as surface soil characteristics are known to be of great agronomic significance (Beinroth. 1981: Buol and Nicholaides 1980). Surface soil characteristics accounted for most of the variation in corn yields which could be attributed to soil on the Coastal Plain of North Carolina (Sopher and McCracken, 1973). As a result, the use of the U.S. system of soil taxonomy as a basis for transfer of agrotechnology will require use of phases of soil taxa which include surface texture (especially among Alfisols and Ultisols), slope, rockiness, and other landscape and surface layer characteristics.

Technical systems based on the U.S. system of soil taxonomy are likely to be used as the basis for transfer of agricultural technology based on soils. In these technical systems taxonomic categories may be combined, but others may have to be split based on important soil properties not considered, such as surface soil texture. Quantitative class limits, chosen to some extent with effects on plant growth in mind, and explicit consideration of soil temperature and soil moisture regimes make the U.S. system of soil taxonomy more suitable as the basis for building technical classifications than earlier, more qualitative classification schemes. The development and widespread application of the U.S. system of soil taxonomy in classification and soil survey has made possible the derivation of large numbers of technical classifications suitable for transfer of particular agricultural technologies. Thus far, this has occurred largely within the United States as a part of soil survey activity. It is now being extended to worldwide agrotechnology transfer.

One attempt to use the U.S. system of soil taxonomy in this way is the Fertility Capability Classification (FCC) system, developed by workers in the Tropical Soils program at North Carolina State University (Buol et al., 1975: Sanchez et al., 1982). The FCC system is a technical classification system, designed to facilitate transfer of information about fertilization of agronomic crops. It is based on soil

properties thought to influence response to fertilization. Many of the class limits of this system can be inferred or determined directly from class limits in the U.S. system of soil taxonomy. However, the system includes surface soil texture, as well as other surface soil properties of importance in soil fertility management. The system is based on surface texture at the highest level, then on subsurface texture, and finally on a number of soil properties and climatic properties called condition modifiers.

Evidence of usefulness of soil classification units in technology transfer.

Reports of work specifically testing classification systems for their usefulness in transfer of technology are rare. There is a considerable amount of evidence from a number of sources indicating that crop yields, response to agronomic practices, and soil-fertilizer relationships do vary between soil classification units. This can be taken as evidence that transfer based on soil classification is feasible, if all other aspects of the technological system are accounted for. However, the usefulness of soil classification for transfer needs further documentation and quantification.

There have been numerous tests of the effect of soil series differences on yields of agronomic crops and on tree growth. Studies of crop yield by series include Odell (1950) and Rust Odell (1957) in Illinois, Webster et al. (1977) in England, and Shrader et al. (1957) in Iowa. Results from these studies indicated that though yields differed by series, management and climate had to be considered as well. In all cases, soils were from relatively small geographic areas. Allgood and Cray (1978) found that classification in the U.S. system of soil taxonomy and surface texture were closely related to 10-year average yields of crops under a defined management level in Oklahoma. Carmean (1961) and Shetron (1972) studied the relationship between soil series and growth of trees in Ohio and Michigan, respectively. Both found soil series to be a relatively poor predictor, but found that other soil properties not considered in series were very important determinants of tree growth. Both felt that series needed refinement to use as predictors of tree growth. The illustrates the need for a separate, technical classification to predict tree growth. It should be pointed out that several of the studies quoted above predated the U.S. system of soil taxonomy. Thus, the soil series used were more broadly defined than those used presently.

There have been a number of tests of crop yield response to fertilization as affected by difference in soil classification unit, usually soil series or type. These include Baird and Mason (1959) in North Carolina. Rennie and Clayton (1960) in Canada, and Pesek and Heady (1967) in Iowa. In all three of these studies, response to fertilization of crops was found to vary by soil type. Varvel et al, (1981) found that the use of different

soil tests extractants for P on Tripp soils (coarse-silty, mixed mesic Aridic Haplustolss) and on Mitchell soils (coarse-silty, mixed (calcareous), mesic Ustic Torriorthents) gave better predictions of response than did any one extractant on the pooled data.

Work in North Carolina has shown that the rate of decline of P in soil solution as a result of continuous cropping and P uptake varies by soil (Novais and Kamprath. 1978). As seen in Fig. 1 three soils showed the same rate of depletion. These were Wagram loamy sand (loamy, siceous. thermic Arenic Paleudults). Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults) and Goldsboro sandy loam (fine-loamy, siliceous, thermic Aquic Paleudults). All three were relatively well-drained upland soils of similar mineralogy, surface clay content, and surface area. Two other soils, Georgevile silty clay clayey, kaolinitic, thermic Typic Hapludults) and Portsmouth sandy loam (fine-loamy over sandy or sandy skeletal, mixed, thermic Typic Umraquults) showed different rates of depletion. Both of these had more clay and more surface area in the A horizon than the other three soils. The amount of P fertilization needed annually to maintain critical levels of P in soil solution varied by soil type (Table 1) and was related to texture, mineralogy, and reaction (Cox et al., 1981).

Table 1. Critical P levels and annual P fertilization rates needed to maintain these levels by soil. After Cox et al., 1981

Soil	Critical P level double acid	Annual Maintenance P
	Kg P ha	
Georgeville sicl pH = 6.0, kaolinitic, thermic, Typic Hapludults	20	42
Portsmouth fsl pH = 6.0, fine loamy over sandy or sandy skeletal, mixed thermic Typic Umbraqult	50	16
Haverhill Wood Mountain cl pH = 6.7, Chernozem (Canadian system)	30	1

All these studies of fertility reactions showed differences in results between soil classification units. All were related to characteristics that could be used in technical classifications for transfer of fertilization technology. However, none of these studies was intended to test the use of a predetermined classification for predicting fertilizer response.

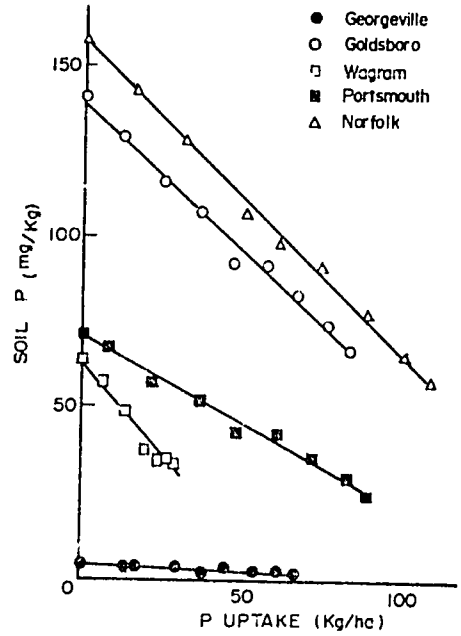


Fig 1 Decrease in Bray I extractable soil P as a function of uptake of soil P by successively cropping five soils.

Aggregate data from the 1978 Census of Agriculture (Bureau of Census. 1978) on the use of irrigation and liming as practices on cropland in selected states can be used to illustrate how frequency of such practices changes as general soil characteristics change. Table 2 shows the proportion of harvested cropland on which lime was applied in 1978 in certain states. The proportion is highest in North Carolina, where most cropland soils are Udults or Aqults, naturally low in bases. It declines greatly in Illinois, where soils are largely Udols, Aquolls, Udalfs, and Aqualfs, naturally higher in bases. The proportion of cropland limed declines further in Iowa where soils are largely Udolls and Aquolls and still further in Nebraska with largely Ustolls and Udolls. This trend closely follows the trend of base content expected as these general soil characteristics change, confirming changes in a technological practices can be related to general soil characteristics. Table 3 shows a similar trend in the proportion of harvested cropland irrigated as soil moisture regime changes from udic with some ustic in Iowa, to ustic with some udic and aridc in Nebraska, to ustic and aridic in Colorado to aridc with some ustic in Utah, through aridic in Nevada. Other factors, such as availability of water obviously influence this, but the trend with change in moisture regime is clear. If such statistics were available by soil moisture regimes or more exactly by soil taxa, the degree to which soil taxa reflect and thus predict soil management practices would be expected to be even more harmonious.

Table 2. Area to which lime applied as a proportion of harvested cropland in selected states (Bureau of Census 1978).

State	Harvested cropland	Area limed	Dominant soils	Proportion of harvested cropland limed
	--------- ha	------		%
North Carolina	1,849,214	382,760	Udults, Aqults.	20.7
Illinois	10,267,446	510,112	Udolls, Aquolls, Aqualfs, Udalfs.	5.0
Iowa	11,445,497	630,354	Udolls, Aquolls.	2.9
Nebraska	9,068,577	37,801	Ustolls, Udolls.	0.4

Table 3. Proportion of harvested cropland irrigated as a proportion of total harvested cropland (Bureau of census 1978).

State	Harvested cropland	Irrigated cropland harvested	Dominant soils	Proportion of cropland irrigated
	--------- ha	--------		%
Iowa	11,445,497	34,581	Udolls, Aquolls.	0.3
Nebraska	9,068,577	2,224,382	Ustolls, Udolls.	24.6
Colorado	2,380,766	1,112,865	Argids, Ustolls.	46.7
Utah	475,588	344,021	Argids.	72.3
Nevada	242,073	242,073	Argids.	100.0

Recently there have been some published reports of attempts to test soil classification systems for their use in transfer of agrotechnology. The Benchmark Soils Project, a joint research project of the Univ. of Hawaii and the Univ. of Puerto Rico, is designed to test the hypothesis that soil family in the U.S. system of soil taxonomy defines a discrete agroenvironmental entity suitable for use in transfer of agrotechnology (Beinroth et al., 1980; Beinroth. 1982). The methodology employed was to locate identical experiments testing the response of corn to N and P fertilization on soils in the same family at widely scattered sites in several tropical countries to determine if the response was the same at all locations within a single family. Three soil families were chosen for study. Results from experiments in Brazil and Puerto Rico on clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox have been reported (Beinroth. 1982). Response was evaluated by three statistical methods in part developed solely for this project. Results were mixed, but the conclusion was that the transfer hypothesis was supported and that transfer was possible if climatic variables and initial soil nutrient levels were determined. These tests actually involved more than N and P response transfer: they involved transfer of a complex technology including practices such as drip irrigation. Beinroth 1982 reports that preliminary results indicate that many soil properties important to plant growth, many responses to management and overall crop production potentials are similar within families but differ between families. The P required for maximum yields (Table 4) and response to K and lime differ between the three soil families. Results have also been reported for the Hydric Dystrandepts (Benchmark Soils Project, 1979; Cady et al., 1982). These results indicate that responses were similar between locations and transfer of technology feasible, if

initial soil nutrient levels were considered. The need for greater cooperation between soil testing and soil classification in agrotechnology transfer is obvious.

Table 4. Maximum corn yields and P fertilization required to reach those in the Benchmark Soils Project by soil family After Beinroth. 1982

Soil Family	Maximum yield	Phosphorus rate
	---------- Kg/ha	---------
Clayey, kaolinitic, isohyperthermic, Tropeptic Eutrustox	9,000	40
Thixotropic, isothermic, Hydric Dystrandepts	7,000	150
Clayey, kaolinitic, isohyperthermic, Typic Paleudults	6,700	100

A few tests of the FCC technical system, described in an earlier section, have been made. In testing the FCC system for its value in transfer of technology a different approach than that of the Benchmark Soils Project has been used. Researchers have attempted to show that the use of the technical classification system results in better prediction of response to a given technology than an aggregate prediction across all soils. If prediction is significantly better, then the technical classification is considered to have value in transfer of technology. Response of potatoes Solantum tubeforum L. in Peru to fertilization was found to differ by FCC grouping (Ryan and Perrin. 1973). Response functions for P are shown in Fig. 2. Average return on these same sites to fertilizer was $770 / ha for a blanket fertilizer recommendation, $860 / ha for soil test-based recommendations, $920 / ha for FCC-based recommendations, and $965 / ha for recommendations using both FCC and soil test information.

A set of response data from fertilizer trials in Minas Gerais and Coias, Brazil with rice (Oruza satita L), corn, field beans (Phascolus oulgaris L) and cotton (Gossypium hirsutum L), and potatoes showed that FCC groupings were related to general yield levels, but not as closely related to fertilizer response (Couto, 1976). Part of the problem with inconsistent results was related to lack of lime, poorly adapted crop cultivars drought, and insect attacks, illustrating the need to consider all facets of production in a technological system when attempting a soil based transfer.

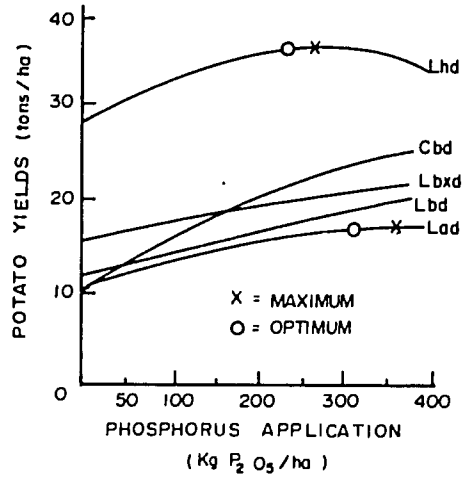


Fig 2. Differential response to different fertility capability in peru potato experiments.

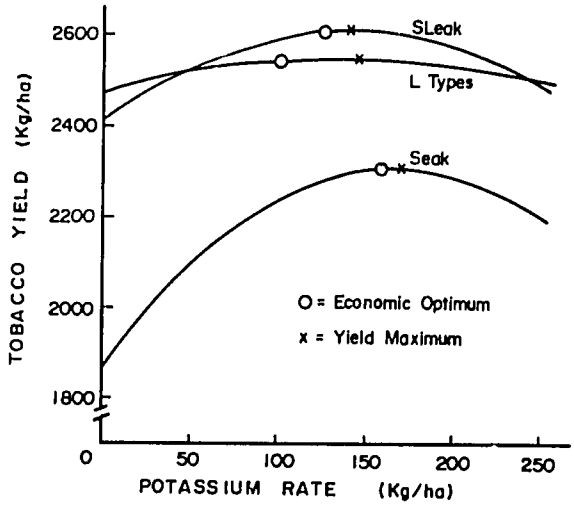


Fig 3. Response of flue-cured tobacco to K fertilization and fertility capability classification soil groupings.

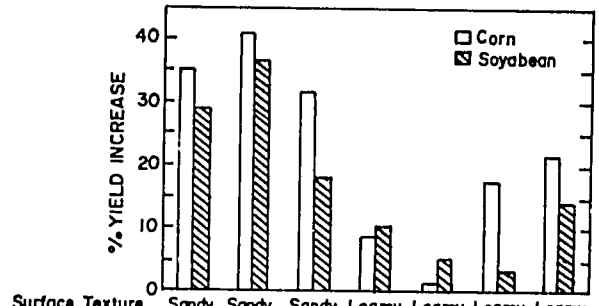
In a series of regional soybean trials in the southeast U.S. FCC criteria were found to be related to overall yields and to frequency of lime additions (Couto, 1978). In North Carolina, yield response of flue-cured tobacco to K fertilization at 13. North Carolina locations differed by FCC unit Fig 3. (H.P. Denton unpublished data). Soils with deep sandy surfaces (Seak) showed stronger response than those with thinner sandy surfaces over loamy subsoils (Sleak). Soils with loamy surfaces (I. type) showed the weakest response.

Presently, studies are being conducted in North Carolina to determine the effect of classification units from a technical soil classification system on yield response of corn and soybeans to tillage treatments. Figure 4 shows the relative response of corn and soybeans to subsoiling to a depth of 45 cm as compared to discing twice to a depth of 15cm without any deeper tillage, by soil group from a series of experiments conducted over several years (unpublished data. H.P. Denton). These results clearly show large differences in corn and soybean (Glycine max I. Merr) response by soil. Soils with sandy-textured surfaces and udic moisture regimes give the strongest responses, while soils with loamy-textured surfaces in general give less response. These responses were predictable using a technical soil classification system based on surface texture, subsoil texture, surface thickness, and drainage class. It appears that tillage techniques can be transferred by soil classification unit in North Carolina.

One of the objectives of any classification is to produce or create units of taxa from within the whole that are more homogeneous than the whole. Hierarchical classification such as the U.S. system of soil taxonomy attempts to do this in a series of ever more narrowly defined, and thus more homogeneous, taxa. Some ongoing studies (B. Hudson, unpublished data) of the height and age of loblolly (Pinus taeda L.) pine growing on 220 Ultisol sites in the Atlantic Coastal Plain illustrates that each level in the U.S system of soil taxonomy provides for greater confidence in the growth curves (Fig.5). Since the soil at each site was identified at the series level the standard deviation from the linear age-height relationship of all sites within each series could be calculated. By aggregation of series into the higher taxa the same test could be calculated for each higher taxa. The observed decrease in standard deviation from about 7.5ft, of growth found when the soils were identified only as Ultisols to about 5.0 ft of growth when the series were identified is one way of illustrating the increased homogeneity of taxa within the U.S. soil taxonomy hierarchical system.

Mathematical Modelling of Soil Properties in Technology Transfer

An alternative to the use of soil classification units as a means of measuring soil effects in technology transfer is the use of mathematical models.



SOIL CLASS	Surface Texture	Sandy	Sandy	Sandy	Loamy	Loamy	Loamy	Loamy
	Surface Thickness	50cm	50-38cm	38cm	38cm	38cm	38cm	38cm
	Subsoil Texture	Loamy	Loamy	Loamy	Loamy	Clayey	Clayey	Loamy
	Moisture Regime	Udic	Udic	Udic	Udic	Udic	Aquic	Aquic
DISK ONLY YIELD	Corn Mg/ha	4·43	5·05	5·63	6·18	6·54	3·67	5·72
	Soyabean Mg/ha	1·29	·67	·67	2·12	1·95	2·40	1·33

Fig 4. Relative yield increases of corn and soyabeans from subsoiling as compared to discing only by soil group.

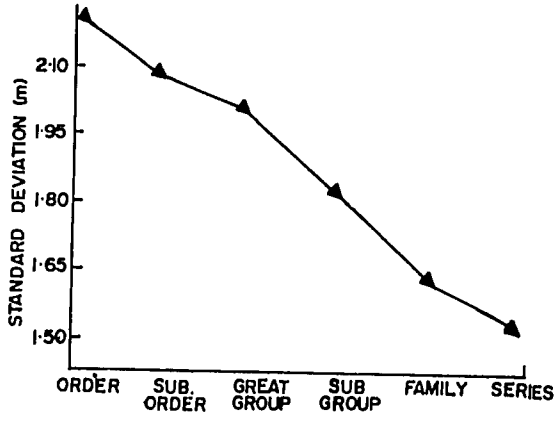


Fig 5. Mean standard deviation for linear relationships between height and age of loblolly pine trees vs level of soil classification–230 plots.

Such models can be derived empirically by relating soil properties directly to response obtained to practices through regression techniques (Sopher and McCracken, 1973). The relationships thus derived can then be used to make predictions about response to the same technological practices in other locations.

The development and use of such models has a great deal of intellectual appeal. Such models give very precise, quantitative predictions. Developing empirical models may result in discovery of very important fundamental information about relationships between soil properties and the technologies employed. However, attempts in North Carolina to develop yield prediction equations of this type across wide ranges of soil conditions have revealed a number of problems in fitting and applying such models. Equations relating corn and soybean yields to soil, management, and climatic variables can be developed that explain high proportions of yield variation (Reich et al.1981: Sopher and McCracken, 1973). However, these equations are limited in their applicability to new sites because of the high degree of intercorrelation of variables (particulary soil variables). The lack of range in the data for many variables, and the lack of fundamental knowledge about many interactions, leading to poor model specification. Thus, predictions at new sites may be very inaccurate. In addition, obtaining the detailed information needed to apply these models at new sites is expensive, difficult, and time consuming. An alternative to empirical regression modeling is the development of large-scale simulation models. Models of various components of production systems are developed separately, based on empirical data and known fundamental relationships. The components are combined to build the simulation model. An example is the EPIC model currently being developed for the purpose of predicting the effects of erosion on productivity (Williams et al., 1982). The effects of application of new technologies to production systems could be simulated by use of these models. To do so would require a great deal of fundamental knowledge about the system, and a great deal of detailed information.

The use of classification units to transfer technology has some disadvantages relative to models, particularly because of the range in properties that exists within the unit. However, it is cheaper and faster, and if the classification has quantitative units and is based on relevant properties, it should define a unit homogeneous enough for most purposes. Given our present state of knowledge about the fundamental relationships between soil properties and many of the technologies being transferred, it is doubtful that more precise information about soils could be efficiently used.

As more knowledge is accumulated about the relationships of soil properties to other facets of agrotechnological system, the use of mathematical modeling techniques as a means of considering soil properties in technology transfer will undoubtedly increase.

For the present, however it appears that soil classification units are more likely to be used than mathematical models for most transfer of technology.

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THE INTERNATIONAL BENCHMARK SITES NETWORK FOR AGROTECHNOLOGY TRANSFER - ADJUSTING NATIONAL PROGRAMMES TO MEET FUTURE NEEDS

Goro Uehara

Introduction

Adjustments in national agricultural development programs to meet future needs will succeed only if the adjustments benefit the farmers. Not only must the farmers benefit from the change, they must be convinced of the benefits. A farmer's incentive to make adjustments is influenced by the opportunity to increase profit and income and to improve social status. Any national policy designed to alter production goals must therefore communicate this intent to farmers and provide them with the capacity to make informed judgement about the consequences of implementing the recommended change.

Next to certainty of failure, uncertainty of success is the main deterrent to adoption of recommended adjustments. For this reason, a major goal of nation agricultural programs must be to reduce uncertainty in the consequences of change at the farm level.

Adjustment Strategies

One means to achieve the desired consequences of program changes is to do so by trial and error. This strategy succeeds if the adjustments, implemented by a few innovative farmers, result in early and highly visible beneficial outcomes and are subsequently adopted by the larger population of conservative farmers. Many of the highly publicized success stories in agriculture began in this way. What is not publicized, however, is the much larger number of failures. Farmers pay a high price for failure, and the risk of failure from trial and error adjustments has made the already conservative agriculture sector even more cautious and suspicious of change.

The farmers' confidence in government recommendations can be regained by providing them with choices that have a high probability of success. One way of improving the chance of success is to implement an adjustment strategy based on systems analysis and simulation.

Systems-Based Adjustment Strategy

The central concept of systems-based adjustment is that the whole system must be understood in order to evaluate changes in any single component of the system. This approach brings together existing knowledge of the farming system, identifies the major components and processes and their interactions, and helps to identify bottlenecks to improve performance.

Until recently, this approach could not be applied to complex systems consisting of large numbers of interdependent and interacting factors. Recent advances in information technology, however, now enable users to organize large quantities of data to simulate complex processes in agricultural systems so that costly and time-consuming trial and error adjustments can be avoided.

The first and basic element for adjusting agricultural programs is to know how to apply knowledge of specific processes within complex agricultural systems consisting of many interacting parts, and then to utilize the knowledge to obtain a comprehensive understanding of the way the system operates as a whole. A thorough understanding of systems operation is the basis for developing models that mimic, and therefore, predict the behaviour and performance of each part as it interacts with other parts in the system. Understanding and prediction provide the basis for controlling outcomes. In fact, a thorough understanding of how agricultural systems operate is important only insofar as it helps farmers and government planners to control outcomes in desirable and predictable ways.

The International Benchmark Sites Network for Agrotechnology Transfer Project.

Before adjustments in agricultural programs are implemented, questions such as how a crop or crop cultivar might perform at a particular location and season must be answered. Questions concerning crop management and economic returns must also be answered. But the complex interactions among soil, weather, crop, and management factors make questions like these difficult to answer. Recent advances in computer technology and information science, however, now permit researchers and government policy makers to make useful predictions about how a new crop will perform in new locations.

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project was established to acquire and test computerized models of crops in a network of benchmark research stations around the world. The aim of the project is to enable decision maker to predict crop performance in new locations so that costly and time-consuming trial and error adjustments might be minimized.

The Minimum Data Set

How much information does one need to predict crop performance in a location where the crop has never been grown? Efforts to answer this question were undertaken in two meetings of IBSNAT collaborators held in March 1983 in Hyderabad, India, and in August 1984 on the island of Maui in Hawaii. The Hyderabad meeting resulted in a publication entitled "Minimum data sets for agrotechnology transfer" (Godwin et al 1984) and a draft of a manual on "Experimental design and data collection

procedures for IBSNAT." This draft document (Jones 1984) was revised at the 1984 Maui meeting and published in final form shortly thereafter. It contains the minimum data set for simulating the growth and performance of ten crops including four cereals (maize, rice, sorghum, and wheat), three grain legume (groundnut, phaseolus bean, and soybean) and three root crops (aroids, cassava, and potato).

SOYGRO and CERES Crop Models

IBSNAT has adopted the SOYGRO and CERES crop models to simulate the growth and development of, respectively, grain legumes and cereals. SOYGRO is a soybean growth simulator designed to improve irrigation and pest management tactics. The model has been tested for Florida conditions, but is currently being modified to simulate soybean performance in a wider range of environmental situations, including the tropics. To this end, the model is being designed to be sensitive to soils, weather, and cultivar differences. Such factors as night length and temperature that affect phenological development, and radiation, temperature, soil water availability, and cultivar characteristics that affect growth and dry weight partitioning are taken into account. The model enables the user to assess the economic feasibility of alternative insect, irrigation, and pesticide tactics. The long-term goal of SOYGRO'S creators is to modify the soybean model to simulate growth of groundnut and phaseolus beans for IBSNAT collaborators.

An interdisciplinary team of scientists at the Grassland, Soil and Water Research Laboratory in Temple, Texas has been responsible for developing crop models for wheat and maize. To distinguish them from other wheat and maize models, the Temple models have been named CERES-wheat and CERES-maize. CERES-wheat has been independently tested in the U.S. (French and Hodges 1985) and found to predict phenological events with a high degree of accuracy. Water balance and nitrogen dynamics subroutines enable CERES-wheat to simulate the effects of water and nitrogen shortages (ICRISAT 1984). The model operates on the law of the minimum, so that with long-term historical weather data the model is able to simulate how nitrogen fertilizer use-efficiency is affected by rainfall regimes.

One aim of IBSNAT is to test and validate the SOYGRO and CERES crop models for use in the tropics. Scientists at the University of Hawaii have made minor adjustments in the CERES-maize model and have tested it with experimental data from Hawaii, the Philippines, and Indonesia. Figure 1 shows a comparison of predicted and observed grain yield from these three locations on three kinds of soils. The Tropeptic Eutrustox soils occur in warm, dry environment; and the Typic Paleudults in warm, humid environments. The predicted yields tend to be higher than the observed because the latter is generally lowered by factors such as insect and disease that are not included in the model.

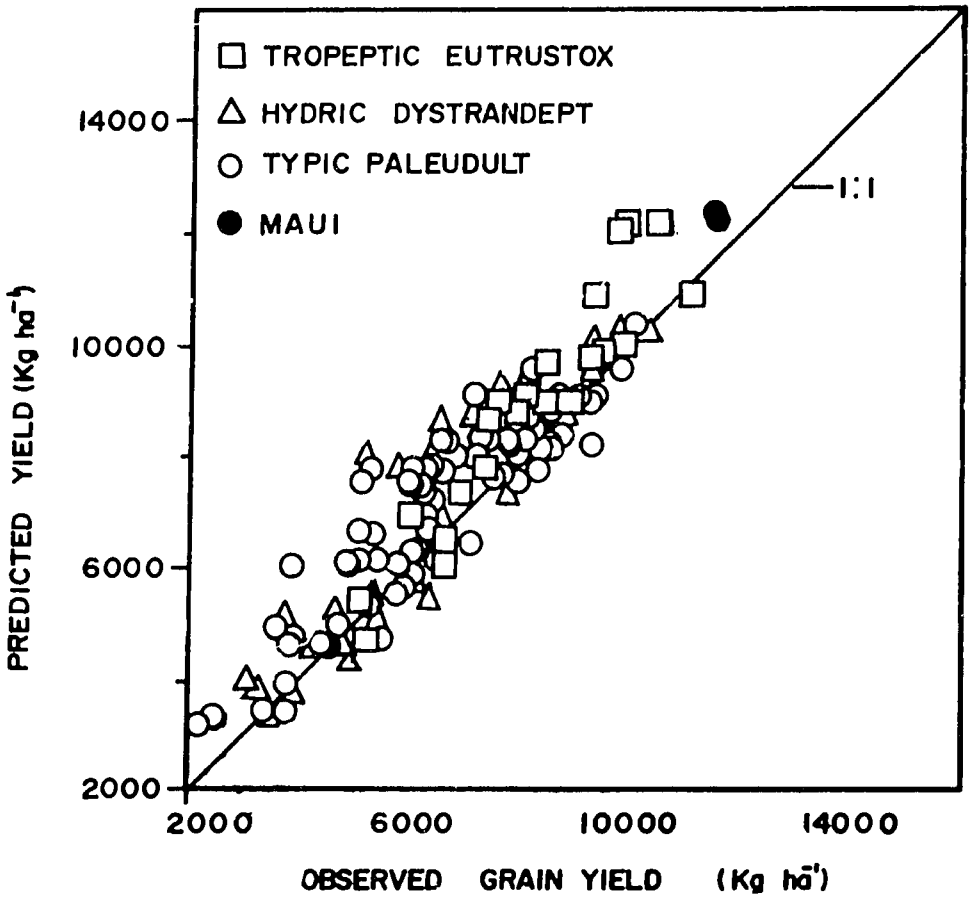

Fig 1 Comparison of predicted and observed maize grain yield on three soils in Hawaii, the Philippines and Indonesia. (5)

IBSNAT crop models are designed to predict not only yield, but major phenological events as well. Figure 2 shows a comparison of predicted and observed days to physiologic maturity and silting.

The capacity of the modified version of CERES-maize to predict phenological events, biomass production, and grain yield under extreme environmental conditions is illustrated by the results summarized in Tables 1 and 2. The results represent maize planted on the same day at three locations on the slopes of Mt. Haleakala on the island of Maui in Hawaii. The effect of environment on maize growth, development, and yield was large, but the model was able to simulate crop development and predict final yield with a high degree of accuracy.

Table 1. Comparison of observed and simulated phenological events for X304C variety on the slopes of Mt. Haleakala, Maui, Hawaii (Singh 1985).

Elevation (cm)		Days after planting			
		Emergence	End of juvenile stage	Silking	Physiological maturity
77	Observed [b]	6	23	62	120
	Simulated	5	25	67	119
340	Observed	7	28	73	138
	Simulated	5	28	73	132
800	Observed	9	42	104	176
	Simulated	7	38	97	174

[a] Planted on April 24, 1984

[b] Bartholomew (unpublished data)

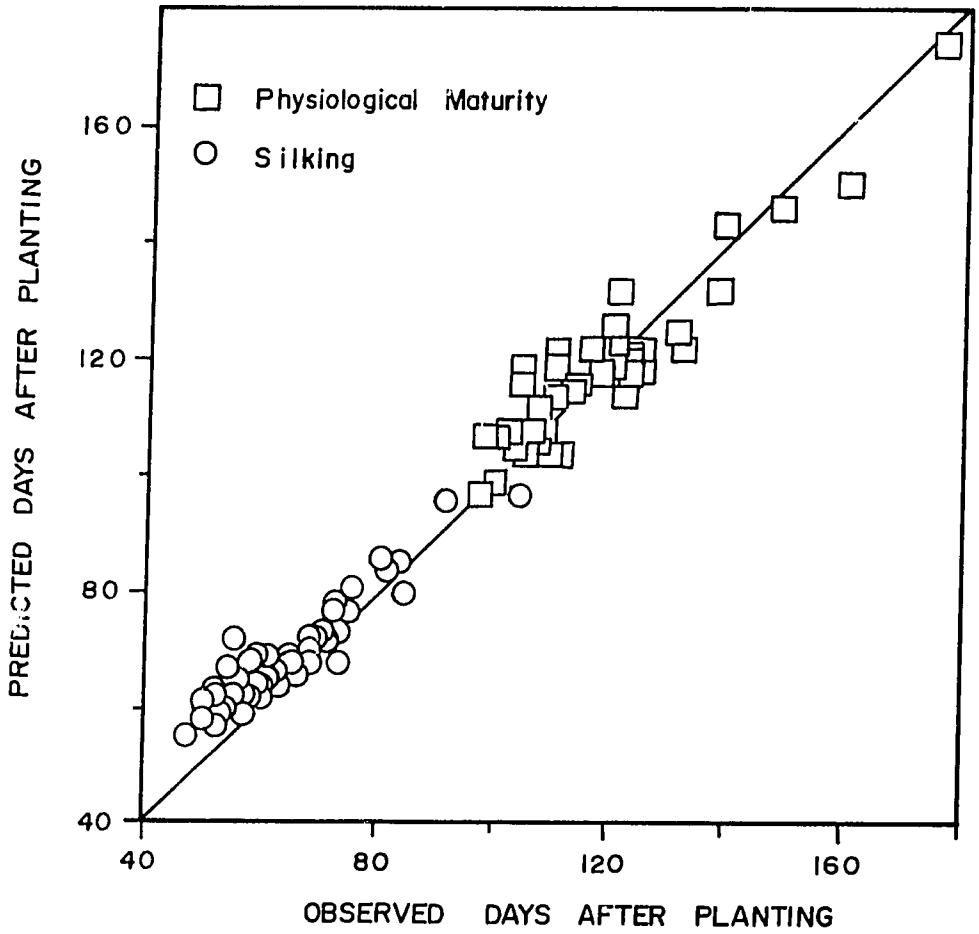

Fig 2 Comparison of predicted and observed phenological events of maize (5)

Table 2. Comparison of observed and simulated yields for X304C variety on the slopes of Mt. Haleakala, Hawaii.

Elevation (m)		Grain yield $kg\ ha^{-1}$	Total dry matter $kg\ ha^{-1}$
77	Observed *	11533 ± 860	25025 ± 2145
	Simulated	12339*	23699*
340	Observed	11600 ± 994	21033 ± 1898
	Simulated	1234*	25182
800	Observed	9178 ± 1654	18731 ± 4659
	Simulated	9009*	22584*

* Bartholomew (unpublished data)

* Simulated result is within a standard deviation of the observed mean.

Conclusion

Recent advances in information technology enable researchers to develop crop models that predict crop performance in a wide range of agroenvironments. These models have the potential to permit policy makers to predict which crops will perform well where, and during which times of the year. The capacity to predict outcomes enables model users to bypass risky, costly, and time-consuming trial and error adjustments, and provides government planners and farmers with the means to choose strategies and tactics that will result in desired outcomes.

IBSNAT is an international programme that enables tropical countries to test and validate crop models for eventual use in national agricultural planning. Participation in this programme is also designed to encourage tropical countries to use systems simulations in agriculture for strategic planning by government planners and tactical planning by farmers.

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GENERATING FIELD DATA FOR VALIDATION OF CROP MODELS IN ZAMBIA

Vernon R.N. Chinene

Introduction

The Soil Science Department in the School of Agricultural Sciences of the University of Zambia is collaborating in an International research project on agrotechnology transfer. The project is called 'International Benchmark Sites Network for Agrotechnology Transfer' (IBSNAT) and is funded by the United States Agency for International Development (USAID). The University of Hawaii, under contract from USAID, serves as the coordinating entity and headquarters of IBSNAT. IBSNAT has created a prototype network for the purpose of developing, validating and using a scientific method for the effective transfer of agrotechnology among and within countries in the tropics and subtropics.

Field experiments are being carried out on a number of crops to generate the minimum data set required to validate the crop models supplied by IBSNAT. The main interest of the Department in this research effort is to have access to several crop models, validate them to Zambian conditions, and then use them to transfer agrotechnology from the sites where it is generated to other sites where it is likely to succeed. This method is very useful in land evaluation where land performance is assessed for specific purposes. The University Farm is the site of IBSNAT research work.

Soil Taxonomy (Soil Survey Staff, 1975) has been adopted as the main system of classifying soils in Zambia. Using this system, the Soil Survey Unit in the Ministry of Agriculture and Water Development is defining agroenvironments in which crops and agricultural systems are likely to respond and perform in common and predictable ways. Within the agroenvironments benchmark soils have been recognised in which all research related to transfer of agrotechnology will be done. In all, 22 benchmark sites have been identified. One of them - the University Farm- became the first IBSNAT site in 1984.

Following is a description of the first IBSNAT experiment at the University Farm.

This was a study on the effects of water and fertilizer nitrogen on maize yields on a Clayey, Kaolinitic, Isohyperthermic, Oxic Paleustalf. Water availability and nitrogen are the major factors limiting maize yields in Zambia. Maize production is heavily dependent on rainfall and consequently very susceptible to periodic droughts. Under adequate water supply to the crop, growth is a function of nutrient availability. However, when water supply becomes

limiting, the effect of soil fertility becomes less significant and hence crop growth becomes a function of water availability. It is therefore important to evaluate quantitatively the effects of these drought spells on maize growth and yield and their interaction with adequate and inadequate levels of nitrogen.

Materials and Methods

The experiment was planted on December 7, 1984 at the University of Zambia Farm on a clayey, kaolinitic, Oxic Paleustalf. A split-plot design with 4 nitrogen treatments, 2 water levels and 3 replications was used. The nitrogen treatments were: 0, 56, 112 and 168 kg N/ha. The water levels were: rain only and rain + supplementary irrigation. A basal blanket application of 40.0 kg P_2O_5/ha and 20 kg K_2O/ha was applied in all plots. Nitrogen was applied at three stages; 20 kg N/ha was applied as part of the basal dressing. The remaining nitrogen for each treatment was equally split and applied at 33 and 56 days after emergence.

Before planting, composite soil samples were collected from each replication and analysed for pH, NO_3^-, NH_4^+ and water content. Plots 9 x 5.25 m were prepared for planting. Seven rows 75 cm apart were cut in each plot. Maize (Zea Mays L.) seeds of MM 752 variety treated with captan were planted on December 7, 1984. The seeds were placed at 5 cm depth and 25 cm intervals in each row with 2 seeds per hill.

When plants had four fully emerged leaves (Stage 1 in Hanway, 1971), they were thinned to one per hill. Where one hill had no plants, two plants were left in one of the adjacent hills. Where two consecutive hills had no plants, two plants were left in both adjacent hills. If more than two consecutive hills had no plants 10 days after planting, they were replanted but not harvested. The plant population was 6 plants per M2.

The experiment underwent two dry spells; the first lasting 12 days occurred at 41 days after emergence and the second, lasting 14 days occurred at 98 days after emergence. In these periods, 3 cm of water was applied by furrow irrigation to the plants in which supplimentary irrigation was one of the treatments. During the course of crop growth, dates of phenological events were recorded. Leaf area index measurements were made as an indicator of crop growth. The method adopted from Turner and Beyy (1973) involved measuring the length and maximum width of each green leaf on a plant and adjusting the length-width product by 0.73. At maturity measurements were made of grain yield and above ground total biomass yield.

The main purposes of generating these data is to be able to validate the Crop Environment Resource Synthesis (CERES) maize model developed in Temple, Texas for use in Zambia. This is a maize growth simulation model sensitive to climate, soil, nitrogen and phosphorus fertility, soil physical properties, and

genotype. Maize genotypes differ in many ways, including sensitivity to day length, thermal time (growing degree days) needed to complete various stages of growth, and potential kernel number per ear. The CERES model contains several genotype-specific variables that quantify this variability. These variables will be adjusted until reasonable agreement between actual and observed dates of silking and kernel numbers are obtained in each treatment. The initial soil nitrogen measurements will be used to simulate the nitrogen balance in the soil throughout the growing period. Actual rates and dates of nitrogen fertilizers, weather data, and irrigation amounts will be used to run the model.

The simulated yield components will form the basis for determining the accuracy of the CERES model to predict maize growth under conditions of the University farm.

Results and Discussion

The grain and stover yields obtained in this study are presented in figures 1 and 2. The data in figure 1 show that under rain only, lower grain yields were obtained in all treatments when compared to rain + supplimentary irrigation. The reductions in grain yields among the treatments were 1.5% under 168 kg N/ha, and 10.9% under 112 kg N/ha. During the growing season, two dry spells occurred; the first, lasting 12 days occurred at 61 days after emergence and the second, lasting 14 days occurred at 98 days after emergence. However, analysis of variance showed that the effect of the water stress was not significant. This suggests that when the soil is at field capacity it is able to meet the evaporation demand of the crop for about 14 days.

The effect of the nitrogen treatment was not significant. Figure 1 shows that high yields were obtained in all the treatments. The highest yield of 9.7 tons/ha was obtained at 112 kg N/ha. The lowest yield of 7.9 tons/ha was obtained at 0 kg N/ha but the difference was only 18.5%.

Tables 1 and 2 show that the soil has very rich chemical properties. The pH is near neutral and although the pre-plant nitrogen levels were low, the soil had high levels of bases in the right proportions. This therefore accounts for the high yields obtained in the partial controls and the lack of significant response to nitrogen in the experiment.

Figure 2 shows the stover yields obtained. The effect of the two dry spells that occurred during the growing period was not significant. Similarly, the effect of the nitrogen treatments was not significant. The plant size and height was about the same in all the treatments. The high inherent fertility of the soil explains this lack of response to nitrogen.

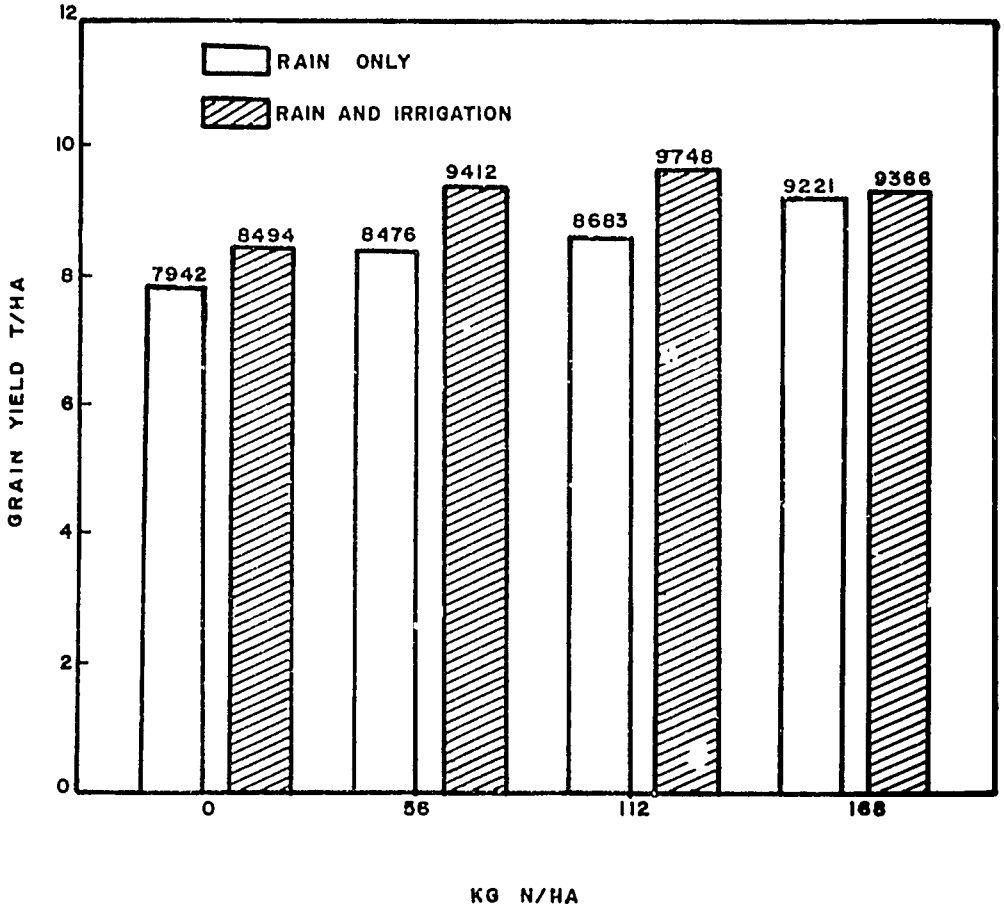

Figure 1. Grain yields of 1984/85 IBSNAT trial

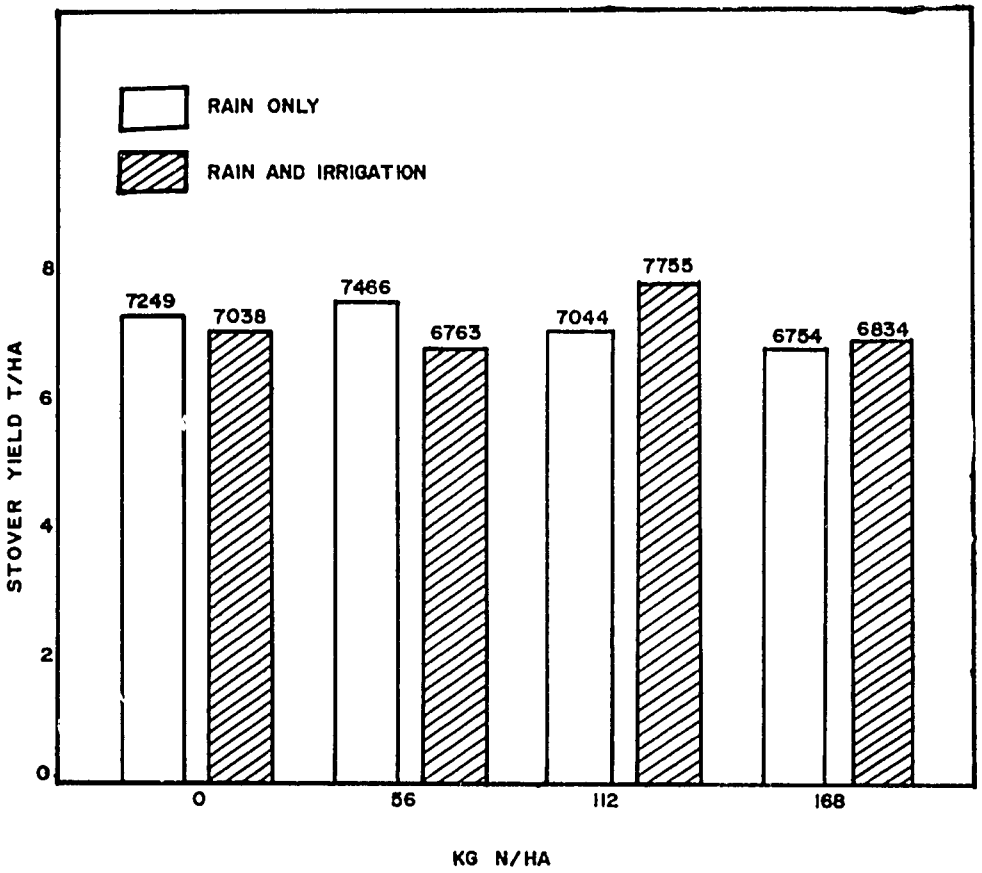

Figure 2. Stover yields of 1984/85 IBSNAT trial

The model testing results are not available at the time of writing this paper.

Table 1. Pre-plant soil analysis

REP	DEPTH (cm)	pH H_2O	pH $CaCl_2$	NH_4-N ppm	NO_3-N ppm	Avail.P ppm
1	0-20	6.70	6.20	47.0	38.0	29.75
	20-40	6.80	6.30	27.0	17.0	7.70
	40-60	6.55	6.05	24.0	22.0	5.60
	60-80	6.75	6.05	27.0	15.0	4.20
	80-100	6.40	5.90	32.0	14.0	7.70
2	0-20	6.70	6.10	52.0	29.0	29.40
	20-40	6.60	5.90	36.0	24.0	4.55
	40-60	6.25	5.60	32.0	23.0	4.55
	60-80	6.15	5.40	27.0	12.0	5.60
	80-100	6.10	5.40	21.0	17.0	7.70
3	0-20	6.85	6.30	52.0	40.0	4.70
	20-40	6.80	6.20	42.0	29.0	7.70
	40-60	6.30	5.75	30.0	26.0	9.80
	60-80	5.60	5.20	26.0	21.0	11.90
	80-100	5.35	4.80	26.0	15.0	5.60

Table 2. Chemical properties

DEPTH (cm)	NH_4OAC EXTR.BASES me/100g soil Ca	Mg	Na	K	SUM OF BASES me/100g soil	CEC/100g clay NH_4OAC	BASE SATURATION NH_4OAC
0 - 24	4.0	1.2	0.1	0.2	5.5	22.1	100
24 - 38	3.3	1.1	TR	0.2	4.6	16.1	100
38 - 66	2.1	1.1	TR	0.2	3.4	14.0	69
66 - 109	1.8	1.1	TR	0.2	3.1	11.5	65
109 - 157	1.8	1.2	TR	0.1	3.1	9.4	74
157 - 195	1.7	1.3	TR	0.1	3.1	9.0	82

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LAND EVALUATION

EDITOR'S NOTE: This paper, which accompanied Professor R. Dudal's presentation, is extracted from "A Framework for Land Evaluation" FAO Soils Bulletin No. 32 1976, Rome

The Nature and Principles of Land Evaluation

Decisions on land use have always been part of the evolution of human society. In the past, land use changes often came about by gradual evolution, as the result of many separate decisions taken by individuals. In the more crowded and complex world of the present they are frequently brought about by the process of land use planning. Such planning takes place in all parts of the world, including both developing and developed countries. It may be concerned with putting environmental resources to new kinds of productive use. The need for land use planning is frequently brought about, however, by changing needs and pressures, involving competing uses for the same land.

The function of land use planning is to guide decisions on land use in such a way that the resources of the environment are put to the most beneficial use for man, whilst at the same time conserving those resources for the future. This planning must be based on an understanding both of the natural environment and of the kinds of land use envisaged. There have been many examples of damage to natural resources and of unsuccessful land use enterprises through failure to take account of the mutual relationships between land and the uses to which it is put. It is a function of land evaluation to bring about such understanding and to present planners with comparisons of the most promising kinds of land use.

Land evaluation is concerned with the assessment of land performance when used for specified purposes. It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. To be of value in planning, the range of land uses considered has to be limited to those which are relevant within the physical, economic and social context of the area considered, and the comparisons must incorporate economic considerations.

The Aims of Land Evaluation

Land evaluation may be concerned with present land performance. Frequently, however, it involves change and its effects: with change in the use of land and in some cases change in the land itself.

Evaluation takes into consideration the economics of the proposed enterprises, the social consequences for the people of

the area and the country concerned, and the consequences, beneficial or adverse, for the environment. Thus land evaluation should answer the following questions:

- How is the land currently managed, and what will happen if present practices remain unchanged?
- What improvements in management practices, within the present use, are possible?
- What other uses of land are physically possible and economically and socially relevant?
- Which of these uses offer possibilities of sustained production or other benefits?
- What adverse effects, physical, economic or social, are associated with each use?
- What recurrent inputs are necessary to bring about the desired production and minimize the adverse effects?
- What are the benefits of each form of use?

If the introduction of a new use involves significant change in the land itself, as for example in irrigation schemes, then the following additional questions should be answered:

- What changes in the condition of the land are feasible and necessary, and how can they be brought about?
- What non-recurrent inputs are necessary to implement these changes?

The evaluation process does not in itself determine the land use changes that are to be carried out, but provides data on the basis of which such decisions can be taken. To be effective in this role, the output from an evaluation normally gives information on two or more potential forms of use for each area of land including the consequences, beneficial and adverse, of each.

Land Evaluation and Land Use Planning

Land evaluation is only part of the process of land use planning. Its precise role varies in different circumstances. In the present context it is sufficient to represent the land use planning process by the following generalized sequence of activities and decisions:

i. recognition of a need for change;

ii. identification of aims;

iii. formulation of proposals, involving alternative forms of land use, and recognition of their main requirements;

iv. recognition and delineation of the different types of land present in the area;

v. comparison and evaluation of each type of land for the different uses;

vi. selection of a preferred use for each type of land;

vii. project design, or other detailed analysis of a selected set of alternatives for distinct parts of the area;

This, in certain cases, may take the form of a feasibility study.

viii. decision to implement;

ix. implementation;

x. monitoring of the operation.

Land evaluation plays a major part in stages iii, iv and v of the above sequence, and contributes information to the subsequent activities. Thus land evaluation is preceded by the recognition of the need for some change in the use to which land is put; this may be the development of new productive uses, such as agricultural development schemes or forestry plantations, or the provision of services, such as the designation of a national park or recreational area.

Recognition of this need is followed by identification of the aims of the proposed change and formulation of general and specific proposals. The evaluation process itself includes description of a range of promising kinds of use, and the assessment and comparison of these with respect to each type of land identified in the area. This leads to recommendations involving one or a small number of preferred kinds of use. These recommendations can then be used in making decisions on the preferred kinds of land use for each distinct part of the area. Later stages will usually involve further detailed analysis of the preferred uses, followed, if the decision to go ahead is made, by the implementation of the development project or other form of change, and monitoring of the resulting systems.

Principles

Certain principles are fundamental to the approach and methods employed in land evaluation. These basic principles are as follows:

i. Land suitability is assessed and classified with respect to specified kinds of use

This principle embodies recognition of the fact that different kinds of land use have different requirements. As an example, an alluvial flood-plain with impeded drainage might be highly suitable for rice cultivation but not suitable for many forms of agriculture or for forestry.

The concept of land suitability is only meaningful in terms of specific kinds of land use, each with their own requirments, e.g. for soil moisture, rooting depth etc. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.

ii. Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land

Land in itself, without inputs, rarely if ever possesses productive potential; even the collection of wild fruits requires labour, whilst the use of natural wilderness for nature conservation requires measures for its protection. Suitability for each use is assessed by comparing the required inputs, such as labour, fertilizers or road construction, with goods produced or other benefits obtained.

iii. A multidisciplinary approach is required

The evaluation process requires contribution from the field of natural science, the technology of land use, economics and sociology. In particular, suitability evaluation always incorporates economic considerations to a greater or lesser extent. In qualitative evaluation, economics may be employed in general terms only, without calculation of costs and returns. In quantitative evaluation the comparison of benefits and inputs in economic terms plays part in the determination of suitability.

It follows that a team carrying out an evaluation require a range of specialists. These will usually include natural scientists (e.g. geomorphologists, soil surveyors, ecologists), specialists in the technology of the forms ofland use under consideration (e.g. agronomists, foresters, irrigation engineers, experts in livestock management), economists and sociologists. There may need to be some combining of these functions for practical reasons, but the principle of multidisciplinary activity, encompassing studies of land, land use, social aspects and economics remains.

iv. Evaluation is made in terms relevant to the physical, and social context of the area concerned.

_____Such factors as the regional climate, levels of living of

the population, availability and cost of labour, need for employment, the local or export markets, systems of land tenure which are socially and politically acceptable, and availability of capital, form the context within which evaluation takes place. It would, for example be unrealistic to say that land was suitable for non-mechanized rice cultivation, requiring large amounts of low-cost labour, in a country with high labour costs. The assumptions underlying evaluation will differ from one country to another and, to some extent, between different areas of the same country. Many of these factors are often implicitly assumed; to avoid misunderstanding and to assist in comparisons between different areas, such assumption should be explicitly stated.

v. Suitability refers to use on a sustained basis

The aspect of environmental degradation is taken into account when assessing suitability. There might, for example, be forms of land use which appeared to be highly profitable in the short run but were likely to lead to soil erosion, progressive pasture degradation, or adverse changes in river regimes downstream. Such consequences would outweigh the short-term profitability and cause the land to be classed as not suitable for such purposes.

This principle by no means requires that the environment should be preserved in a completely unaltered state. Agriculture normally involves clearance of any natural vegetation present, and normally soil fertility under arable cropping is higher or lower, depending on management, but rarely at the same level as under the original vegetation. What is required is that for any proposed form of land use, the probable consequences for the environment should be assessed as accurately as possible and such assessments taken into consideration in determining suitability.

vi. Evaluation involves comparison of more than a single kind of use

This comparison could be, for example, between agriculture and forestry, between two or more different farming systems, or between individual crops. Often it will include comparing the existing uses with possible changes, either to new kinds of use or modifications to the existing uses. Occasionally a proposed form of use will be compared with non-use, i.e leaving the land in its unaltered state, but the principle of comparison remains. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several different, alternatives. If only one use is considered there is the danger that, whilst the land may indeed be suitable for that use, some other and more beneficial use may be ignored.

Levels of Intensity and Approaches

Certain groups of activities are common to all types of land

evaluation. In all cases evaluation commences with initial consultations, concerned with the objectives of the evaluation, assumptions and constraints, and the methods to be followed. Details of subsequent activities and the sequence in which they are carried out, vary with circumstances. These circumstance include the level of intensity of the survey and which of two overall approaches is followed.

Levels of Intensity

Three levels of intensity may be distinguished: reconnaissance, semi-detailed and detailed. These are normally reflected in the scales of resulting maps.

Reconnaissance surveys are concerned with broad inventory of resources and development possibilities at regional and national scales. Economic analysis is only in very general terms, and land evaluation is qualitative. The results contribute to national plans, permitting the selection of development areas and priorities.

Surveys at the semi-detailed, or intermediate, level are concerned with more specific aims such as feasibility studies of development projects. The work may include farm surveys; economic analysis is considerably more important, and land evaluation is usually quantitative. This level provides information for decisions on the selection of projects, or whether a particular development or other change is to go ahead.

The detailed level covers surveys for actual planning and design, or farm planning and advice, often carried out after the decision to implement has been made.

Two-stage and parallel approaches to land evaluation

The relationships of resource surveys and economic and social analysis, and the manner in which the kinds of land use are formulated, depend on which of the following approaches to land evaluation is adopted (Fig. 1):

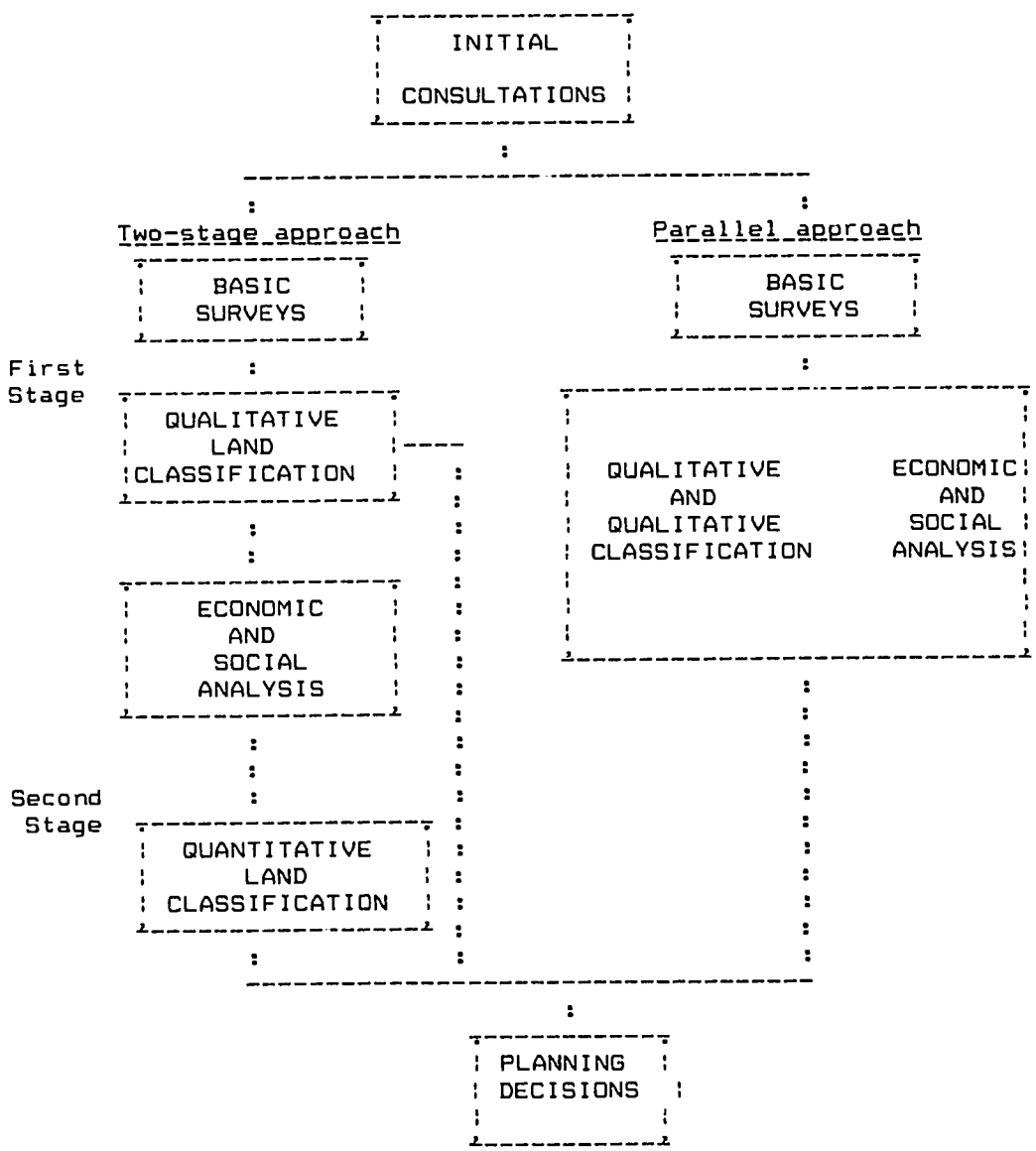
- a two-stage approach in which the first stage is mainly concerned with qualitative land evaluation, later (although not necessarily) followed by a second stage consisting of economic and social analysis;

- a parallel approach in which analysis of the relationships between land and land use proceeds concurrently with economic and social analysis.

The two-stage approach is often used in resource inventories for broad planning purposes and in studies for the assessment of biological productive potential. The land suitability classifications in the first stage are based on the suitability of the land for kinds of land use which are selected at the

begining of the survey, e.g. arable cropping, dairy farming, maize, tomatoes. The contribution of economic and social analysis to the first stage is limited to a check on the relevance of kinds of land use. After the first stage has been completed and its results presented in map and report form, these results may then be subject to the second stage, that of social and economic analysis, either immediately or after an interval of time.

FIG. 1 TWO-STAGE AND PARALLEL APPROACHES TO LAND EVALUATION



In the parallel approach the economic and social analysis of the kinds of land use proceeds simultaneously with the survey and assessment of physical factors. The kinds of use to which the evaluation refers are usually modified in the course of the study. In the case of arable farming, for example, this modification may include selection of crops and rotations, estimates of the inputs of capital and labour, and determination of optimum farm size. Similarly, in forestry it may include, for example, selection of tree species, dates of thinning and felling and required protective measures. This procedure is mostly favoured for specific proposals in connection with development projects and at semi-detailed and detailed levels of intensity.

The parallel approach is expected to give more precise results in a shorter period of time. It offers a better chance of concentrating survey and data-collection activities on producing information needed for the evaluation.

However, the two-stage approach appears more straightforward, possessing a clear-cut sequence of activities. The physical resource surveys precede economic and social analysis, without overlap, hence permitting a more flexible timing of activities and of staff recruitment. The two-stage approach is used as a background in the subsequent text except where otherwise stated.

The Nature of the Framework

The Framework does not by itself constitute an evaluation system. The range of possible uses of land and purposes of evaluation is so wide that no one system could hope to take account of them. Besides such obvious contrasts as those of climate, differences in such matters as the availability and cost of labour, availability of capital, population density and levels of living will all cause differences of detail and emphasis in the evaluation of land.

It was recognition of this situation, coupled with the need for some degree of standardization or compatibility, which led to the concept of the Framework for Land evaluation. The Framework is a set of principles and concepts, on the basis of which local, national or regional evaluation systems can be constructed. Thus the Framework is not an evaluation manual; it does not, for example, specify such matters as limiting slope angles or soil moisture requirements for particular kinds of land use, since such values can never have universal applicability. Instead, the Framework sets out a number of principles involved in land evaluation, some basic concepts, the structure of a suitability classification and the procedures necessary to carry out a land suitability evaluation.

The principles and procedures given in the Framework can be applied in all parts of the world. They are relevant both to less developed and developed countries. At the one extreme, they

can be applied to areas where development planning is being applied to the more or less unaltered natural environment; at the other, to densely populated lands where the main concern of planning is to reconcile competing demands for land already under various forms of use. The Framework can be used to construct systems applicable at all levels of intensity ranging from, at one extreme, national, continental or world-scale assessments, and at the other to detailed local studies. The Framework covers all kinds of rural land use: agriculture in its broadest sense, including livestock production, together with forestry, recreation or tourism, and nature conservation. Engineering aspects involved in rural land use, such as foundation suitability for roads or small structures, are also included.

The Framework is not intended for the distinct set of planning procedures involved in urban land use planning, although some of its principles are applicable in these contexts. Nor does the Framework take account of the resources of the seas. Water on and beneath the surface of the land is, however, of relevance in land evaluation.

This framework is written mainly for those actively involved in rural land evaluation. Since most land suitability evaluations are at present carried out for purposes of planning by national and local governments, this is the situation assumed in references to decision-making, but the evaluation can also be applied to land use planning by firms, farmers or other individuals. The principles and procedures which are set out can be applied either to land evaluation for individual land development projects or to the construction of local or national evaluation systems.

Basic Concepts

Certain concepts and definitions are needed as a basis for the subsequent discussion. These concern the land itself, kinds of land use, land characteristics and qualities, and improvements made to land.

For the sake of clarity, some definitions are given here.

Land

Land comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use. It includes the results of past and present human activity, e.g. reclamation from the seas, vegetation clearance, and also adverse results, e.g. soil salinization. Purely economic and social characteristics, however, are not included in the concept of land; these form part of the economic and social context.

A land mapping unit is a mapped area of land with specified characteristics. Land mapping units are defined and mapped by

natural resource surveys, e.g. soil survey, forest inventory. Their degree of homogeneity or of internal variation varies with the scale and intensity of the study. In some cases a single land mapping unit may include two or more distinct types of land, with different suitabilities, e.g. a river flood plain, mapped as a single unit but known to contain both well-drained alluvial areas and swampy depressions.

Land is thus a wider concept than soil or terrain. Variation in soils, or soils and landforms, is often the main cause of differences between land mapping units within a local area: it is for this reason that soil surveys are sometimes the main basis for definition of land mapping units. However, the fitness of soils for land use cannot be assessed in isolation from other aspects of the environment, and hence it is land which is employed as the basis for suitability evaluation.

Land use

Suitability evaluation involves relating land mapping units to specified types of land use. The types of use considered are limited to those which appear to be relevant under general physical, economic and social conditions prevailing in an area. These kinds of land use serve as the subject of land evaluation. They may consist of major kinds of land use or land utilization types.

Major Kinds of Land Use and Land Utilization Types

A major kind of land use is a major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, or recreation. Major kinds of land use are usually considered in land evaluation studies of a qualitative or reconnaissance nature.

A land utilization type is a kind of land use described or defined in a degree of detail greater than that of a major kind of land use. In detailed or quantitative land evaluation studies, the kinds of land use considered will usually consist of land utilization types. They are described with as much detail and precision as the purpose requires. Thus land utilization types are not a categorical level in a classification of land use, but refer to any defined use below the level of the major kind of land use.

A land utilization type consists of a set of technical specifications in a given physical, economic and social setting. This may be the current environment, or a future setting modified by major land improvements, e.g. an irrigation and drainage scheme. Attributes of land utilization types include data or assumptions on:

- Produce, including goods (e.g. crops, livestock, timber), services (e.g. recreational facilities)

or other benefits (e.g. wildlife conservation)

- Market orientation, including whether towards subsistence or commercial production

- Capital intensity

- Labour intensity

- Power sources (e.g. man's labour, draught animals, machinery using fuels)

- Technical knowledge and attitudes of land users

- Technology employed (.e.g. implements and machinery, fertilizers, livestock breeds, farm transport, methods of timber felling)

- Infrastructure requirements (e.g. sawmills, tea factories, agricultural advisory services)

- Land tenure, the legal or customary manner in which rights to land are held, by individuals or groups

- Income levels, expressed per capita, per unit of production (e.g. farm) or per unit area.

Management practices on different areas within one land utilization type are not necessarily the same. For example, the land utilization type may consist of mixed farming, with part of the land under arable use and part allocated to grazing. Such differences may arise from variation in the land, from the requirements of the management system, or both.

Some examples of land utilization types are:

i. Rainfed annual cropping based on groundnut with subsistence maize, by smallholders with low capital resources, using cattle-drawn farm implements, with high labour intensity, on freehold farms of 5-10 ha.

ii. Farming similar to (i) in respect of production, capital, labour, power and technology, but farms of 200-500ha operated on a communal basis.

iii. Commercial wheat production on large freehold farms, with high capital and low labour intensity, and a high level of mechanization and inputs.

iv. Extensive cattle ranching, with medium levels of capital and labour intensity, with land held and central services operated by a governmental body.

v. Softwood plantations operated by a government Department of

Forestry, with high capital intensity, low labour intensity, and advanced technology.

vi. A national park for recreation and tourism.

Where it is wished to relate agricultural land utilization types to a general classification, the Topology of World Agriculture of the International Geographical Union may be considered (Kostrowicki, 1974). The role of land utilization types in land evaluation is discussed further in Beek (1975).

Multiple and Compound Land Use

Two terms, multiple and compound land utilization types, refer to situations in which more than one kind of land use is practiced within an area.

A multiple land utilization type consists of more than one kind of use simultaneously undertaken on the same area of land, each use having its own inputs, requirements and produce. An example is a timber olantation used simultaneously as a recreational area.

A compound land utilization type consists of more than one kind of use undertaken on areas of land which for purposes of evaluation are treated as a single unit. The different kinds of use may occur in time sequence (e.g. as in crop rotation) or simultaneously on different areas of land within the same organizational unit. Mixed farming involving both arable use and grazing is an example.

Sometimes an appropriate land utilization type can be found by making several land mapping units part of the same management unit, e.g livestock management which combines grazing on uplands in the rainy season and on seasonally flooded lowlands in the dry season.

Land utilization types are defined for the purpose of land evaluation. Their description need not comprise the full range of farm management practices, but only those related to land management and improvement. At detailed levels of evaluation, closely-defined land utilization types can be extended into farming systems by adding other aspects of farm management. Conversely, farming systems that have already been studied and described can be adopted as the basis for land utilization types.

Land Characteristics, Land Qualities and Diagnostic Criteria

A land characteristic is an attribute of land that can be measured or estimated. Examples are slope angle, rainfall, soil texture, available water capacity, biomass of the vegetation, etc. Land mapping units, as determined by resource surveys, are normally described in terms of land qualities.

A land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities may be expressed in a positive or negative way. Examples are moisture availability, erosion resistance, flooding hazard, nutritive value of pastures, accessibility. Where data are available, aggregate land qualities may also be employed, e.g. crop yields, mean annual increments of timber species.

Table 1 gives an illustrative list of land qualities related to productivity from three kinds of use and to management and inputs. It is not exhaustive, nor is each land quality necessarily relevant for a particular area and type of land use. The qualities listed in B and C are in addition to those of A, which may be relevant to all three kinds of use (based in part on Beek and Bennema, 1972). There may also be land qualities related to major land improvements. These vary widely with the types of improvement under consideration. An example is land evaluation in relation to available supplies of water where irrigation is being considered.

A land quality is not necessarily restricted in its influence to one kind of use. The same quality may affect, for example, both arable use and animal production.

There are a very large number of land qualities, but only those relevant to the land use alternatives under consideration need be determined. A land quality is relevant to a given type of land use if it influences either the level of inputs required, or the magnitude of benefits obtained, or both. For example, capacity to retain fertilizers is a land quality relevant to most forms of agriculture, and one which influences both fertilizer inputs and crop yield. Erosion resistance affects the costs of soil conservation works required for arable use, whilst the nutritive value of pastures affects the productivity of land under ranching.

Land qualities can sometimes be estimated or measured directly, but are frequently described by means of land characteristics. Qualities or characteristics employed to determine limits of land suitability classes or subclasses are known as diagnostic criteria.

A diagnostic criterion is a variable which has an understood influence upon the output from, or the required inputs to, a specified use, and which serves as a basis for assessing the suitability of a given area of land for that use. This variable may be a land quality, a land characteristic, or a function of several land characteristics. For every diagnostic criterion there will be a critical value or set of critical values which are used to define suitability class limits.

Examples of Land Qualities

Table 1

A. Land Qualities Related to Productivity from Crops or Other Plant Growth

- Crop yields (a resultant of many qualities listed below)
- Moisture availability
- Nutrient availability
- Oxygen availability in the root zone
- Adequacy of foothold for roots
- Conditions for germination
- Workability of the land (ease of cultivation)
- Salinity or alkalinity
- Soil toxicity
- Resistance to soil erosion
- Pests and diseases related to the land
- Flooding hazard (including frequency, periods of inunoation)
- Temperature regime
- Radiation energy and photoperiod
- Climatic hazards affecting plant growth (including wind, hail, frost)
- Air humidity as affecting plant growth
- Drying periods for ripening of crops.

B. Land Qualities Related to Domestic Animal Productivity

- Productivity of grazing land (a resultant of many qualities listed under A.)
- Climatic hardships affecting animals
- Endemic pests and diseases
- Nutritive value of grazing land
- Toxicity of grazing land
- Resistance to degradation of vegetation
- Resistance to soil erosion under grazing conditions
- Availability of drinking water.

C. Land Qualities Related to Forest Productivity

The qualities listed may refer to natural forests, forestry plantations or both.

- Mean annual increments of timber species (a resultant of many qualities listed under A.)
- Types and quantities of indigenous timber species
- Site factors affecting establishment of young trees
- Pests and diseases
- Fire hazard.

D. Land Qualities Related to Management and Inputs

The qualities listed may refer to arable use, animal

production or forestry.

- Terrain factors affecting mechanization (trafficability)
- Terrain factors affecting construction and maintenance of access roads (accessibility)
- Size of potential management units (e.g. forest blocks, farms, fields)
- Location in relation to markets and to supplies of inputs.

Examples

These terms may be illustrated with reference to the land quality "oxygen availability in the root zone". This quality can be most closely estimated by the diagnostic criterion of the period when the redox potential (Eh) in the root zone is less than +200 millivolts. Such information would frequently not be available, in which case the next most direct criterion would be periods when the root zone lay below the water table. For example, oxygen availability might be classed as "moderate" with 3-6 months below the water table, and "low" with over 6 months. Failing information on periods with a high water table, then soil mottling, soil drainage class or natural vegetation could be used as diagnostic criteria for assessing oxygen availability.

Land qualities can sometimes be described by means of a single land characteristic, as in the preceding example. In many cases, however, their rating involves combinations of several characteristics, as in the case of moisture availability illustrated by the following example.

Moisture availability to plants is a land quality that is relevant in a wide variety of cirmustances. It can apply to arable cropping, animal productivity (via its influence on growth of pastures) and forest production. It can affect both productivity, e.g. crop yields, and inputs, e.g. mulching measures necessary, or amounts of irrigation water required. Among the land characteristics which affect the quality moisture availability are: amount of rainfall, its seasonal distribution and variability; potential evapotranspiration, and hence the characteristics which themselves affect it (temperature, humidity, wind speed, etc.); and available water capacity or the soil, and the characteristics which affect it - effective soil depth (depth of which roots penetrate) and the field capacity and wilting point of each soil horizon, the latter being in turn influenced by texture, organic matter content, etc. The probable recurrence interval at which the soil moisture level falls to wilting point within the entire rooting zone is a further land characteristic of importance (which can be estimated but not measured within a short period). By no means all these land characteristics would be employed as diagnostic criteria. Supposing, for example, that differences in both rainfall and potential evapotranspiration within the surveyed area were so

small as to be of little importance in differentiating types of land, then this characteristic would become part of the physical context of the evaluation and would not be used in defining class limits. The most appropriate diagnostic criterion used to define class limits might be available water capacity of the soil profile. However, where soil data were not available, then some function of effective depth and soil texture, believed to bear a linear relationship with available water capacity, could be used. In the former case, the set of critical values for available water capacity used to define class limits might be such as: over 40 cm, 30-40 cm, 24-30 cm.

The Scarcity Value of Land

The value of a particular type of land may be increased by its scarcity, or the rarity of certain of its qualities, within a given region or country. This is often the position with nature reserves. In the extreme case, the presence of a plant or animal species unique to one area may make that land virtually irreplaceable, resulting in strict protection even against highly profitable other uses. Situations where land acquires added suitability for a particular use by virtue of its scarcity can also arise with productive forms of use, for example where dry-season grazing land is in short supply.

Requirements and Limitations

Requirements of the land use refer to the set of land qualities that determine the production and management conditions of a kind of land use.

Limitations are land qualities, or their expression by means of diagnostic criteria, which adversely affect a kind of land use.

For example, the requirements for mechanized cultivation of wheat include high availability of oxygen in the root zone and absence of obstructions (boulders or rock outcrops); waterlogging and the presence of boulders are limitations. Thus limitations may be regarded as land qualities expressed in such a way as to show the extent to which the conditions of the land fall short of the requirements for a given use.

Land Improvements

Land improvements are activities which cause beneficial changes in the qualities of the land itself. Land improvements should be distinguished from improvements in land use, i.e changes in the use to which the land is put or modifications to management practices under a given use.

Land improvements are classed as major or minor. A major land improvement is a substantial and reasonably permanent improvement in the qualities of the land affecting a given use.

A large non-recurrent input is required, usually taking the form of capital expenditure on structure and equipment. Once accomplished, maintenance of the improvement remains as a continuing cost, but the land itself is more suitable for the use than formerly. Examples are large irrigation schemes, drainage of swamps and reclamation of salinized lano.

A minor land improvement is one which either has relatively small effects or is non-permanent or both, or which lies within the capacity of individual farmers or other land users. Stone clearance, eradication of persistent weeds and field drainage by ditches are examples.

The separation of major from minor land improvements is intended only as an aid to making a suitability classification. The distinction is a relative one; it is not clear-cut and is only valid within the technical and financial capacity of individual farmers or other landowners (including small communal owners, e.g. village co-operatives). In many areas improvements such as subsoiling, dynamiting or terracing cannot be undertaken by individual farmers, and are therefore regarded as major land improvements; in countries with large farms and high capital resources coupled with good credit facilities, however, these changes may be within reach of individuals and are therefore considered as minor improvements. Field drainage is another improvement that may or may not be regarded as major, depending on farm size, permanency of tenure, capital availability and level of technology.

Land Suitability and Land Capability

The term "land capability" is used in a number of land classification systems, notably that of the Soil Conservation Service of the U.S. Department of Agriculture (Klingebiel and Montgomery, 1961). In the USDA system, soil mapping units are grouped primarily on the basis of their capability to produce common cultivated crops and pasture plants without deterioration over a long period of time. Capability is viewed by some as the inherent capacity of land to perform at a given level for a general use, and suitability as a statement of the adaptability of a given area for a specific kind of land use; others see capability as a classification of land primarily in relation to degradation hazards, whilst some regard the terms "suitability" and "capability" as interchangeable.

Because of these varying interpretations, coupled with the long-standing association of "capability" with the USDA system, the term land suitability is used in this framework, and no further reference to capability is made.

Land Suitability Classifications

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present

condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses.

In this chapter, the structure of the suitability classification is first described. This is followed by an account of the range of interpretative classifications recognized: qualitative, quantitative and of current or potential suitability. In accordance with the principles given in chapter 1, separate classifications are made with respect to each kind of land use that appears to be relevant for the area. Thus, for example, in a region where arable use, animal production and forestry were all believed to be possible on certain areas, a separate suitability classification is made for each of these three kinds of use.

There may be certain parts of the area considered, for which particular kinds of use are not relevant, e.g. irrigated agriculture beyond a limit of water availability. In these circumstances, suitability need not be assessed. Such parts are shown on maps or tables by the symbol NR: Not Relevant.

Structure of the Suitability Classification

The framework has the same structure, i.e. recognizes the same categories, in all of the kinds of interpretative classification (see below). Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land use. Four categories of decreasing generalization are recognized:

i.	Land Suitability Orders:	reflecting kinds of suitability.
ii.	Land Suitability Classes:	reflecting degrees of suitability within Orders.
iii.	Land Suitability Subclasses :	reflecting kinds of limitation, or main kinds of improvement measures required, within classes.
iv.	Land Suitability Units:	reflecting minor differences in required management within Subclasses.

Land Suitability Orders

Land suitability Orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders represented in maps, tables, etc. by the symbols S and N respectively.

Order S Suitable:	Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.
Order N Not Suitable:	Land which has qualities that appear to preclude sustained use of the kind under consideration.

Land may be classeo as Not Suitable for a given use for a number of reasons. It may be that the proposed use is technically impracticable, such as the irrigation of rocky steep land, or that it would cause severe environmental degradation, such as the cultivation of steep slopes. Frequently, however, the reason is economic: that the value of the expected benefits does not justify the expected costs of the inputs that would be required.

Land Suitability Classes

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by arabic numbers, in sequence of decreasing degrees of suitability within the Order. Within the Order Suitable the number of classes is not specified. There might, for example, be only two, S1 and S2. The number of classes recognized should be kept to the minimum necessary to meet interpretative aims; five should probably be the most ever used.

If three Classes are recognized within the Order Suitable, as can often be recommended, the following names and definitions may be appropriate in a qualitative classification:

Class S1 Highly Suitable:	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Class S2 Moderately Suitable:	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.

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

In a quantitative classification, both inputs and benefits must be expressed in common measurable terms, normally economic. In different cirmustances different variables may express most clearly the degree of suitability, e.g. the range of expected net income per unit area or per standard management unit, or the net return per unit of irrigation water applied to different types of land for a given use.

Where additional refinement is necessary it is recommended that this should be achieved by adding classes, e.g. S4, and not by subdividing classes, since the latter procedure would contradict the principle that degrees of suitability are represented by only one level of the classification structure, that of the suitability class. This necessarily changes the meanings of class numbers, e.g. if four classes were employed for classifying land with respect to arable use and only three with respect to forestry, Marginally Suitable could refer to S4 in the former case but S3 in the latter.

An alternative practice has been adopted in some countries. In order to give a constant numbering to the lowest Suitable class, classes have been subdivided as, e.g. S2.1, S2.2. This practice is permitted within the Framework, although for the reason given in the preceding paragraph it is not recommended.

Suitability Class S1, Highly Suitable, may sometimes not appear on a map of a limited area, but could still be included in the classification if such land is known or believed to occur in other areas relevant to the study.

Differences in degrees of suitability are determined mainly by the relationship between benefits and inputs. The benefits may consist of goods, e.g. crops, livestock products or timber, or services, e.g. recreational facilities. The inputs needed to obtain such benefits comprise such things as capital investment, labour, fertilizers and power. Thus an area of land might be classed as Highly Suitable for rainfed agriculture, because the value of crops produced substantially exceeds the costs of farming, but only Marginally Suitable for forestry, on grounds that the value of timber only slightly exceeds the costs of obtaining it.

It should be expected that boundaries between suitability classes will need review and revision with time in the light of technical developments and economic and social changes.

Within the Order Not Suitable, there are normally two Classes:

Class N' Currently Not Suitable:	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Class N2 Permanently Not Suitable:	Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Quantitative definition of these classes is normally unnecessary, since by definition both are uneconomic for the given use. The upper limit of Class N1 is already defined by the lower limit of the least suitable class in Order S.

The boundary of Class N2, Permanently Not Suitable, is normally physical and permanent. In contrast, the boundary between the two orders, Suitable and Not Suitable is likely to be variable over time though changes in the economic and social context.

Land Suitability Subclasses

Land suitability Subclasses reflect kinds of limitations, e.g. moisture deficiency, erosion hazard. Subclasses are indicated by lower-case letters with mnemonic significance, e.g. Sum, S2e, S3me. Examples are given in Table 5. There are no subclasses in Class S1.

The number of Subclasses recognized and the limitations chosen to distinguish them will differ in classifications for different purposes. There are two guidelines:

- The number of subclasses should be kept to a minimum that will satisfactorily distinguish lands within a class likely to differ significantly in their management requirements or potential for improvement due to differing limitations.

- As few limitations as possible should be used in the symbol for any subclass. One, rarely two, letters should normally suffice. The dominant symbol (i.e. that which determines the class) should be used alone if possible. If two limitations are equally severe,

both may be given.

Land within the Order Not Suitable may be divided into suitability subclasses according to kinds of limitation, e.g. N1m, N1me, N1m although this is not essential. As this land will not be placed under management for the use concerned it should not be subdivided into suitability units.

Land Suitability Units

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. The units differ from each other in their production characteristics or in minor aspects of their management requirements (often definable as differences in detail of their limitations). Their recognition permits detailed interpretation at the farm planning level. Suitability units are distinguished by arabic numbers following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass.

Conditional Suitability

The designation Conditionally Suitable may be added in certain instances to condense and simplify presentation. This is necessary to cater for cirmustances where small areas of land, within the survey area, may be unsuitable or poorly suitable for a particular use under the management specified for that use, but suitable given that certain conditions are fulfilled.

The possible nature of the conditions is varied and might relate to modifications to the management practices or the inputs of the defined land use (occasioned, for example, by localized phenomena of poor soil drainage, soil salinity); or to restrictions in the choice of crops (limited, for example, to crops with an especially high market value, or resistant to frost). In such instances, the indication "conditional" can avoid the need for additional classifications to account for local modifications of land use or local major improvements.

Conditionally Suitable is a phase of the Order Suitable. It is indicated by a lower case letter c between the order symbol and the class number, e.g. Sc2. The conditional suitable phase, subdivided into classes if necessary, is always placed at the bottom of the listing of S classes. The phase indicates suitability after the condition(s) have been met.

Employment of the Conditionally Suitable phase should be avoided wherever possible. It may only be employed if all of the following stipulations are met:

i. Without the condition(s) satisfied, the land is either not suitable or belongs to the lowest suitable class.

ii. Suitability with the condition(s) satisfied is significantly higher (usually at least two classes).

iii. The extent of the conditionally suitable land is very small with respect to the total study area.

If the first or second stipulation is not met, it may still be useful to mention the possible improvement or modification in an appropriate section of the text. If the third stipulation is not met, then the area over which the condition is relevant is sufficiently extensive to warrant either a new land utilization type or a potential suitability classification, as appropriate.

As the area of land classed as Conditionally Suitable is necessarily small, it will not normally be necessary to subdivide it at the unit level.

It is important to note that the indication "conditional" is not intended to be applied to land for which the interpretation is uncertain, either in the sense that its suitability is marginal or because factors relevant to suitability are not understood. Use of "conditional" may seem convenient to the evaluator, but its excessive use would greatly complicate understanding by users and must be avoided.

Summary

The structure of the suitability classification, together with the symbols used, is summarized in Table 2. Depending on the purpose, scale and intensity of the study, either the full range of suitability orders, classes, subclasses and units may be distinguished, or the classification may be restricted to the higher two or three categories.

Table 2. Structure of the suitability classification.

CATEGORY			
ORDER	CLASS	SUBCLASS	UNIT
S Suitable	S1	S2m	S2e-1
	S2	S2e	S2e-2
	S3	S2me	etc.
	etc	etc.	
Phase: Sc Conditionally Suitable	Sc2	Sc2m	
N Not Suitable	N1	N1m	
	N2	N1e	
		etc.	

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EVALUATION OF SOIL PHYSICAL PROPERTIES

Jaak S. Lenvain

Introduction

First of all the physical characterization involved in Soil Taxonomy will be reviewed. Some attention will be paid to the more difficult aspects of procedures. In the second part of the document the physical condition of some Zambian soils selected as potential benchmark sites will be evaluated.

It has been observed that in the advanced stage of weathering the loss of physical fertility is considerable. This is extremely important for the agricultural sector since tillage, irrigation and crop management depend on the level of physical fertility.

Physical Determinations in the actual Soil Taxonomy

Particle Size Analysis

This analysis is the measurement of the percentage of the different particle sizes of a soil such as sand (2mm -50um), silt (50um -2um) and clay (<2um). The procedure (SCS-USDA, 1972) has two aspects: dispersion of the soil and fractionation into particle size classes. Dispersion of the soil is the most difficult aspect of the analysis since soils rich in organic matter, calcium carbonate or sesquioxides may need a special treatment (Kunze, 1965) while other soils might be sufficiently dispersed by stirring and the use of sodium hexametaphosphate (Day, 1965).

When fractionating the mineral matter, priority should be given to the pipette method before the successive sedimentation or the hydrometer method. The sub-fractionation of the sand particles is determined by sieving.

It should be noted that in studies of clay movement in soil profiles, the ratios of the fine clay (<0.2um) to the coarse clay (0.2um -2um) are useful indicators for clay movement since fine clay is considered more mobile than coarse clay (Buol et al, 1980). In some parts of Africa the fine silt (2um - 20um) to clay ratio seems to be related with the stage of weathering (Sys, 1981).

Bulk density.

Bulk density of a soil (Blake, 1965) is the dry weight of a known soil volume compared to the weight of an equal volume of water. It is ordinarily expressed in units of g/cm. Bulk density data are used for computing total porosity and volume percent of available water. It is therefore recommended to use

undisturbed samples taken at a moisture content close to field capacity. The coated clod method is in this respect less appropriate since it will yield relatively high values because it does not include the interped void space.

In relation to genesis and classification the bulk density in-form about organic materials (<0.1g/cm); about volcanic ashes in soils (<0.85g/cm); about the alteration of the C horizon (< 2.65g/cm) and about the physical degradation of A horizons (>1.6g/cm).

Soil moisture characteristic

The water held at a tension of 0.33 bar (field capacity) and at 15 bar (permanent wilting point) are important to distinguish wet from moist and dry soils. Wet soil conditions have more water than at field capacity, moist soils contain an amount of water corresponding with a tension between field capacity and wilting point. A dry soil contains a lesser amount of water than at 15 bar. The definitions of wet moist and dry soil are important in relation with soil consistency and the Franklin Newhall method of computation of soil moisture regimes (1972).

Interesting to remark is that the 15 bar water percentage multiplied by a factor of 2.5 yields a good estimate of the clay percentage (S.C.S-USDA, 1972). It should be further noted that field capacity is depending on field-conditions and that wilting point is depending on crop-conditions. Both parameters may thus vary especially in irrigation and moisture supply studies. Maclean and Yaeger (1972) advised to use for Zambian soils a field capacity of 0.1 bar. Furthermore it is recommended to read moisture content values for field capacity and wilting point rather from a balanced curve than to determine those values separately.

When a moisture characteristic curve is made, methodology should be adapted to the level of pressure imposed. Up to 0.1 bar water columns can be used: between 0.1 and 15 bar the pressure plate apparatus is used and finally above 15 bar the vapour pressure technique is recommended.

Shrink - Swell Capacity

Soils with a high content of montmorillonite clay have the capability to swell when moist and to shrink and crack when dry. Besides its impor tance as a soil physical property it is also considered as a soil genetic process and thus important in soil classification.

This shrink - swell capacity is quantified through the use of a coefficient of linear extensibility (COLE) and is defined as follows (SCS - USDA, 1972)

$$COLE = \frac{Lm}{Ld}$$

Lm and Ld being respectively length of moist and dry sample. Practically, the Cole coefficient is determined from wet and dry bulk density according to following equation:

$$COLE = \sqrt{pd / pm} - 1$$

If Cole coefficient exceeds 0.03 a significant amount of montmorillonite clay is present; if it exceeds 0.09 significant shrink - swell activity can be expected (Grossman et al 1968)

Physical conditions of some weathered Zambian Soils

Relation between % clay and 15-bar water

This relationship is quite useful in estimating the clay content in iron rich soils. Soil Taxonomy advises to multiply the 15 bar water content (g/100g of dry soil) by a factor of 2.5 in order to find the clay content. For Zambian soils as well as for Zairean soils (Sys, 1981) this factor seems to be slightly higher.

In figure 1 it is shown that for a soil depth between 75 and 100cm of the 20 potential Zambian benchmark sites (analysis by SMSS), all orders included, the factor is rather 3. Besides the equation presented in figure 1, one can also propose $y = 3.07 x$ ($n=20$, $r = 0.93$). For the surface horizons a lower conversion factor has been found, since the organic matter content influences the amount of 15 bar water. Based on the same set of data a factor of 2.6 with a correlation coefficient of 0.95 has been found.

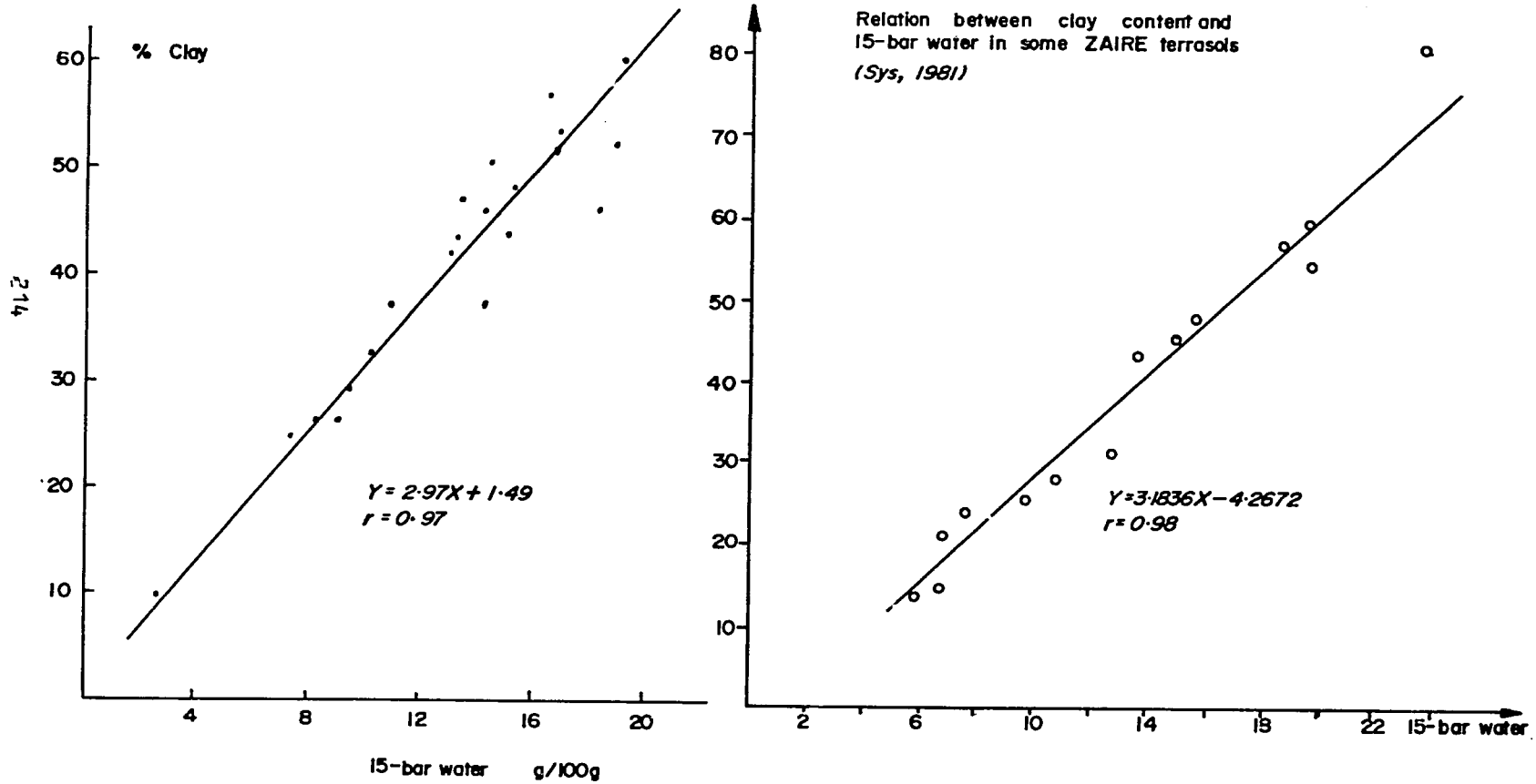
Poor structure in weathered soils

From the already mentioned set of data, it is clear that the majority of the ultisols and the oxisols have a weak or a very weak subangular blocky structure, while the majority of the alfisols have already a moderate structure.

The very weak structure in oxisols is very often described as floury or massive porous, indicating almost no structure and low bulk density. In table 1 an attempt has been made to relate soil structure as described in the field to aggregation percentage in the laboratory.

It can be seen that the aggregation % after dry sieving quotes strong structure highest and weak structure lowest, but that the results are not as much spread as could be expected from the field. The aggregation % after wet seiving is larger in range.

FIG I RELATION BETWEEN CLAY CONTENT & 15 BAR WATER IN SOME ZAMBIAN & ZAIRE SOILS



Strong structure (vertisol) remains stable for 72% of the aggregates while 0% aggregates remain stable in the case of a weak structure (oxisols). Table 1 indicates that soil structure is measurable and that older soils loose both their chemical and physical fertility.

Table 1. Structure evaluation of some soil from Lusaka.

Family name	Structure in the B-horizon as observed in the field	Aggr. % after dry sieving (1)	Aggr. % After wet Sieving(2)
Clayey montmorillonitic isohyperthermic udic pellustert	strong coarse and very coarse plastic structure	81	72
very fine clayey kaolinitic isohyperthermic oxic paleustalf	moderate fine subangular blocky structure	69	31
fine clayey mixed isohyperthermic ultic haplustox	weak fine subangular block structure	54	0
clayey, kaolinitic isohyperthermic oxic, paleustalf (field tour guide, pedon 14)	moderate coarse subangular block structure	76	50

(1), (2) -diameters of the sieves are respectively 10mm and 2mm.
-all sieving has been done by hand.

Besides the decrease in soil structure, other aspects of soil physical degradation can be observed in older soils. In oxisols the water holding capacity can be so low, that the lower limit of the moisture control section as defined by Soil Taxonomy is situated at a depth of 179 cm and sometimes deeper, while for moderately structured alfisols the lower limit is only situated at a depth of 118 cm and sometimes even less deep (Field-tour guide, pedons 3 and 5)

It has also been noted that oxic paleustalfs (Field-tour guide, pedons 6 and 8) have high bulk densities (1.6 g. cm^{-3}) in their profile. This denser horizon has probably a pedogenic origin. Traditional agriculture is worsening the situation and ripping of this "sandveldt" soils from middle Zambia is

recommended in order to increase crop production.

What intensive agriculture can do to an oxic paleustalf is shown in pedon 14 of the field tour guide. The entire surface horizon and the top of the argillic horizon has a bulk density ranging from 1.62 to 1.86 g. cm^{-3} while the rest of the soil has a value close to 1.50g. cm^{-3}. This high bulk density in the plough layer is attributed to continuous tilling when dry in absence of an organic matter management.

Conclusions

1. Only a limited number of soil physical properties are used in Soil Taxonomy.

2. More physical characteristics can be used as secondary criteria are helpful in soil classification.

3. It should be recommended that oxisols are to be identified both on their chemical and physical properties (low water holding capacity, floury structure and low bulk density).

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FERTILITY EVALUATION OF SOILS

Obed I.M. Lungu

In soil fertility evaluation emphasis is placed on diagnosing plant nutritional problems with a view to removing soil-related constraints. We seek to improve or sustain crop production. In trying to achieve this, we recognise that soil amendments such as lime and fertilizer which are commonly applied to alleviate some of the soil fertility limitations are site specific. Differences in soil properties are one of the major reasons for this specificity. Immediately we see the need for well organized information about soils, and a need to relate this information to soil fertility evaluation programs.

Soil Taxonomy may bridge the existing gap between soil survey and soil fertility (Buol et.al. 1975, cf. Sanchez, 1976), and provide a means for effective transfer of agrotechno'ogy. Soil characteristics affecting fertility including depth, texture, mineral contents, and soil reaction are considered at family level in Soil Taxonomy. Organic matter content is taken account of at higher levels.

This paper highlights problems in relating soil fertility parameters to plant growth. It also attempts to show how the inclusion of more refined soil fertility parameters in Soil Taxonomy can improve the quality of recommendations and reduce the risk of agrotechnology transfer.

Problems in Relating Soil Taxonomy to Fertility

Sentiments have been expressed over too many laboratory analyses being required in the use of Soil Taxonomy (Panichapong, 1983). Instead a simpler system relying more on field identification of soil parameters is advocated. A move in this direction would diminish the potential value of Soil Taxonomy to provide means of transferring fertility information about soils. This is because soil fertility evaluations are commonly based on analytical properties of soils and plants rather then on morphological properties.

Morphological properties are described in the field, and soil survey largely depends on this. Some of the most easily identified, properties, however, are of no direct agricultural significance. Soil colour, for example, has no known effect on plant growth. Clay skins are a very useful diagnostic feature of soil type, but these are described in the subsoil which is out of the domain of soil fertility evaluation. Descriptions of weatherable minerals, routinely reported in soil surveys, have little bearing on plant growth because the rates of nutrient release by weathering are too slow to meet crop demand during a growing season.

Unambiguous soil fertility evaluation may be provided by

analytical procedures. Soil reaction is the most useful single analytical test for predicting crop response. Unfortunately this soil property is only used in two families of Entisols and Aquepts. Although clay mineralogy can be judged in the field from texture and consistence, analysis by X-ray and DTA give better estimates.

Great potential exists to include more analytical properties related to soil fertility at family level. A suggestion by some (Panichapong, 1983) to create a subfamily category to cater for fertility parameters, defined on the surface rather than subsurface soil characteristics, might improve the system.

Inclusion of more soil fertility parameters in Soil Taxonomy presents some problems. Some of our most reliable indices of soil fertility, for instance soil reaction and levels of available nutrients are transient rather than permanent soil properties. Transient fertility attributes of soils are suitable for practical agriculture. The need for research into the relationship between Soil Taxonomy and fertility is apparent, and the efforts of SMSS in the direction are timely.

Soil-Related Constraints in Zambia.

Unless quantum yield increases are obtained in areas where yields are low, farmers are unlikely to adopt any fertilizer recommendations. This problem is singled out as one of the limiting factors preventing widespread fertilizer use in Africa (Russel, 1974). There is need, therefore, to study the relationships of plant and soil nutrients to various soil parameters in order to rationalize fertilizer use and to achieve sustained high yields. Blanket fertilizer recommendations which ignore soil variations, plant characteristics, and climatic differences are not only uneconomical, but often fail to yield desired results.

In Zambia special attention is needed only in removing soil-related constraints from soils which have potential for agricultural expansion. Like in most African countries, potential exists to expand agriculture into new areas as well as to improve yields in cultivated lands.

The soils of Zambia range from the young, unleached varieties in the south (18deg.S) to the older, leached ones in the north (9deg.S.). This trend follows the rainfall pattern which averages 700 mm annually in the south and increases progressively northward to values above 1000 mm annually. The tropical climate with rather high temperatures and rainfall during November to March (the rest of the year is dry) are responsible for the prevalent mineral composition of the clay fraction. This is dominated by Kaolinite and hydrous oxides of iron and aluminum especially in the high rainfall areas (>1000 mm annual rainfall). The cation exchange capacity (CEC) is low, generally <16 meq per 100g, and values of below 10 meq per 100g

are not uncommon in the high rainfall areas. Acidity is a common feature of most soils and so is the low base saturation and organic matter. Phosphorus deficiency is widespread in most soils, and phosphate fixation is an important problem especially on the deeply weathered and leached soils.

Problems associated with soil amendments

These soils provide unique management problems. They are ranked among the world's coarsest in texture, the lowest in organic matter, CEC, and the most acid of several international soils studied by Sillanpaa (1982). The mean values for texture index, organic C, CEC, and pH with international means in brackets are respectively 27 (44), 0.8 (1.3)%, 11.4 (27.3) meq per 100g, and 5.0 (6.6) in $CaCl_2$.

Lime is seldom effective on these acid soils. Table 1 shows data which typifies results from many of the liming trials on acid soils especially from high rainfall areas of the country.

Table 1. The effect of lime, manure, and lime plus manure on soil pH and plant growth on an acid soil at UNZA farm.

Treatment	Soil pH postharvest [1] 0-20cm	20-40cm	Maize height 71 days after planting (m)		
Control	3.9	4.1	1.20	±	0.36
Lime (3t/ha)	4.4	4.1	1.19	±	0.27
Lime (6t/ha)	4.5	4.3	1.40	±	0.25
Manure(30t/ha)	4.8	4.4	2.20	±	0.06
Lime + manure	4.9	4.2	2.30	±	0.20

[1]. Preplant soil pH at the two soil depths were 3.7 and 3.6. Exchangeable Al = 1.3 meq per 100g.

Soil pH is not much affected by lime in spite of applying the requisite amount of 3 ton $CaCO_3$ per ha based on exchangeable Al extracted by 1 M KCl (Kamprath, 1970). Not even double the value of lime requirement (6 ton per ha) showed any more different results. We have no plausible explanation for these negative results, but we strongly suspect the quality of lime.

Table 1 also highlights the classical neglect of physical conditions of the soil when making soil fertility evaluations. In this experiment a maize crop showed greater response to additions of manure than to lime alone. Although we did not evaluate soil physical conditions, it is not unreasonable to partly attribute crop response on manured plots to the beneficial effect of organic matter on soil physical properties.

Examination of some physical properties of soils at the location on the experiment (Table 2) supports this view.

The organic matter content is low throughout the profile, and the surface 30cm are compacted as is reflected by the high bulk densities. This limits water movement into the subsoil. The data shows that following rainfall the surface 10cm of the soil have moisture contents at Field Capacity (pF=2). However, the soil below this depth is relatively drier, with moisture content values close to Wilting Point, (pF=4.2).

Table 2. Some selected physical properties of soils at the University of Zambia farm.

Soil depth cm	Bulk density g/cm	Organic C % [1]	Percent moisture pF=2	pF=4.2	content After mm rain
10	1.71	0.72	28.4	15.03	26
30	1.76	0.68	28.9	17.04	22
50	1.56	0.50	30.3	19.39	17
80	1.54	0.36	30.7	21.69	19
145	1.47	0.18	32.6	21.61	ND

Source: J.S. Lenvain, Department of Soil Science, UNZA (Research Report, 1985, unpublished)

[1] From Toogood, Department of Soil Science, UNZA (Internal Report, 1982, unpublished)

ND = not determined.

This data suggests that constraints in soil physical conditions are just as crucial to the growth of crops as is chemical fertility. Our Soil Advisory Laboratory at Mt. Makulu conveniently recognizes three categories of acid soils. There are soils where both the top and subsoils have a pH < 4.5 in 0.01 M $CaCl_2$. These soils are also often physically degraded, and reclamation type of management (use of acid tolerant species, liming, and soil structure amendments) are recommended. The other category includes soils with surface pH values of <4.5 and subsoil values of >4.5. This condition only calls for remedial liming where lime, or lime coupled with use of acid tolerant species is the recommended management strategy. The third category of soils have pH values of >4.5 throughout the profile. Here maintenance liming is recommended, and involves applying lime at regular intervals to cropped lands. Two tones of $CaCO_3$ per ha every two years seems to be a common practice among the

commercial farmers. A mixed fertilizer containing lime is also commercially available. The constituent lime is meant to neutralize the effect of acid-forming fertilizers on soil.

It has also been reported that where lime has had some effect on soil pH, the crop has not responded to the improved soil reaction (Larsen, 1984). Only certain soils tend to behave this way. The real cause of this adverse effect remains to be demonstrated, and it probably can be partly explained by cation imbalance in tropical soils.

Table 3 gives few data showing the disparity between the actual values of exchangeable Ca and Mg, and calculated values on the basis of optimum cation balance. Yield of a crop is found to be maximal for one well defined ratio of cations, and 75% of the total exchangeable cations held by soil ought to be Ca and 18% of Mg (Personal communication by Prof. C. Sys).

Table 3. Comparison of exchangeable Ca and Mg held by some acid soils to expected values calculated on the basis of optimum cation balance.

Profile	pH	BSP	Actual CEC	Actual Ca	Actual Mg	Expected Ca	Expected Mg
			me / 100g				
COP 6/72	4.8	28	9.4	1.6	0.77	3.16	0.76
COP 6/73	4.4	-	4.1	0.6	0.40	0.85	0.20
COP 8/72	4.2	15	3.0	0.20	0.20	0.36	0.08
COP 9/72	4.7	40	3.2	0.70	0.30	0.95	0.23
COP 12/72	4.2	18	2.8	0.25	0.20	0.38	0.10
WEP 16/72	3.2	6	10.8	0.45	0.20	0.51	0.12
LUP 4/72	4.0	6	8.4	0.45	0	0.83	0.10
LUP 3/72	4.0	10	8.4	0.60	0.15	0.75	0.16
LUP 2/72	4.1	36	8.0	1.20	1.50	2.18	0.52
SOP 13/72	4.3	52	5.4	1.80	0.85	2.10	0.51
NOP 1/72	4.1	18	13.0	4.10	1.30	4.5	1.08
NOP 2/72	4.1	5	44.9	0.50	0.20	0.55	0.13

Adapted from Brammer, 1973

The amounts of Ca and Mg, and the Ca/Mg ratio are commonly less than those expected of soils with such CEC and base saturation. This condition will determine the success of a liming program. Dolomitic limestone applied to acid soils only marginally supplied with Ca can be expected to create an imbalance between Ca and Mg. Gillman (1983) has highlighted this problem in acid tropical soils.

The technology to alleviate soil constraints and to increase land productivity is generally available. A dilemma we are facing, however, is the high prices of input and the low efficiency of their use. For instance, lime is generally added in relatively large amounts, and the costs of mining and handling become significant factors. Local sources of lime are cheaper. In Zambia some of the major locations of acid soils have lime deposits which could be used. (Table 4). These are, however, not yet developed, and many have been found to be of too low neutralizing values to be suitable liming materials. The Geology department at the University of Zambia has determined values which are less than 30% for some of the most accessible deposits in potential arable areas. The variations in Ca to Mg ratios of these limestones can be expected to further limit their efficiency on soils with different Ca and Mg requirements.

Table 4. Location of some major acid soils and the location and composition of most feasible limestone deposits in Zambia.

Province (deposit)	Mineral Composition (%)		
	Calcite ($CaCO_3$)	$MgCO_3$	Dolomite $CaMg(CO_3)_2$
Northern	5	-	77
Luapula (Chembe)	11	-	77
North-Western			
(Kansanshi)	78	-	6
(Solwezi south)	-	-	77
Copperbelt (Ndola)	97	0.37	-
Lusaka (Chinika)	95	2.4	-
(Chalimbana)	95	1.3	-
Southern (Chilala)	90	-	3
(Jones Ranch 1)	18	-	52
(Jones Ranch 2)	52	-	13

Source: Munyinda and Ngwenya (1980)

Consideration of Economic Conditions in Fertility Assessments.

It is believed that the technologies that will raise yields sustainable and economically are yet to be developed (Gerloff, 1976). It is being suggested that much of the research needed will be applied and will be aimed at adapting plant varieties or practices to soil and local conditions.

Plant species even varieties of the same species having grown side by side in the same soil under identical conditions often show differential nutrient uptake. Table 5 shows one such case where clover (Trifolium spp.) and buckwheat (Fagopyrum esculentum L.) can absorb phosphorus from sparingly soluble rock phosphate as well as from a water soluble source.

Table 5. Relative P uptake from untreated rock phosphates by some selected crops (uptake from water soluble calcium monophosphate = 100).

Crop	Rock phosphate 1.	Hydroxy apative 2.
Sweet clover	83	-
Buckwheat	72	108
Rye	67	-
Alfalfa	62	-
Soybean	47	53
Maize	42	42
Wheat	42	13
Oats	41	-

Source: 1. Collings, 1947

2. van Ray, and van Diest, 1979

This variation represents great potential to expand cultivation into marginal soils, or to improve yields in low input systems such as is common among the many small scale farmers. Use of nutrient efficient crops might be beneficial on soils with high residual phosphorus (plant unavailable). The practice might also extend the utility of direct applications of rock phosphate to soils, currently being tested on acid soils.

Limitations of Soil test Procedures

Table 6 shows the common problem of lack of correlation between soil test values and plant nutrient uptake in the field. The data proves that the amount of phosphorus taken up by oats approximates that extracted by resin. Buckweat, however, absorbed much more from the same soil. This takes place as a result of direct action of the buckwheat plant itself (Karpinsky and Glazunova, 1968) because it is hardly probable that the additionally extracted phosphorus would spontaneously dissolve into the solution.

Fried and Dean (1952) could not have summed it up better when they wrote: "The amount of nutrient available in a soil depends not only upon the soil itself, but also upon the specific conditions under which a crop is grown. In a true sense, the plant is the only agent that can determine the amount available."

Table 6. Comparison of the amount of P taken from chernozen soil by oats and buckwheat with the value extracted with resin.

Crop	Plant Removal stage	Uptake by plant	Extracted by resin
		mg per 100g	
Oats	1	0.6	-
Buckwheat		0.6	-
Oats	2	1.7	1.4
Buckwheat		2.5	1.1
Oats	3	2.3	2.1
Buckwheat		3.6	1.5

Source: Karpinsky and Glazunova (1968).

Conclusions

The task of finding out where to use the various nutrient elements, or agrotechnology, and how to use them to insure a more productive agriculture is a complex undertaking. Plant growth is influenced by many stresses including soil-related constraints. some soils have more and others have less of these constraints.

There is a clear need to study soil constraints. Further, there is need for an international language of soil science, such as Soil Taxonomy, to facilitate the exchange and transfer of soil information. At present there are problems in trying to include some soil fertility indices (based on transient soil properties) in Soil Taxonomy. In spite of these limitations it is hopeful

that Soil Taxonomy can be related to soil fertility and crop production.

One major problem related to fertility evaluation based on soil testing is the reliability of the methods. Some suffer from the limitation that they take no account of the extent to which plants interact with solid components of the soil. This is partly the cause of apparent lack of correlation between laboratory data and plant growth in the soils.

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EFFECT OF LIMING ON SOIL PROPERTIES OF OXISOLS AND ULTISOLS

Bal Ram Singh

Introduction

The acid tropical soils belonging mainly to Oxisols and Ultisols occupy 1675 million hectares, constituting 38% of the agricultural land in the tropical areas. In Zambia, about 35% of the total arable land belongs to this group of soils. These soils are characterized by low pH (often pH <5.0), high Al and Mn, low nutrient retention capacity, high P fixing capacity. low organic matter, and low moisture retention capacity. Therefore, major constraints for agricultural production in these soils are of chemical rather than of physical nature.

When the chemical soil constraints are eliminated by liming and application of the necessary amounts of fertilizers, the productivity of these soils can be among the highest in the world (Vuebte-Chandler et al., 1974). It has also been reported that a sustained and stable food crop production is possible in the Oxisols and Ultisols of Amazon Basin with use of appropriate technology (Sanchez et al., 1982). They, however, stressed that it will be unwise to assume that continuous cultivation technology is applicable to the millions of hectares of Ultisols and Oxisols in the tropics. The new technology developed for Amazon basin need to be tested locally to suit soil, climatic, and socioeconomic conditions of the farmer in the area.

In spite of wide differences in results of liming, which have not been satisfactorily explained, there is a general mandate that liming is a keystone of soil management in humid tropics (Ayres, 1961; Laroche, 1966; Kamprath, 1972). In areas with a history of adequate N fertilization, the most common yield-limiting factor of soil fertility is an inadequate liming program (Pearson et al., 1961). In areas just recently brought into cultivation, liming generally shares the "most yield-limiting" soil fertility factor with P fertilization.

The purpose of this paper is to describe effect of liming on soil properties of Oxisols and Ultisols with special emphasis on chemical properties. However, effects of liming on microbiological and physical properties are also discussed.

Effect of Lime on Soil Chemical Properties

Soil pH and exchangeable Ca

In temperate regions, liming causes immediately a fairly predictable soil pH change and subsequently, long-term gradual changes, but soils of tropical regions often respond differently. Grant (1979), working with strongly acid soils in Rhodesia,

reported that roughly one-third of the applied lime was lost by leaching during the first two seasons after liming, but the proportion varied from 10 to 60 percent, according to soil and ambient conditions. This was reflected in soil pH, which increase sharply during the first season after liming, then drifted downward, approaching the initial level by the end of the second season.

These observations are consistent with reports from various humid tropical regions. Foster (1970), for example, reported results of liming experiments at a number of locations in Uganda on ferrallitic and related soils whose initial pH values ranged from 4.3 to 5.9, and CEC's by cations varied from 4 to 23 meq/100g. The first 5 t/ha of lime increased soil pH about 0.6 unit, regardless of initial pH, but the second increment of 10 tons had a varied effect (Table 1). In general, the soils were highly resistant to pH, change induced by liming and seldom exceeded pH 5.5 to 6.0, although two of them had initial pH in this range and responded sharply to the first increment of lime. Presumably, this peculiar behaviour was at least partly due to the very high pH-dependent charge exhibited by these soils. Uehara and Keng (1975) point out that this type of behaviour is caused by the development of high surface-charge densities on the oxides and hydroxides of Si. Fe, and Al, particularly in Oxisols and Ultisols. In Colombia, Medina and Luna (1971) found that on strongly acid soils from volcanic ash, even 60 t/ha of $CaCO_3$ did not raise pH above about 6.5, whereas in red soils of the area, only 5 to 10 t/ha were required to raise pH to this level.

Table 1. Effect of lime on pH of several "ferallitic" and related soils included in field trials reported by Foster (1970).

Location	Exchangeable Al meq/100g	Initial pH	Soil reaction: 1 yr after 5 t/ha lime pH	Soil reaction: 2-1/2 yr after 15 t/ha pH
Rubare I	0.38	4.53	5.16	5.95
Kachwekano II	0.14	5.02	5.38	6.14
Kawanda II	0.13	5.06	5.62	5.86
Kachwekano I	0.14	5.20	5.76	6.42
Namulonge I	0.08	5.25	6.36	6.53
Balindi II	-	5.64	6.20	6.37
Bukalasa II	-	5.77	6.40	6.67

In general, it seems that soil pH changes induced by liming tend to be more transient in tropical soils than in those of temperate regions. Pearson (1975) found that exchangeable Al practically disappeared from buth Ultisols and Oxisols in Puerto

Rico at pH values around 5.5 and that it was difficult to maintain levels that high, regardless of the rate of lime used. This is clearly shown in figure 1 for an Oxisol and an Ultisol in field experiments in Puerto Rico. The initial application of lime, calculated to essentially neutralize exchangeable Al, raised pH in both soils to approximately the level anticipated within about a year. During the next 18 months, however, pH in the Oxisol dropped to 4.65, near the original value, while that of the Ultisol held constant. Application of an additional rate calculated to raise pH to about 6 resulted in pH of only 5.5 in the Oxisol, and during the following 4 years it fell to 4.7. In this same period, pH of the Ultisol dropped from 6.3 to 5.1. The fact that residually acid N fertilizer applied during this 7-years period would have offset no more than 3 tons of the lime removed fertilization as a determining factor in the rapid pH shifts observed. Also, in as much as in both experiments the lime was incorporated into the plowed layer, erosion losses should have been relatively small. Of course, if seasonal variations in salt concentration caused some of this fluctuation, that would support the concept of standardizing pH measurements in a salt solution such as 0.01 M $CaCl_2$ (Peech, 1965).

Mikami and Kimura (1964 pointed out that Ca added to tropical soils as lime often is not recovered even in the absence of leaching of erosion losses, and suggested a fixation reaction of undetermined nature. In laboratory studies using Hawaiian soils, they found up to 15 per cent of applied Ca fixed within 5 months. Ameddee and Peech (1976), however, found no indication of Ca fixation by six Oxisols and one Ultisol included in their study. Rios et al. (1968) noted that soil pH decreased in the absence of leaching or use of residually acid fertilizer during the 6 months after lime application and suggested a possible reaction of Ca with P released from a Fe and Al combination as the reason for the soil pH decrease.

Exchangeable and soil solution Al

Relationship between Al, percent Al saturation, and pH

As early as 1925, Magistad related pH to the level of Al in soil solution and in culture solutions and showed that the levels of Al in solution decreases rapidly to <1 mq kg^{-1} at around pH 5 and above. Accordingly little response to liming would be expected in many soils at soil solution pH values above 5. The fact that observed plant response usually does extend above a soil pH of 5 is at least partly a reflection of the difference in soil suspension and true soil solution-pH, which is usually around 0.5 unit, being lower in the soil solution. Also, exchangeable Al does persist in appreciable proportions well above a soil suspension pH of 5.0. This is shown clearly in figure 2, which presents data for both Oxisols and Ultisols.

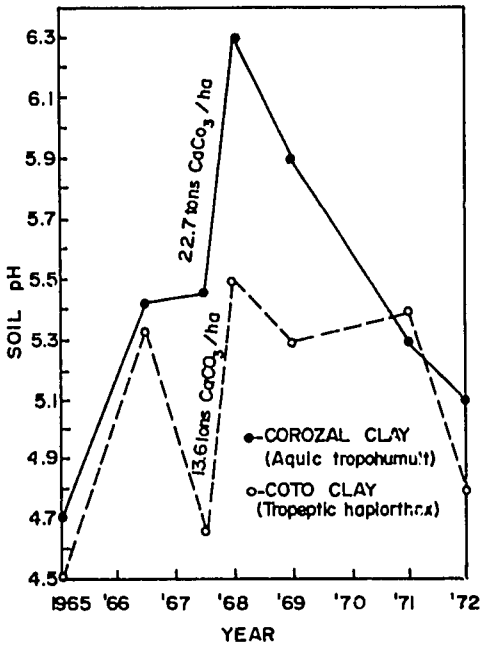

Fig. 1 Changes in pH over time after lime was applied to a puerto Rican Ultisol and an Oxisol (Pearson, 1975).

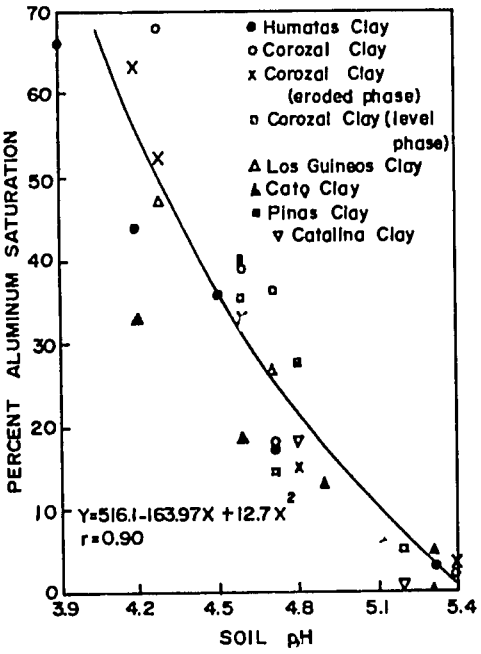

Fig. 2. Changes in Al saturation percentage with pH in several Puerto Rican Ultisols and Oxisols (Abruna et al., 1975)

This relationship between soil pH and Al saturation is consistent with observations reported from various tropical areas of the world (Brams, 1971; Fox et al., 1962; Brenes and Pearson, 1972).

While soil pH is closely related to Al saturation and solubility of Al, both the concentration and the chemical activity of Al in the soil solution are drastically influenced by electrolyte level in the soil. This phenomenon was early noted by Fried and Peech (1946), who found Al concentration in a water extract of an acid soil treated with gypsum to be increased more than 100 per cent; and later by Cate and Sukhai (1964), who recommended that salt content of acid rice soils be kept below 1000 ppm to prevent Al toxicity. This salt effect on the activity of Al^{+++} in the soil solution itself is shown in figure 3 for an Ultisol and an Oxisol in Puerto Rico. What appears to be anomaly in this instance, in that Al^{+++} activity should take electrolyte content into account, is probably due to the use of soil suspension pH rather than soil solution pH in the correlation. Thus, soil solution pH would have been lower than soil suspension pH for any soil with pH above zero point of charge, but higher for those with pHs below that point (Van Raij and Peech, 1972). When the salt effect was taken into account by including electrical conductivity of the soil solution in the expression of Al level, the variations of a given soil pH were essentially eliminated (Figure 4).

This concept is further supported by the data presented in table 2 (Gillman 1984). From the data in Table 2 it appears that the amount of H + Al extracted is very dependent upon the pH of the KCL extractant after it has interacted with the soil. (Actually the amounts of H in the extract would be negligible at these pH values, so that H + Al is really Al). It is well known that Al is quite insoluble in water between pH 5 and pH 7, so that as pH_{KCl} increases towards pH 5, H + Al decreases. Theory helps us to explain the variation in pH_{KCl} between the different soil samples. If soil pH > pHo solution pH will decrease when the ionic strength is increased, and this is the case with the 0-15 cm basaltic sample and all granite and metamorphic samples. However, if soil pH < pHo solution pH will increase with increasing ionic strength, and this explains the low H + Al values of pH_{KCl} differences between samples reflect the amount of surface negative charge and its degree of occupation by basic cations, the presence of Al compounds that may be solubilized, as well as Al bound to organic matter.

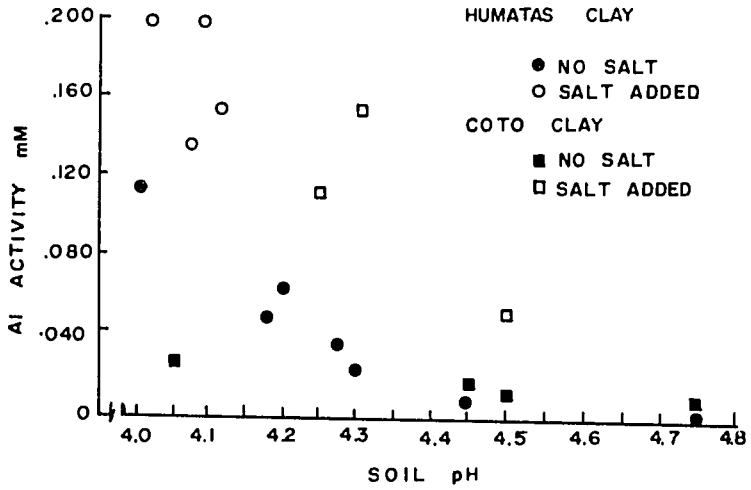

Fig 3 Effect of presence of free electrolyte on Al level in the displaced soil solution. KCL added at 0.5 meq/100g average to 2 Puerto Rican soils and equilibrated before displacement. (Brenes and Pearson 1972)

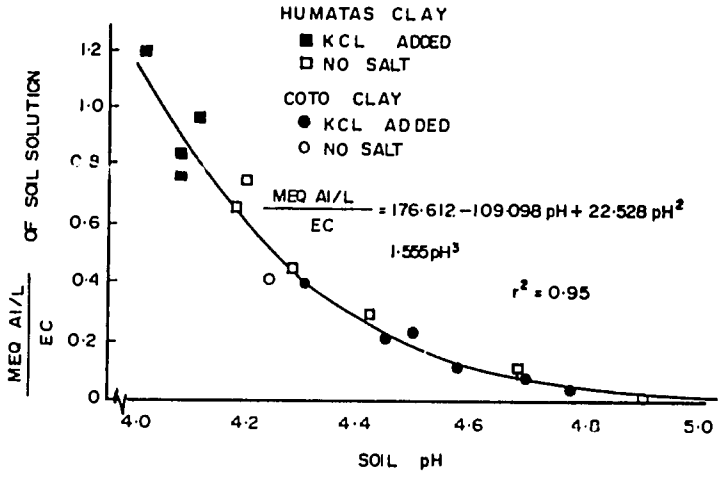

Fig 4 Relationship of pH to soil solution Al in an Oxisol and an Ultisol when free salt content as reflected in electrical conductivity (EC) of soil solution is considered (Brenes & Pearson, 1972)

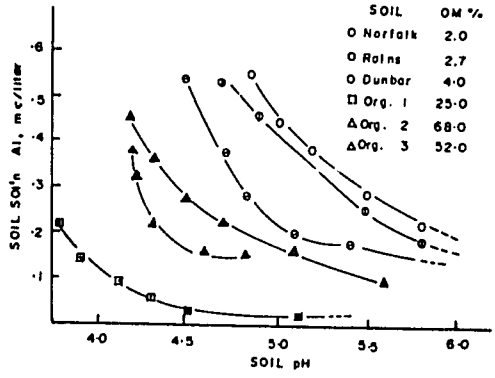

Fig 5 Effect of organic matter on the soil solution Al–pH relationship (Evan & Kamprath 1970)

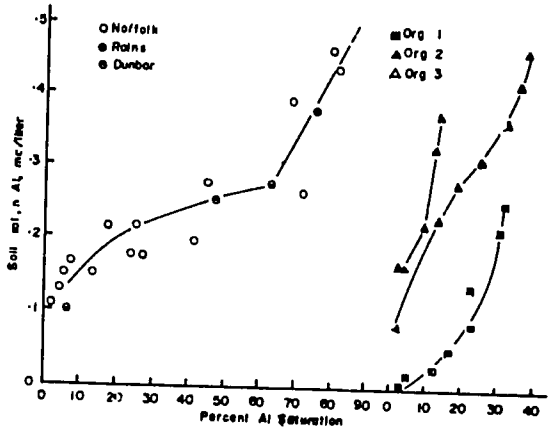

Fig 6 Relationship between percent Al saturation & soil solution Al (Evans & Kamprath 1970)

Table 2. Selected data for three virgin highly weathered soil from north Queensland (Gillman, 1984)

Depth (cm)	Acrorthox on basalt Soil OM	pHo	pH	pH_K	H+Al	Tropudult on granite Soil OM	pHo	pH	pH_K	H+Al	Acrorthox on metamorphics Soil OM	pHo	pH	pH_K	H+Al
0-15	8.8	3.8	5.1	4.9	0.6	4.7	3.6	5.5	5.2	0.2	5.9	3.7	4.7	4.3	1.7
15-30	5.0	4.9	4.9	5.0	0.4	1.9	4.2	5.2	4.9	0.3	3.2	4.2	4.8	4.5	1.4
30-60	3.1	6.1	4.8	5.2	0.3	1.2	4.2	5.0	4.8	0.5	1.7	4.3	4.7	4.5	1.2
60-90	1.5	6.7	4.8	5.5	0.2	0.6	4.2	4.7	4.6	1.0	0.7	4.4	4.6	4.5	1.2

Relationship between Al and organic matter

Carboxyl groups of organic matter are the primary functional groups involved in exchange reactions with cations. Using infrared techniques, Schnitzer and Skinner (1963) found that Al would react with organic matter up to a 6:1 molar ratio indicating six carboxyl groups per organic matter molecule. It is possible that Al could be electrostatically bound to one or more carboxyl groups depending on the degree of polymerization and effective charge of the Al molecule. Clark and Nichol (1966) suggested the formation of insoluble Al organic matter complexes. It is possible that organic matter reduces the solubility of Al through compex formation and results in less Al in the soil solution. This may be one reason why plants grow well at a lower pH on organic soils than on mineral soils. Clark and Nichol (1966) suggest that it may be necessary to take into account both the pH and the solubility of Al in estimating the liming needs of organic soils.

Evan and Kamprath (1970) reported that as the organic matter content of soils increased, there was less Al in the soil solution at a given pH. (Fig. 5.) This can be attributed to the competing of Al by organic matter and reducing the amount of Al in the soil solution. There is only one exception to this relationship, namely, organic 1 which had 25% organic matter. The mineral fraction for this soil was mainly fine sand and the effective influence of organic matter may have been greater than that for other organic soils. Small increments of lime resulted in relatively rapid decreases in soil solution Al for all soils.

The relationship between soil solution Al and per cent Al saturation for the mineral and organic soils is shown in figure 6. The concentration of Al in the soil solution of mineral soils is determined by the per cent saturation of the effective CEC with exchangeable Al. All mineral soils behaved similarly and one line appeared to satisfactorily characterize that relationship. At about 60 to 70% Al saturation there was a relatively sharp change in slope of the curve with large increases in soil solution Al as per cent Al saturation increased

above 70%. These results agree quite well with those of Nye et al. (1961) in which they report low concentrations of soil solution Al in soils of small electrolyte concentration when Al saturation is below about 60%.

With the organic soils there was no general relationship between per cent Al saturation and the amount of Al in the solution such as was found with the mineral soils. For organic soils, small changes in per cent Al saturation resulted in large changes in soil solution Al. The lines are almost linear and do not show a sharp break at a given point as was the case for mineral soils. The data suggest that for organic soils, the amount of exchangeable Al rather than the per cent saturation is more important in determining the amount of Al in the soil solution.

Manganese solubility

Pearson (1975) noted that Ultisols in Puerto Rico seldom present a Mn problem, whereas Oxisols frequently do. In other areas, however, Ultisols frequently present Mn problems (Adams and Pearson, 1967), while Oxisols may contain only traces of MnO2 (Ayers, 1961). The solubility of MnO2 increases as pH decreases or as the redox potential decreases because of the reaction

$$MnO_2 + 4H^+ + 2e^- \leftrightarrow Mn^{2+} + 2H_2O$$

An increase in solution Mn^{2+} is favored by lower pH, soil drying, soil heating, and lower redox potentials. The latter condition is enhanced by waterlogging conditions, especially when accompanied by rapid decomposition of organic matter (Redman and Patrick, 1965). As a general rule, Mn toxicity is not a problem in any soil unless pH is <5.5 (Adams and Pearson, 1967; Pearson, 1975).

Threshold toxic concentrations of Mn in solution were reported by Morris and Pierre (1949) to vary from about 1 to >10 ppm. They also reported the following relative tolerance to excess solution Mn: peanuts > cowpeas (Vigua sinensis Endl.) = soybean > sweetclover > LesPedeza (Lespedeza striata Thurb.). Manganese concentration decreased to a very low level where liming raised the soil pH from 4.05 to 4.75. In other experiments, Mn uptake of various crops decreased progressively as soil pH was increased by lime application (Abruna et al., 1975), indicating that soil solution levels of Mn decreased as soil pH increased.

Phosphorus availability

A common benefit ascribed to liming is that it renders P more available. But there has been controversy over this benefit and as pointed out by Kamprath (1972), published results show that the effect of lime on P availability can vary from beneficial to deterimental.

Numerous studies have failed to show either reduction in P fixation after liming or improvement in solubility in various extractants. Soil P solubility in an Oxisol from Colombia decreased sharply as pH was increased by $CaCO_3$ application up to about pH 6.5, and the limed soil has a higher maximum P adsorption capacity than the unlimed soil (Amarasiri and Olsen, 1973). The authors suggested that the freshly precipitated Fe and Al hydroxides were responsible for the increased inactivation of added P as lime rate increased. Pot-grown rye and millet were given a wide range of lime and P applications. Essentially no growth of either crop occurred at Po, but yield was near maximum at the highest rate. Phosphorus uptake was higher around pH 5.5 than at either higher or lower values, as is shown for rye in figure 7. Per cent P in the plants increased with liming at the lower levels, but remained constant after reaching a maximum at the third lime level, indicating that the rye yield decrease at the upper lime rates caused the drop in P uptake and was due to some factor other than depressed P did not reduce P fixation in eight Natal Oxisols. They also reported that P retention was not related to exchangeable Al levels in these soils. Again, lime applied to ferrallitic soils of West Africa with pH levels of around 5.3 and exchangeable Al ranging from 6 to 26 per cent did not influence availability of P applied to maize or groundnuts (Brams, 1971).

Data by Soltanpour et al. (1974) showed that all rates of lime decreased the availability of all levels of previously added P. The observation that liming sometimes increases the availability of soil P may result from an increased P release from organic matter because of an accelerated decomposition rate (Awan, 1964). It may also be the result of an improved root system because a Ca deficiency was corrected (Hortenstine and Blue, 1968).

Since the neutralization reaction of lime results in the precipitation of exchangeable Al, adding successive increments of lime prior to fertilizing can be expected to render the fertilizer P progressively more available until enough lime has been added to reduce the exchangeable Al to nil; above this pH, additional lime increments can be expected to progressively decrease P availability (Amarasiri and Olsen, 1973; Reeve and Sumner, 1970; Soltanpour et al. 1974).

Stoop (1983) reported that P solubility in the oxidic soils depended mainly on salt concentration and cation valency. It was decreased by the accompanying cation according to $K < Mg \leq Ca$. This cation effect on P solubility decreased with increasing contents of layer silicate clay minerals and/or increasing base saturation of the soil. The P solubility increased greatly when the pH was raised with NaOH as compared to $Ca(OH)_2$. (Table 3).

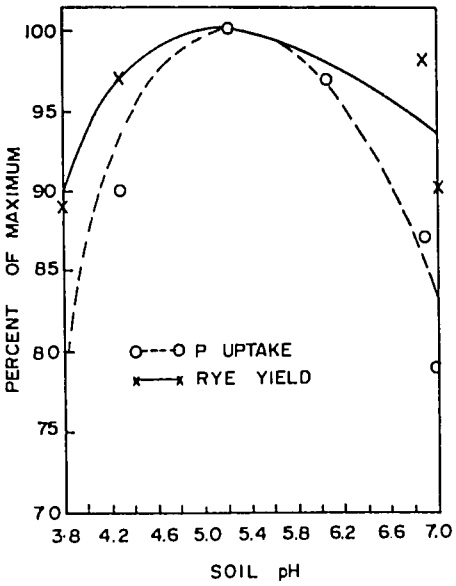

Fig 7 Soil pH effect on rye yield and P uptake from Oxisol (Amarasiri & Olsen, 1973)

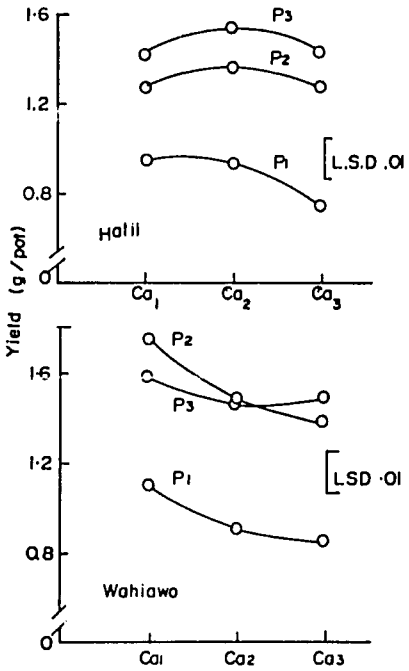

Fig 8 Yields of Sudan grass as a function of Ca and P treatments for the Halil and Wahiawa soils (Stoop 1983)

Table 3. Effect of pH on the concentration of P in solution when using NaOH and $Ca(OH)_2$ to raise the pH*1

Soil	Treatments		P in solution
	added P (ug P/g soil)	pH	(ppm)
Honokaa	3000	4.8	0.6
	3000	5.8 NaOH	7.7
	3000	5.8 $Ca(OH)_2$	0.9
Halii	1500	4.8	1.7
	1500	5.8 NaOH	3.3
	1500	5.8 $Ca(OH)_2$	1.5
Wahiawa	750	4.8	2.3
	750	5.8 NaOH	5.1
	750	5.8 $Ca(OH)_2$	2.7
Waialua	375	5.8	4.1
	375	6.8 NaOH	3.8
	375	6.8 $Ca(OH)_2$	2.5

*Equilibration was in 0.01 N KCl, phosphate added as $NH_4H_2PO_4$

This result explains why in many oxidic soils even moderate liming rates were not found to increase the P availability. He further showed the negative effect of the Ca ion on P uptake by Sudan grass in two Oxisols (Fig. 8).

Mendez and Kamprath (1978) reported that liming has relatively little effect on P concentration of the tops as compared with P rate (Table 4). The increased plant growth with liming at the lower pH rates without any effect on P concentration supports the view that liming improved P absorption by plants rather than affecting solubility of soil P (Reeve and Sumner 1970).

Both P rate and % Al saturation had significant influences on the beneficial effect of liming on P response. Neutralization of Al by liming increased relative growth at low rates of applied P. However, with larger amounts of applied P there was no benefit from liming when the Al saturation was <60%. Previous studies have shown that if the Al saturation is <60%, the amount of Al in the soil solution is relatively low as compared with Al saturations >60% (Evans and Kamprath, 1970). At these lower concentrations of Al the larger P additions either precipitated Al internally and still provided sufficient P for metabolic purposes (Wright, 1937), or removed the detrimental effect of Al by precipitating it in the soil (Munns, 1965). When Al

saturations were >60%, large P additions apparently could not completely overcome the detrimental effects of Al on plant growth.

Table 4. Effect of liming and P rate on dry matter production and P concentration of millet grown on Latosols

Fertilizer P, ppm	No lime Tops	No lime P	Lime Tops	Lime P
	mg/pot	%	mg/pot	%
		La Mesa I		
0	24	-	36	-
115	439	0.27	595	0.25
230	591	0.30	757	0.35
460	680	0.60	752	0.60
LSD 0.05L x P				
		Pacora II		
0	36	-	65	-
35	261	0.17	651	0.14
70	674	0.18	958	0.20
140	818	0.30	1026	0.37
LSD 0.05L x P	167			
		Pacora III		
0	23	-	46	-
35	223	0.17	354	0.17
70	762	0.20	791	0.20
140	772	0.32	928	0.32
LSD 0.05L x P	146			

Potassium availability

Liming can increase plant efficiency in the use of K simply by removing other growth-limiting factors and improving the positional availability of K through an expanded and more effective root system. In addition, liming usually decreases leaching losses of K, tends to increase reversion of K to less soluble forms, and may or may not affect the rate of release of native mineral K into soluble or exchangeable form (Peech and Bradfield, 1943; Rogers, 1948). Thus, the use of lime on highly weathered and leached soils of the humid tropics could conceivably have a wide range of effects on plant growth through

its influence on the K economy of the soil, depending upon various soil characteristics. Amarasiri and Olsen (1973) found that yield depression in millet at high rates of liming an Oxisol from Colombia was related to the K/Ca ratio in the plants. They noted that the ratio increased progressively as yield increased, and that 70 percent of the variation in yield from individual pots could be accounted for by this ratio. Ayres (1961) showed that leaching loss of K from two Hawaiian soils was substantially reduced by even modest applications of lime. In one soil, an application of lime of only 2 t/acre halved the K loss. This effect would be especially significant in the generally permeable upland soils of hot humid regions.

Micronutrient availability

Micronutrient deficiency does not occur as commonly as anticipated in such generally infertile soils. Certainly in areas where widespread micronutrient deficiencies have been identified or where incipient deficiencies are known to exist, the use of lime rates beyond minimum levels required for satisfactory crop growth would be hazardous. Hawaiian researchers have recorded that overliming caused a Zn deficiency in corn and cucumbers (Young and Plucknett, 1963; Fox and Plucknett, 1964), and that when soil pH reached about 7, severe symptoms of deficiency in Desmodium intortum became evident.

In Uganda, Foster (1970) reported that an interaction between lime and a complete micronutrient treatment affected groundnut yield at only one of about 20 experiment sites. In this instance, the micronutrient treatment increased yield only in the presence of lime. In the same series of experiments, micronutrient application decreased bean yield in the absence of lime and had no effect when lime was applied, which suggests a toxic effect. Widespread Mo deficiencies in groundnuts have been identified in Uganda by Nye and Greenland (1960), where a 12 per cent average yield increase for applied Mo was found in nineteen field trials. This probably explains the frequently observed response of groundnuts to lime on these soils even at pH levels as high as 6.

Liming an acid soil has a pronounced effect on Mo availability (Fig. 9). Generally, it corrects Mo deficiency, either partially or completely, by increasing the availability of Mo already present in the soil (Anderson and Moye, 1952).

Legumes are somewhat more responsive than non-legumes to the increased availability of Mo. The response difference is not necessarily because of a greater Mo requirement per se of legumes; it appears to be because the increased Mo increases the N fixation capacity of the Rhizobium organisms.

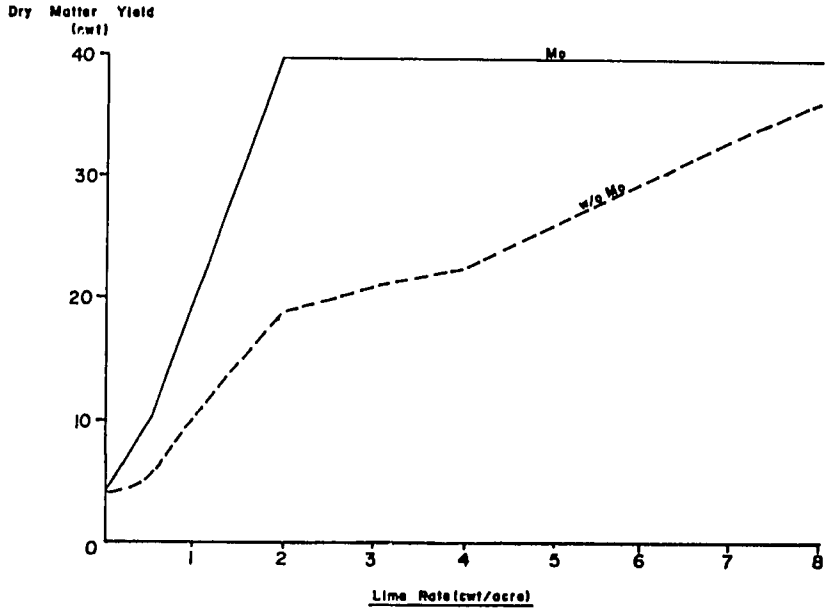

Fig. 9. Effect of lime and molybdenum on yield of subterranean clover (Trifolium subterraneum L.) on an acid soil in southeastern Australia Southeastern Australia (Anderson and Moye, 1952).

Liming increases Mo availability by releasing the Mo from soil minerals, primarily Fe and Al oxides (Ellis and Knezek, 1972), with the hydrous Fe oxides binding Mo in greater quantities than Al oxides or other clay minerals (Jones 1937). The overall release reaction as a function of pH was proposed by Reisenauer et al. (1962) to be:

$$Fe_2(MoO_4)_3 + 6OH^- \leftrightarrow 2Fe(OH)_3 + 3\ MoO_4^{2-}$$

The obvious effect of pH on the above reaction is for $Fe_2(MoO_4)_3$ formation to be favoured by low pH and for soluble MoO22- to be favored by high pH. Soils high in free Fe_2O_3 appear to be most prone toward Mo deficiency, but too few data are available for any conclusive cataloging of soils according to potential Mo deficiency.

Sulphate availability

Liming an acid Ultisol or Oxisol will increase the level of soluble or extractable SO_4. Data by Elkins and Ensminger (1971) present an excellent example of the effect of lime on soil-solution SO4 concentrations (Fig. 10). The increased solution SO4 is believed to come primarily from Fe and Al oxides. These soil minerals have a high capacity to remove SO_4 from solution and retain it as part of the soil's solid phase.

Because Fe and Al oxides are major components of the clay fraction of Oxisols and of many Ultisols, such soils can be expected to retain significant amounts of any added SO_4, particularly in the lower soil horizons where base saturation is low and where soil clays may even be positively charged.

Effect of Liming on Soil Microbiological Properties

Organic matter decomposition

In general, the population shifts from bacteria to actinomycetes to fungi as soil acidity increases, although the acid tolerance of individual microbial species varies widely. Thus, transformations of such nutrient elements as N,P, and S between the organic and inorganic state, and both the symbiotic and nonsymbiotic fixation of N would be affected to an important degree by liming. Ayres (1961) found that organic matter decomposition in Hawaiian soils was speeded up considerably by liming. In an 8-month incubation test, 35 ppm N was released in the unlimed treatment, compared to 125ppm in the limed soil. Bornemisza (1967) also reported more rapid decomposition of soil organic matter in Costa Rican soils after liming.

The broad range of fungi as well as of bacteria and actinomycetes that contribute to the mineralization of organic N (conversion of soil organic N to ammonium) means that the process does not show a marked sensitivity to pH (Alexander, 1980).

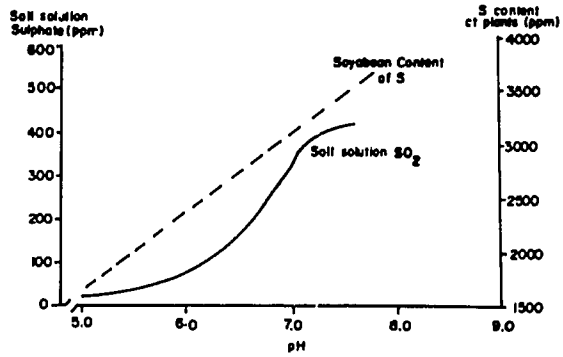

Fig 10 Effect of lime rates on the availability of sulfate in an acid Ultisol (Elkins & Ensminger 1971)

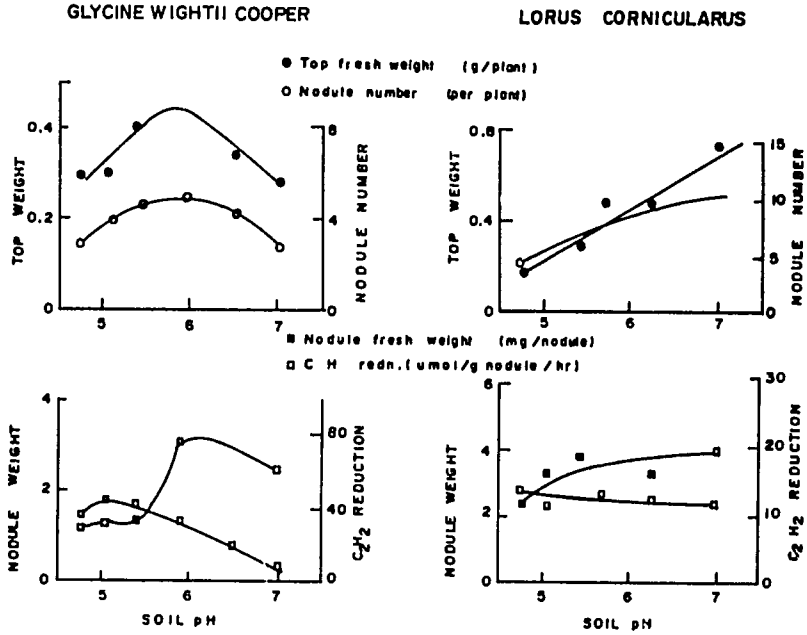

Fig 11 Effect of liming on yield (nodule number and weight) and acetylene reduction by two legumes grown in an N-deficient Oxisol. (Data from Munns et al 1977)

Nevertheless, liming acid soils generally results in increased nitrogen mineralization rates (Table 5) (Ayres, 1961; Bornemisza et al., 1967; Nyborg and Hoyt, 1978) although this may only be a temporary effect (Nyborg and Hoyt, 1978). Increased mineralization of organic S following liming can also result in increase uptake of sulfate by plants (Barrow, 1965).

Table 5. Mineralization of Organic N and Nitrification in Two Acid Soils Incubated for 4 Weeks with and without Lime to Give a Soil pH of 6.7[a]

Soil [b]	Treatment	Organic N mineralized [c] (ug g^{-1})	Nitrification [c,d] (%)
Site 1	No lime	36a	8a
	Limed at start of incubation	61b	66b
	Limed 2 years before in the field	33a	94c
Site 2	No lime	90a	28a
	Limed at start of incubation	177c	83b
	Limed 2 years before in the field	134b	94c

a Data from Nyborg and Hoyt (1978).
b Site 1 (pH 5.5, 0.20%N); site 2 (pH 5.7, 0.83% N)
c Within each column, at each site, numbers followed by the same letter do not differ significantly at $p < 0.05$.
d Percentage nitrification calculated as 100 (nitrate)/(nitrate + ammonium).

Gaseous losses of N.

Some N2-fixing rhizobium species posses denitrifying capabilities (Daniel et.al., 1980) so that the stimulation of nodulation and N2 fixation by liming could also stimulate gaseous losses of N.

Where N is applied as urea or as ammonium salts, ammonia volatilization (a nonmicrobial process) is likely to increase with increased pH (Terman, 1979). In general, results indicate that liming is likely to increase gaseous losses of N from the soil through a variety of mechanisms; the ratio of N2 to N2O emitted will also increase.

Vesicular-Arbuscular Mycorrhizae

The role of vesicular-arbuscular mycorrhizae (VAM) in plant nutrition and crop agronomy has received considerable attention in recent times. Vesicular-arbuscular mycorrhizae infection generally increases plant growth and the uptake of phosphate, and sometimes of Cu and Zn, by the plant (Tinker, 1975).

It is well documented that different strains of VAM have different pH optima in soils (Green et al., 1975). It is therefore not surprising that some species of VAM are readily established in acid soils whereas others become established when an acid soil is limed (Skipper and Smith, 1979).

Plant species and cultivars differ in their susceptibility of mycorrhizal infection and spore production by a particular species of VAM (Sipper and Smith, 1979). They showed that VAM fungal strain-host cultivar interactions can occur and that indeed these can be influenced.by soil pH.

Rhizobium Symbiosis

It is well known that nodulation and N_2 fixation can be affected by soil pH. Data of Munns et al. (1977) from a nitrogen-deficient Oxisols demonstrate the complexity of the response of legumes to lime (Fig. 11). For Glycine withtii, top weight, nodule weight, and number initially increased but then decreased markedly above pH 6 or so. Nodule effectiveness (acetylene reduction rate per unit nodule) was, however, greater above than below pH 6. On the other hand, for Lotus corniculatus, top weight, nodule weight, and number all increased as pH increased from 4.7 to 7.1, whereas nodule effectiveness remained unchanged.

When considering the growth of legumes in acid soils, the tolerance of both the rhizobial strain and the host plant to high levels of Al and Mn and low levels of P and Ca should be examined. Keyser and Munns (1979a) showed that the tolerance of rhizobial strains to low pH in culture did not necessarily entail tolerance to Al. High Al appeared to be a more severe stress than low pH or low phosphate and generally the cowpea type rhizobia were more tolerant of Al than Rhizobiuim japonicum strains. De Carvalho et al. (1981) studied the effect of Al toxicity on the growth of six Stylosanthes species.

They observed that high Al concentrations, in sand culture, delayed nodulation in most species and had greater detrimental effects on nodule weight than on root weight. High Al concentrations generally depressed plant growth more severely in those plants dependent on symbiotic N_2 fixation than in those supplied with combined N. In contrast, Munns et al. (1981) found that liming two Ultisols, initially high in soluble and exchangeable Al, from pH 4.4 to 6.0 doubled growth of soybeans regardless of cultivar, N, source, or Rhizobium strain or numbers. Inoculated plants were nodulated, green, and high in N even when their growth was severely restricted by acidic soil conditions. Solution culture experiments (Munns et al., 1981) confirmed that soybean growth in acid soils was limited by Al toxicity to the host plant rather than to the rhizobia. Thus, either the rhizobial strain or the crop plant can be most sensitive to Al^{+} toxicity, depending upon the crop being considered.

In culture studies, Keyser and Munns (1979b) found that Rhizobium strains were not particularly sensitive to high concentrations of Mn, and they concluded that Mn may be more toxic to host plants than to rhizobial strains.

Effect of Liming on Soil Physical Properties

Liming has been shown to decrease the area of surface cracking in soils (Gaheen and Njos, 1978) increase the waterholding capacity by increasing the proportion of medium- and fine-sized soil pores (Kohn, 1975), increase aggregate stability (Czeratzki, 1972).

If lime is worked into the soil, it will stimulate a large increase in root growth as well as top growth of plants, and this could influence soil structure. The stabilization of soil aggregates by the growth of the plant root system through the soil volume is well known (Tisdall and Oades, 1980).

In soils where organic matter is the main binding agent, the aforementioned mechanism could be important. However, many highly weathered soils such as Ultisols and Oxisols possess very stable aggregates as a result of flocculating and binding actions of Al oxides and hydroxides (Greenland, 1979).

When Al and Fe oxides and hydroxides are sorbed into clay mineral surfaces, they can raise the PZC of the mineral so that the colloidal fraction is flocculated at the pH of the soil (Oades, 1979). Precipitation of Al has been found to reduce swelling of Na-montmorillonite and Na-illite soils (El Swaify and Emerson, 1975). Oades (1979) showed that the addition of hydroxy-Al cations to kaolinite caused marked reductions in surface areas of clays, a result indicating that cementation of fine particles had occurred. The increased contact between particles by cementing Al hydroxide resulted in the formation of strong, water-stable aggregates.

Calcium, in excess of the saturation capacity of a soil, can flocculate clays. Thus, polyvalent salts (e.g. gypsum ($CaSO_4$) and lime ($CaCO_3$) are known to be effective in flocculating clays and are therefore used as soil conditioners for sodic soils (Davidson and Quirk, 1961). Greene et al. (1978) showed that a high ratio of lime to clay cause rapid coagulation of clay into aggregates. The large deposits of adsorbed lime stabilized the aggregates by acting as an amorphous cement which bound adjacent particles together. Such mechanisms may be applicable, although for soils initially high in exchangeable Al the flocculating and cementing action of hydroxy-Al polymers formed following liming would seem more likely to be of importance in terms of changes in soil physical properties.

Factor to be Considered for Liming needs of Oxisols and Ultisols

1. The soil pH has to be raised to a level where soil solution

Al, other than that complexed to organic matter, is reduced to a very low level.

2. Kamprath (1980) suggests that the KCL extractable Al value should be the criterion for lime application, but acknowledges that more lime is necessary than its chemical equivalent. In fact, some soils require three times the Al equivalent. This is because variable charge soils will neutralize added base by deprotonation in addition to the Al precipitation reactions. Deprotonation of hydroxy groups is desirable if the negative charge is low, since the additional negative generated is needed for retention of nutrient cations such as Ca, Mg, K, and NH_4.

3. A third consideration is the volume of soil to which lime should be mixed. Since Ca has to be supplied at the actual growing tip of a plant root, soil Ca has to be distributed through the whole soil volume in order to obtain good root proliferation. This then allows maximum exploitation of soil water and other soil nutrients. Ritchey et al. (1980) have demonstrated the practical advantages of applying lime in conjunction with ordinary superphosphate to Brazilian Oxisols. The combination was particulary successful in causing calcium to leach to depths that would greatly expand root growth. In a subsequent paper, Ritchey et al. (1982) showed that correction of Ca deficiency is far easier than having to correct Al toxicity at depth and we need to delineate the high Al soils with low Ca, from those that are low in both Ca and Al.

4. One has to consider the effects on other exchangeable cations when liming a variable charge soil. If calcium carbonate is applied to a soil that is only marginally supplied with Mg and K, the additional charge developed will be saturated with Ca and an imbalance created. The use of dolomitic limestone will alleviate a Mg deficiency, but applied K could be a poor competitor for exchange sites. Magdoff and Bartlegg (1980), however, showed that even though lime addition to a Spodosol caused a selectivity for Ca over K, there was sufficient "pull" on solution K by the increased CEC to greatly reduce solution K. They calculated that 500 K/ha would have to be added if this soil was limed to pH 6.

5. The acidifying effects of applied NH_4-N need to be taken into account. Since the majority of highly weathered tropical soils are acid, nitrification rates might normally be relatively slow. Ironically, the addition of lime to a soil to which NH_4-N has also been added could promote nitrification and hence produce acidity, requiring more lime for neutralization.

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AGRONOMIC PERFORMANCE OF MAIZE IN ZAMBIA

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Introduction

On a world wide basis, maize is the third most important cereal crop, exceeded only by wheat and rice in terms of production (Renfro; 1976; Ullstrup, 1976). In Zambia, however maize is the dominant cereal crop, both as a staple food and cash crop.The other cereal crops grown are wheat, rice, sorghum and millet, with triticale being grown on a small scale (MAWD, 1984). Maize is used mainly to make the main dish called nshima, which is eaten with a variety of foods such as beans, groundnuts, okra, meat, fish, chicken, etc. In view of the fact that maize has an inherently low nutritional quality, the use of these other crops provide some kind of balanced diet. Small quantities of maize are used for brewing and for animal feed. The importance of maize can be demonstrated by the amount of land under maize cultivation. Zambia has 74.6 million ha, of which 78.6% or 58.6 million ha are arable. However, at the moment only 2% or 1.5 million ha are under production at any one time (Wood, 1983). Approximately one third or 500,000 ha of the area under cultivation is under maize production (MAWD), 1984). With the ever increasing population pressure, even more of the arable land will have to be utilized to meet the demand. It is estimated that by 1995 Zambia's population will reach 11 million. In order to properly feed this population, it is estimated that 1.4 million ha of maize and other cereals will be required to meet the demand for grains and cereals (Wood, 1983).

Average annual maize production in Zambia is currently about 900,000 metric tons, which accounts for half of the total cereal crop production (MAWD, 1984). Sixty percent of the total production is marketed, while 40% is consumed on-farm. Fourty percent of the marketed production comes from 500 commercial farmers, with the balance coming from the 600,000 small-scale and emergent farmers.

On a long term basis, the total marketed maize production has increased from 2.2 million 90 kg bags in 1964 to approximately 6.0 million bags in 1983. (Fig 1). This translates into 173% increase. Further examination of Fig. 1 shows that there have been tremendous fluctuations in the total production during this period. The all time high production of 8.3 million bags was realized in 1976. This shows the tremendous potential for maize production in the country especially under good growing conditions. Between 1976 and 1984, maize production has actually shown a moderate annual decline in growth rate of 2.5% (MAWD,1984). During this period there has been a 3.1% per annum increase in human population, indicating that the country has not been able to produce sufficient maize for home consumption. This has necessitated the use of foreign exchange to meet the balance

(Table 1). At the same time that the country has been importing maize, it has also been exporting maize, especially to neighbouring countries. This apparent anomaly can be partially explained by the need to earn foreign exchange.

Table 1. Maize grain exports and imports (MT)

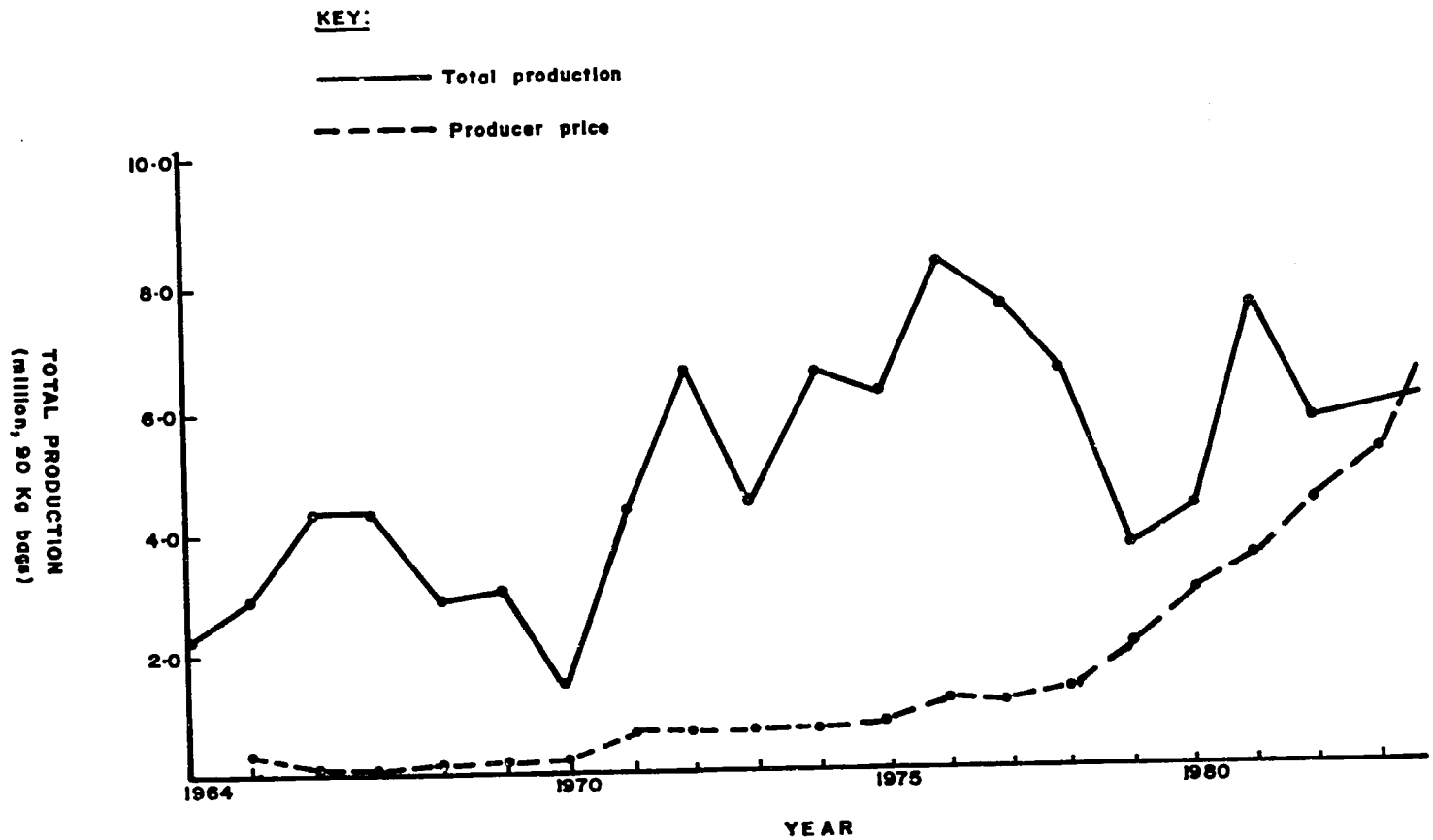
YEAR	EXPORT	IMPORT
1973	50,086	-
1974	111,212	17
1975	16,621	39
1976	8,803	25
1977	25,606	401
1978	61,284	22
1979	Negligible	23,457
1980	-	43,178
1981	-	80,577
1982	3	17

Source: Annual agricultural statistical bulletin, 1983. Ministry of Agriculture and Water Development, Lusaka Zambia.

Increases in production over a long period of time are attributable to genetic (varieties) and agronomic improvements (including fertilization, weed control, planting density, cultivation, etc) (Cardewell, 1982). This increase can be through increased area under production as well as increase in yield per unit of land. It is estimated that within the true topics (where Zambia belongs) the increase in maize production over the years has equally been due to increase in area and yield increases (Renfro, 1976). The yield of maize in Zambia has increased from about 4 tons ha -1 in 1967 to the current level of 5 to 6 tons ha -1 (MAWD. 1984).

One factor that affects total production either through area increase or yield per unit area is the price paid to the farmer. Fig 1 also shows that the increase in total marketed production has partly been the result of more favorable producer prices paid to the farmer.

Fig. 1. Total marketed grain in maize production and producers prices for grade A maize from 1964 to 1984.



Source: Annual Agricultural statistical bulletin, 1983. Ministry of Agriculture and water Development, Lusaka, Zambia.

It is worth noting, however, that over the same period of time, producer price has shown a much higher rise (559%) than the total marketed production 173%). This can mean either that the prices were not favorable enough or that some other factors (e.g. climate) were limiting production or both.

In order to meet the expected increasing demand for maize in the country, more research efforts will have to be put into defining more specifically the different environments suitable for maize production and improving the agronomic aspects of maize production.

Areas of Production

Maize can be grown all over the country, but the major areas of production are the Central, Eastern, Southern and Northern Provinces (Table 2). Differences in the provincial contributions reflect in part differences shown through the maize suitability map (Fig. 2) as well as agro-climatic zones. For the purposes of maize production, Zambia is divided into three agro-climatic zones (MAWD, 1984), based on rainfall, length of growing season and mean temperature.

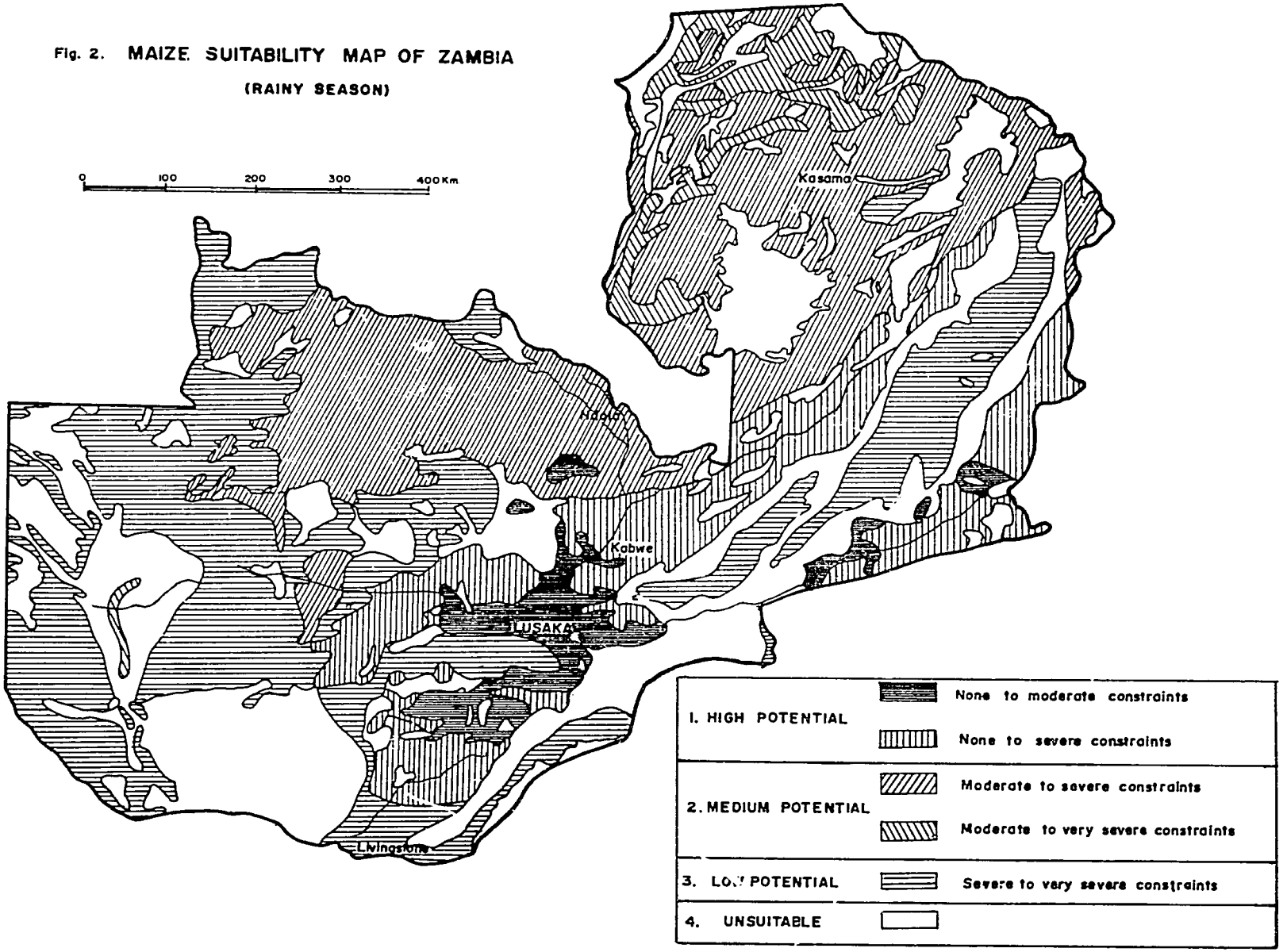
Table 2. Provincial contribution to the total maize production in 1983.

PROVINCE	% CONTRIBUTION
Central	37.9
Eastern	27.1
Southern	16.2
Northern	11.1
Lusaka	3.6
Copperbelt	1.5
North-Western	0.9
Western	0.9
Luapula	0.8

Source: Annual Agricultural Statistical Bulletin, Ministry of Agriculture and Water Development, Lusaka, Zambia; December 1984.

Fig. 2. MAIZE SUITABILITY MAP OF ZAMBIA

(RAINY SEASON)



Zone I has 1000 to 1500 mm of rain annually, with a growingseason of 150 - 200 days, and a mean temperature during the growing season of 20-25deg. C. This zone consists mainly of Northern, Luapula, Copperbelt and North-Western Provinces. The main constraints are high acidity, aluminium toxicity and lower insolation.

Zone II is defined by a rainfall of 800-1000 mm, a 150-180 day growing season, and a mean temperature of 20-25deg.C. It includes most of Eastern and Central Provinces, and parts of Southern, Western and North-Western Provinces. The main maize growing areas are located in this agro-climatic zone.

Zone III receives 700 to 800 mm of rainfall, with a growing season of 120-150 days, and mean temperatures of above 20deg.C, with some regions above 25deg.C. This zone includes the Southern part of Western Province, most of Southern Province and Luangwa River Valley. The main constraint is the low and variable rainfall, and its variable distribution throughout the growing season.

One of the main objectives of the maize research programme has been, still is, and will continue to be the development of varieties/hybrids and agronomic practices suitable for the respective agro-climatic zones.

Some Agronomic Factors Affecting Maize Production

Variety

The yield of maize, like any other crop, is strongly influenced by the variety or hybrids grown (Yamaguchi, 1974 a, b, c; Goldsworth, 1974a, b; Fisher and Palmer, 1980; Mbewe, 1978). In Zambia, until recently, the single-cross hybrid SR 52 or its successor MM 752 has been the dominant type of maize grown. It is pointed out that the parents of SR 52 and MM 752 are the same, except that the parent lines of the Zambian version of SR 52 were purified to develop MM 752, which has the same strengths and weakness as the original SR 52. It is high yielding with adequate rains and high inputs but very susceptible to drought at tasseling. It yields, on the average, 10-15% more than the original SR 52. It is a long-season hybrid, with a maturity range of 160-170 days.

As far back as 1967, the need for the development of alternative hybrids and varieties to SR 52 for the various climatic regions was recognized (Min. of Agriculture, 1967). These research efforts have resulted in the development and use of a number of varieties and hybrids to suit a wide range of growing conditions and management capability of the farmer (Tables 3 and 4): These new varieties and hybrids are different in maturity and yielding ability (Table 3 and 4). The new varieties are resistant to streak virus disease, early maturing, and more tolerant to drought stress.

Table 3. Effect of genotype on morphological and physiological characteristics of Maize.

Entry	Yield Kg/ha	100 kernel weight g	No. rows/ ear	Ear length cm	Ear diam. cm	Plant height cm
MM 601	7602 a	45.6 a	12.8 a	17.8 a	4.9 a	263 a
MM 603	6063 ab	40.9 ab	13.5 a	17.5 a	4.6 a	238 bc
MM 606	6499 ab	36.0 a	13.3 a	15.5 a	4.6 a	230 ab
MMV 600	5981 b	30.7 b	13.5 a	14.6 a	4.4 a	254 bc
PR 7832 x L12	6594 ab	38.0 ab	13.8 a	18.4 a	4.8 a	236 c
A 7844	5686 b	29.5 b	14.0 a	15.4 a	4.5 a	235 bc
POP 10 x L12	5466 b	30.0 b	14.0 a	15.8 a	4.5 a	299 c
MM 752	5998	49.1 a	10.8 b	16.8 b	4.7 a	265 a
Signif.	*	**	**	-	-	**
C.V. %	16	23	10	12	6	7

Means in the same column followed by the same letter are not significantly different.

*, ** = Significance at 5% and 1% probability respectively.

Source: Tamala and Mbewe (1985)

Another reason that has necessitated the development of a wide range of hybrids, varieties, composites and possibly top-crosses is the practice by 50% of the maize farmers (small scale farmers) of saving planting seed stocks from year to year, sometimes because commercial seeds are not available at planting time or the farmers cannot afford to buy new seeds due to high cost. This leads to a genetic deterioration of potential yield. Studies done in other countries have shown, however, that the loss of yield from retaining seed of a top-cross is lower than retaining seed of a single-or double-cross hybrid. This is attributed to the broader genetic base of the top-cross. Up until now, there has been very little information on this aspect based on Zambian conditions. However, research was begun at the School of Agricultural Sciences, University of Zambia during the 1984/85 growing season to examine this question in detail. Preliminary results indicated that first generation seed yields were highest for single-cross hybrids followed by double and three-way crosses, open-pollinated varieties and top-crosses,

respectively (Table 3). Apart from examining the differences in yield losses due to the use of seed from the previous year's crop, the study will also determine whether these differences are economical or not.

Continued improvements of varieties and hybrids depends, to a large extent, on the understanding of the morphological and physiological characteristics that are associated with yield increases or reductions (Fischer and Palmer, 1980). Some researchers (Crosbie and Mock, 1981) have shown that maize grain yield increases in breeding programmes can be due to increases in the filling period, leaf area duration and harvest index. Others (Yamaguschi, 1974;c; Hanway and Russell, 1969; Mbewe, 1978), showed that yield differences between hybrids were due to differences in leaf area duration, leaf area index, filling period and plant height. In most of these studies, high grain yields were attributed to higher kernel number and kernel size.

These results are generally in accord with the preliminary data from the experiment conducted at the School of Agricultural Sciences (Table 3). The data showed that a number of the hybrids and varieties differed in most of morphological and physiological traits examined. The higher yield of the newly released MM 601 compared to the old MM 752 was mainly due to its higher harvest index. If these preliminary results are confirmed, they could form a good basis for further variety improvement in Zambia.

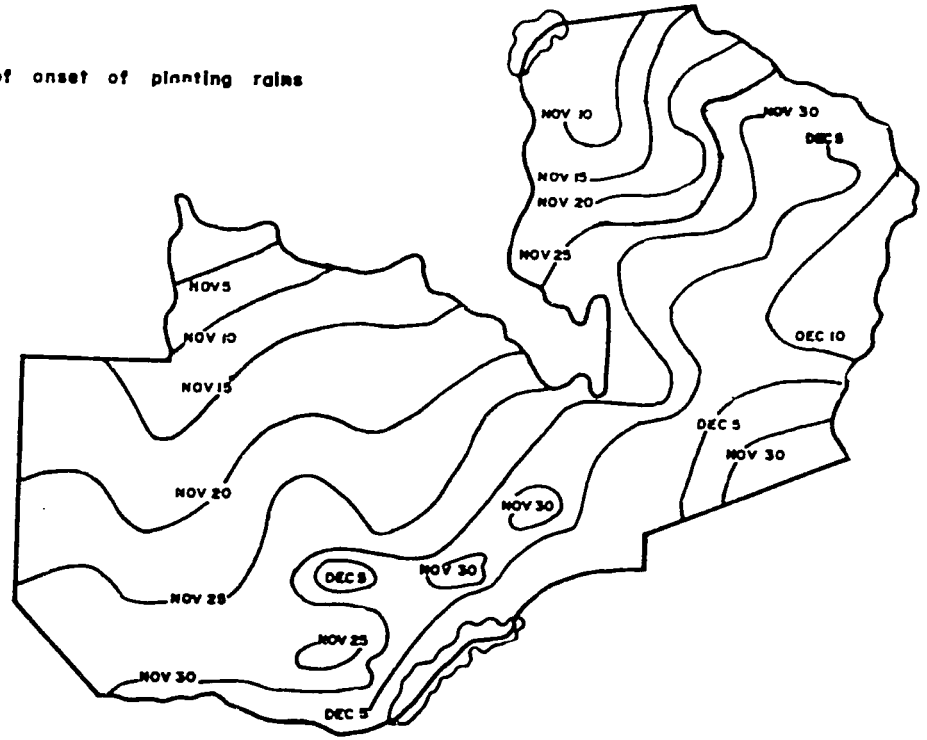
Efforts to breed for shorter varieties may not necessarily result in higher yielding types. Results in Table 3 and studies by other researchers (Yamaguchi, 1974 b) indicate that plant height is positively related to yield, although some results (Table 3; Fischer and Palmer, 1980) show a negative relationship. Very short varieties yield lower probably because of a lower efficiency of dry matter accumulation by leaves during the filling state (Yoshida, 1972; Yamaguchi, 1974b). The lower efficiency is attributed to the reduced sink size and compact distribution of leaves (Yamaguchi; 1974b) leading to increased mutual shading (Yoshida, 1972). These results show that breeding for short varieties in Zambia may not be a good idea.

Planting Date

The recommended time for planting maize in Zambia is at the beginning of the first planting rains, normally November. Many factors influence the time of planting maize. These include soil moisture, soil temperature (Carr and Milbourn, 1976), availability of inputs, incidence of diseases (especially maize streak virus), techniques employed, and varieties used.

In Zambia, the most important factor determining the date of planting is the soil moisture. Figure 3 shows the approximate dates when the first planting rains start in various parts of the country.

Fig. 3. Approximate dates of onset of planting rains



Sources: Davies, H.D. (1971). Zambia in Maps. London, University of London Press Ltd.

Since the length of the growing season in Zambia is determined by the start and finish of the rains, it means that these areas have a shorter growing season, thus justifying their being classified under zone III of the agro-climatological zones. Soil temperature has been found to be an important factor influencing the date of planting in temperate and high altitude areas in the tropics.

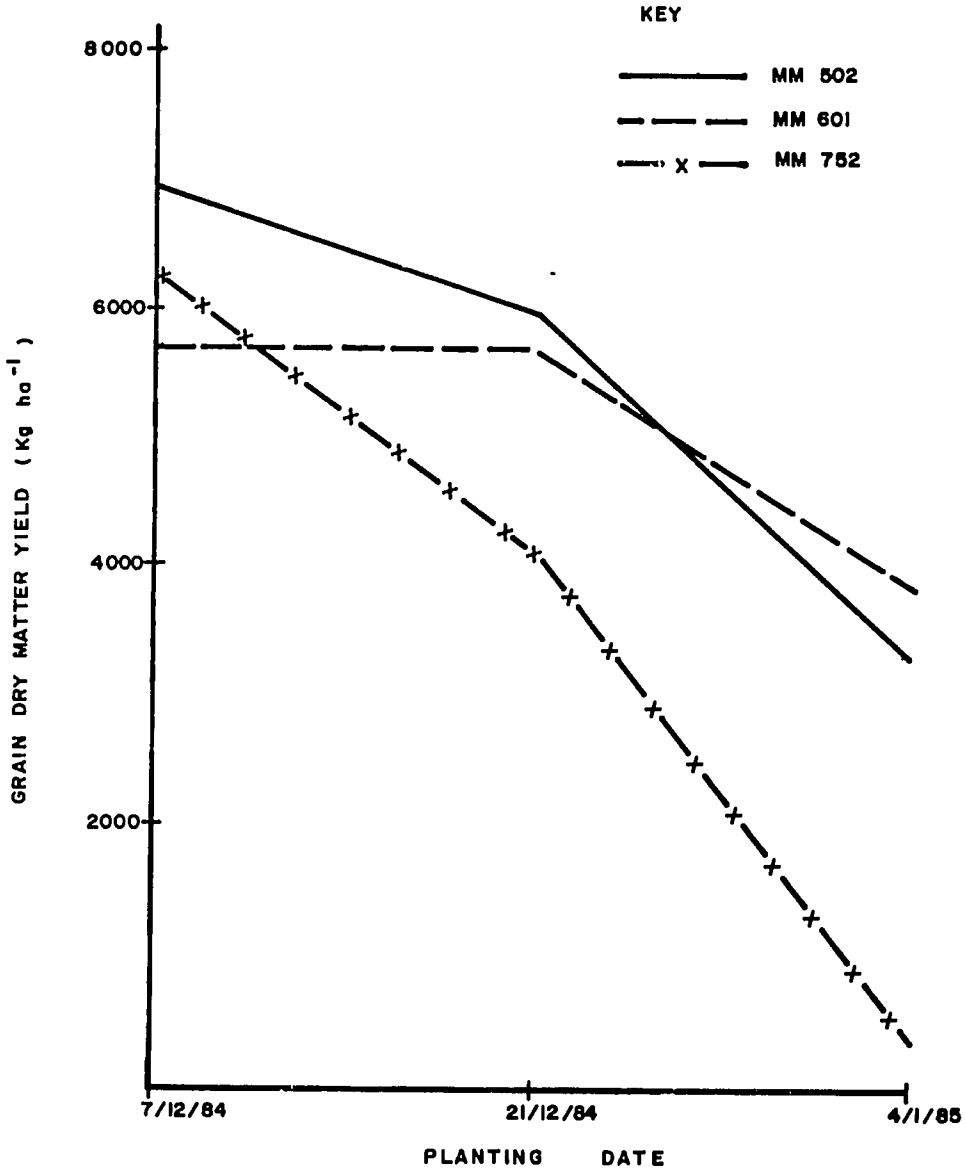
In these areas planting does not start until the soil temperature has reached at least 10deg.C. In Zambia, however, soil temperatures are not a significant factor. This is attributed to the fact that there are small differences between the mean monthly minimum and maximum temperatures (Table 5). such differences would not be expected to have a serious effect the soil temperatures. The effects of soil temperature are through the effects on the growth and activity of the roots (Allan, 1971; Carr, 1976; Duncan, 1975). Lower temperatures reduce root growth, leading to reduced hormone synthesis and water and mineral absorption (Allan, 1971; Duncan, 1975) and subsequently, lower yields. Higher soil temperatures lead to early rapid growth and high yields (Carr and Milbourn, 1976).

The problem of the availability of inputs mostly affects the small-scale and emergent farmers. The inputs include fertilizers, seeds and those that are required for the preparation of the land. These farmers have very little capital to pay for these inputs - resulting in delayed planting.

Late planting for any reason leads to severe yield losses (Figure 4; Table 6). Similar results have been obtained in many other countries. Several reasons have been suggested to explain the loss in yield with delayed planting: lower soil temperatures, air temperatures, (Siemer et al., 1969), increased incidence of diseases and pests (Fajemisin and Shoyinta, 1976). The resultant effect of most of these factors is that the developmental phases of the maize plant are thrown off balance. For examples, delayed planting was found to reduce the differentiation rate of leaf primordia and the kernel growth rate during the filling period, as well as reducing the length of the filling period (Torigoe, 1984). Similar information under Zambian conditions is lacking. There is need, therefore, to carry out experiments to determine the effect of planting dates on the morphological and physiological characteristics of maize in Zambia.

In Zambia, as well as many tropical countries, delayed planting is associated with increased incidence of maize streak virus disease (Renfro, 1976; Fajemisin and Shoyinka, 1976; Guthrie, 1976) leading to severe yield losses. The exact cause for the increase in streak virus disease with delayed planting is not yet known. It could be related to decreasing temperatures as the growing season progresses. It is worthy of note, however, as pointed out earlier, that the newer varieties being developed in Zambia are relatively more resistant to the disease than older varieties.

Fig. 4. Effect of planting date and variety on grain yield of maize



1 Results represent one year data.

Since resistance is the best way to control this disease (Fajemisin and Shoyinka, 1976), the breeding of streak virus disease resistant varieties should be encouraged.

Data in Fig. 4 confirm that the effects of delayed planting are influenced by variety. This effect seems to be related to the maturity of the variety (Asafa-Agyei, 1979). The effects are more severe for late maturing or long season varieties (compare MM 752 and MM 502 or MM 601 in Fig. 4). Non-prolific varieties also show a marked reduction in yield than prolific varieties (Earley et al., 1974). There is need to study the morphological and physiological characteristics accounting for these differences. It is only through such studies that we can help the farmer manage his crop better. In addition, there is need to revise the actual planting dates as new varieties are developed.

Table 5. Mean monthly min., night and max. temperature at 2.0 m height for 24 stations (means of Dec., Jan. & Feb.).

STATION	MINIMUM	NIGHT	MAXIMUM (DEG C)
Solwezi	15.0	19.0	26.3
Mwinilunga	16.1	19.1	25.9
Kasempa	16.8	20.0	27.2
Kabompo	17.4	20.8	28.5
Lundazi	17.4	20.3	27.1
Chipata	18.0	20.8	27.4
Petauke	18.3	21.1	27.5
Choma	16.5	19.5	26.7
Serenje	15.8	18.8	25.7
Kabwe	17.3	20.2	26.6
Mt. Makulu	17.1	20.0	26.6
Kafue polder	18.1	21.2	28.4
Mongu	18.5	21.5	28.5
Kaoma	17.4	20.6	28.4
Sesheke	18.3	21.8	30.0
Livingstone	18.4	21.6	29.2
Kawambwa	16.5	19.5	26.2
Mansa	17.0	19.9	26.8
Ndola	17.0	19.8	26.4
Zambezi	17.6	20.8	28.2
Mbala	14.7	17.3	23.2
Mpika	16.1	19.0	25.5
Kasama	16.1	19.2	26.2
Samfya	17.4	20.4	27.0

Source: Veldkamp, W.J., Muchinda and A.P. Delmotte. 1984. Agro-climatic zones in Zambia. Department of Agriculture, Land Use Branch, Soil bulletin No. 9.

The main maize fertility problem in Zambia is nitrogen followed by phosphorus and potassium in that order. The effects and the exact rates of these nutrients are influenced by the

initial soil fertility and environmental conditions, especially rainfall (Mbewe, 1978; Dept. agric., 1979). This means, therefore, that the lower rainfall areas of the Southern and Western Provinces would apply lower rates of nitrogen. On the

Table 6. Effect of date of planting on maize grain yield.

Date of planting	Yield ha-1 (90 kg bags)
October 20	54.3
November 2	52.3
November 9	42.5
November 16	42.8
November 23	30.8
November 30	21.9
December 7	19.2
December 14	14.6
December 21	14.0
December 28	10.4

Source: Wood, D. 1983. A banker's agricultural notebook. NECZAM, Lusaka, Zambia,

average, however, it is recommended to apply 140 kg N, 60 kg P_2O_5 and 20 kg K_2ha^{-1} (Dept. Agric., 1979). These recommendations are based on field experiments which have shown a positive response of yield to increasing rates of nitrogen fertilization (Table 7). In this study, rate of nitrogen higher than 80 kg ha^{-1} gave no significant change in yield. The results showed that the positive response to higher rates of nitrogen was partially the result of increased partitioning of assimilates as indicated by the increase in the harvest index. Kernel size (as 1000-kernel weight) did not seem to have an effect (Table 7), although there was a tendency for kernel size to increase with N rates. These results are in accord with those reported by other researchers (Duncan, 1954; Engelstad and Terman, 1966).

Table 7. Effect of nitrogen rate on grain yield, 1000-kernel weight and harvest index.

N rate (kg na-1)	Grain yield (kg ha-1)	1000-kernel weight	Harvest index %
0	3629 a1	368.3 a	40.1
40	5902 b	366.4 a	42.8
80	6981 c	382.4 a	45.6
160	7053 c	399.4 a	38.6

1 - Means in the same column followed by the same letter are not significantly different. Source: Gumbo and Sisodia 1985.

Depending on the soil pH level, a maintenance lime application is necessary. This is most critical in the Northern areas which have acidity problems.

The ever increasing costs of artificial fertilizers necessitate a search for methods to either increase the efficient use of applied fertilizers or finding alternative sources of fertilizers. These methods include matching fertilizer rates to variety type, rotations (Boyd and Needham, 1976) and use of organic manure.

The current fertilizer recommendations are based on the old, long season, single-cross hybrid SR 52. However, as pointed our earlier, new and shorter-season hybrids and varieties have been developed. There may be need, therefore, to study whether these new hybrids and varieties need the same rates as currently recommended. As yet there is very little such information. However, from the preliminary results presented in Table 8, it seems that there is no interaction between nitrogen rate and genotype. This means that rate of N and genotype may be affecting yield independently. These results suggest that the current levels of nitrogen may be used for the new varieties and hybrids.

Table 8. Analysis of variance for some characteristics studied.

		MEAN SQUARES		
Source of variation	df	Grain yield kg ha -1	Total DM yield (kg ha -1) (kg ha)	1000-Kernel weight (g)
Nitrogen (N)	3	14.70 **1	84.88 **	36.95
Blocks (B)	3	0.06	0.72	18.24
Error a	9	0.34	2.45	22.38
Genotype (G)	3	13.30 **	57.78 **	477.91 **
N x G	9	0.23	1.73	13.20
Error b	36	0.28	0.83	14.03
Total	63			

Source: Gumbo and Sisodia (1985).
1 - ** Means significant at 1% level of probability.

One way of reducing fertilizer costs would be to practice crop rotations. Extensive experiments have shown that maize in Zambia does well in rotation with small cereals (e.g. wheat), legumes (soyabeans field beans, cow peas) cotton, tobacco and pasture crops. Maize grown in rotation yields higher than when grown in monoculture (Table 9) (MAWD, 1973). These increases may be attributed to the beneficial effect rotations have on crop yields. If the preceeding crop is a legume, less nitrogen may be applied because legumes have the ability to increase soil nitrogen.

Table 9. Effect of crop rotation on maize yield (9-year average) on two soil series.

Soil series	Rotation sequence	Yield (kg ha -1)	% increase in yield
Mufulira	Continuous Maize	4667	
	Maize after Soyabeans	5979	28.1
Misamfu	Continuous Maize	3008	-
	Maize after Soyabeans	4265	41.8

Source: MAWD (1983): Copperbelt Regional Res. Station data.

An alternative source of nutrients, especially on mixed arable farms is farm yard manure (FMY) or slurry (Cooke, 1982; Harper, 1983). The main advantages of using these organic sources are the possibility of cutting the cost of artificial fertilizers, slow release of nutrients to the soil and physical improvement of the soil (Cooke, 1982). In drier areas, application of FYM increases the water-retaining capacity of soils thereby indirectly increasing yields and the efficiency of nutrient uptake (Harper, 1983). Another advantage of using organic sources is that they contain a range of trace elements

(Table 10). However, the bulkiness and low levels of major elements make these sources an uninviting alternative.

Table 10. The nutrient contend of farmyard (FYM) and slurries (average values)

	Nutrient			
	N	P2Os	K2O	Mg
Cow FYM (kg t -1	1.5	2.0	4.0	0.8
Cow slurry (kg m -3)	2.5	1.0	4.0	0.6
Pig slurry (kg m -3)	4.0	2.0	2.7	0.4
Poultry slurry (kg m -3)	9.0	5.5	5.5	1.3

Source: Harper, f. (1983) p. 246.

At the moment there is very little use, if any, of organic manures on commercial basis in Zambia, except may be in backyard vegetable gardens. However, experiments initiated at the School of Agricultural Sciences (Temba et al., 1985) show promising results. These results showed that using either pig or poultry manure good yields of maize were obtained. An application of 1200 litres (9 kg N) of pig manure slurry or 30 tons of solid poultry manure were found to be as effective as the recommended rate of commercial fertilizer (300 kg "D" compound and 200 kg ammonium nitrate). This was attributed to the slow release of nutrients combined with some physical effect on soil. These findings are in agreement with those reported by Djokoto and Stephen (1961).

The study reported by Temba et al (1985) also showed that the growth rates of plants treated with manure were similar to those treated with normal rates of commercial fertilizers up to the tasseling stages. This is probably because the slow release of nutrients by manure was unable to meet the increased demand for nutrients by the plants at that stage. This suggests that on a commercial basis manure could be applied as a basal dressing, with commercial fertilizers as top dressing. This would result in reducing the cost of commercial fertilizer.

Temba et al. (1985) also found that the response to manure was influenced by genotype early maturing one. This might be related to the timing of the N stress (due to slow release of N) with respect to the critical stage of growth.

As promising as these results look, a few problems need to

be ironed out before commercial use of FYM or slurry can be recommended. They include (1) control of possible toxic levels of some minor elements in the manure; (2) determining the rates of manure to use, and (3) best method(s) of application. In addition, morphological and physiological studies need to be conducted to examine how manure affects yield compared to the inorganic fertilizers.

Conclusion

In the past twenty years or so, tremendous improvements have been made in the areas of varieties and cultural practices in Zambia. Together with favorable prices paid to farmers, these improvements have resulted in increased national maize production. However, with the increasing population pressure, more efforts need to be made to increase maize production in the country. More and better varieties/hybrids will have to be developed for the various agro-ecological zones in order to maximize these respective environments. These varieties/hybrids should have resistance to maize streak virus and other important diseases of maize in Zambia (including stalk rot and cob rot). As these new genotypes are developed, the agronomic practices (e.g. planting date and fertilization) may need to be adjusted to suite their requirements. More efforts should also be put into finding alternative sources of nutrients (e.g. organic manure) to cut down the cost of inorganic fertilizers.

Such efforts combined with proper weed, pest and disease control should increase maize production even further and assure self-sufficiency and a real surplus for export.

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THE ROLE AND SUITABILITY OF SUNFLOWER IN ZAMBIA FARMING SYSTEMS

V.J. Eylands

Introduction

The Food and Agricultural Organization of the United Nations (FAO) was invited to Zambia in 1971 to explore the possibilities of developing an oilseed crop that would help the country alleviate its dependence on imported cooking oil. Many crops were screened for this purpose in the initial stages, but only groundnut was being produced in any marketable quantity. Several growers were producing small amounts of sunflower and soybean, and there was some interest in castor bean and sunflower as well as the possibilities of oil extraction from maize and cotton seed. At that time, South Africa was producing sunflower commercially, but production among small farmers in southern Africa was limited to small plots for poultry and livestock feed. Germplasm from Kenya, the US and Eastern Europe was brought in for screening along with wild Helianthus collected from around the region. The US and USSR had by this time developed high-yielding hybrid sunflower varieties that had oil contents in excess of 40%. Not surprisingly, it was discovered that this germplasm selected under the high soil pH and long-day conditions of these temperate countries did not adapt well to Zambian conditions. It was recognized immediately that soil constraints were a large part of the adaption problem, but as small Zambian farmers had little cash for soil amendments, sunflower varieties would have to develop to fit the existing environment. At that time sunflower was not being produced to any extent in any other tropical country, so germplasm adapted to tropical conditions was not available from outside sources.

It was decided that open pollinated composite varieties with a wide germplasm base would be best suited to Zambian soils and farming systems. Variety testing got underway and ROP, Zambia's oil processor, purchased 11 MT of sunflower in late 1971 (Table I). The release of the first composite varieties adapted to Zambian conditions and a government-backed push towards sunflower resulted in a dramatic response by Zambian growers. Marketed sunflower jumped from 398 MT in 1973 to 4000 MT in 1974.

Small farmers adopted sunflower not only as the major oilseed crop for Zambia, but also as a new and welcome source of income. In fact sunflower remains the only cash crop produced on many small farms today.

Sunflower's rapid rise in popularity had much to do with its quick adaption to Zambian soils. The strong taproot was able to penetrate some compacted soils and draw moisture and nutrients from deeper in the soil profile than maize. Because it is a short-season crop, it fits well into the Zambian farming systems as it could be planted after maize. The deep rooting and quick

maturity also made it popular in drought prone areas, especially in those areas of Southern Province that are marginal for maize production. Although sunflower is not noted as being particulary acid-tolerant, it fared well even in some of these problem soils. reasonable yields were obtained even without fertilizer or intensive management.

Table 1. Sunflower Intake by Official Marketing Organizations in Zambia.

Year	Metric Tons
1970	-
1971	11
1972	124
1973	398
1974	4,003
1975	8,243
1976	15,965
1977	13,321
1978	7,551
1979	11,919
1980	17,238
1981	19,222
1982	21.304
1983	30,465
1984	41,100

*From Annual Agricultural Statistical Bulletin, Ministry of Agriculture and Water Development.

Discussion

Despite the popularity of sunflower in recent years and the relative maturity of the sunflower breeding program, relatively little work has focused on identifying the constraints to increased production or identifying recommended agronomic practices for Zambian conditions. Zambian-developed hybrids yield as well as hybrids anywhere in the world, and the composite varieties have also shown excellent yield potential. However, a tremendous gap exists between farm yields and potential yields (Table 2).

Table 2. Yields (Kg/ha) of Sunflower in Zambia

	Hybrids	Composites	Estimated National Ave.	Central Prov. ARPT Survey
Average	1500	1100	500	297
Best	3000	2300	-	665

Although one expects a disparity between on-farm and experiment station yields, the magnitude demonstrated here shows just how much room for improvement exists. Extensive farmer surveys by ARPT (Adaptive Research and Planning Teams) and field visits by Sunflower Commodity Team scientists have begun to identify and quantify the reasons for low sunflower yields in Zambia (Table 3).

Table 3. Estimated sunflower yield losses due to major constraints to production in Zambia.*

Constraint	Yield Loss
Planting date	40%
Soil condition (acidity, fertility, structure)	15%
Weed control	15%
Plant spacing and population	15%
Variety	10%
Diseases and pests	10%

*Percentages reflect experimental results and formal and informal data from on-farm surveys.

As sunflower is planted as a low-input cash crop by small Zambian farmers, planting dates are often from late January until March, instead of the recommended mid-December to mid-January. This inevitably results in lack of moisture at seed filling. Since maize and other staple crops must be given labour and input priority, there is little that can be done to move up average planting dates other than to effectively demonstrate to farmers the potential yield loss from late planting. Some of the new shorter-season varieties will help to move back optimum plating dates by a couple of weeks.

Soil constraints of various types are also a serious problem in many parts of Zambia. The more serious of these include acidity, drainage, capping, and fertility. Due to its development in temperate climates, sunflower is not noted for a tolerance to soil acidity. Little field work has been conducted pertaining to screening of germplasm for tolerance to Al toxicity in the several tropical countries that do produce sunflower. A programme is to start in Zambia this coming year, and already scientists from Brazil, India, and Burma have expressed interest in obtaining Al-tolerant germplasm. Currently, soils with a surface or subsurface pH of less than 4.5 must be considered unsuitable for sunflower production. This includes most of the leached sandveldts of northern Zambia. Also considered unsuitable are those deep sandy soils of western Zambia or areas in Southern or Eastern Provinces where rainfall is insufficient. Soils best suited for sunflower production include the sandveldts, red clays, and red brown loams of Central, Eastern, Lusaka, and Southern Provinces. The leached red clays of northern Zambia may also be suitable if soil pH is not too low or if lime is applied.

The nutrient status of most Zambian soils, especially the red clays and red brown loams, does not appear to be the yield limiting constraint at present low yield levels. Fertility studies over the years have shown moderate responses to fertilizers, particulary N, P and B, but only at higher yield levels (above 1000 kg/ha) and not in sufficient magnitude to justify advising farmers to withhold some fertilizer from maize to apply to sunflower. Response to various fertilizers has, of course, depended on available moisture and soil type. Nitrogen is considered the most limiting nutrient in sunflower production on a worldwide basis, but response in Zambia is not consistent. Yields in excess of 1000kg/ha are often produced without nitrogen fertilizer on some Zambian soils. Response to P has also been demonstrated, but again not consistently or in magnitude to justify a country-wide recommendation. Boron deficiency symptoms have been noted in sunflower fairly frequently, especially in dry years and on sandy soils. Although it has not been experimentally proven, it is likely that soil pH, or in particular Al toxicity and its complications, limits growth more than lack of any essential nutrients. The few liming studies to date have shown a positive response to liming when soil pH is less than 5.0. Currently the fertilizer recommendations for commercial farmers are 200 kg/ha 10-20-10 applied basally at planting and 100 kg/ha N top-dressed at the 10-leaf stage. Smaller farmers are encouraged to apply some 10-20-10 at planting, but at present fertility is not a major component of sunflower research in Zambia.

Because of its strong taproot system and short growing season, sunflower has become known as a drought-tolerant crop. Compared to most Zambian crops this is true, but it should be noted that in many Zambian soils a subsurface hardpan inhibits root development and that even sunflower needs moisture and seed fill. The taproot system has been given credit in many countries for "mellowing" a soil by breaking through hardpans that fibrous-rooted crops cannot penetrate. Growers in mechanized agricultural systems may often plant sunflower immediately following a ripping (subsoiling) operation to establish long-lasting root channels through the hardpans.

Capping or soil crusting is also a constraint to establishing a good stand. Depth of seeding is not easily controlled with hoe plantings, and sunflower cannot emerge from a depth of greater than 3-5 cm if there is even a light cap on the soil. Farmers who plant sunflower the same depth as maize and expect good emergence are often disappointed. Planting more than one seed per station or mechanically breaking the cap will help alleviate this problem.

The other major constraints include weeding, plant populations, varieties, diseases, and pests. Much sunflower in Zambia is not weeded at all, and yield losses can be up to 100% under severe infestations. A labour constraint at weeding time is more at the root of the problem than a lack of understanding

of weed competition. Planting methods range from broadcast seeding to row seeding by hoe or tractor. Population counts in the field range from less than 10,000 to more than 100,000 plants/ha. Sunflower is fairly tolerant of population variations between 25,000 and 45,000 plants/ha, but anything outside this range results in yield loss. While it is recommended to overplant and thin to stand, this is often not done, and in fact is extremely difficult to do in broadcast plantings, as are weeding operations.

New disease resistant, short season, and high oil varieties can also help overcome Zambia's cooking oil shortage. At present, however, farmers are only paid on a weight basis, and the new varieties have not yet shown a great enough yield advantage for farmers to accept them over local varieties (which are largely open-pollinated varieties released in the past that have since become contaminated through cross-pollination). The diseases Alternaria and Septoria continue to hinder production in some areas, but genetic resistance has been found and incorporated into the new varieties. Termites and birds continue to be the major pests, but to date no economic method of control other than timely harvest has been discovered.

The major emphasis of sunflower research today consists of developing suitable varieties for Zambian management and soil conditions, and the development of agronomic practices appropriate for the labour and management constraints faced by the small farmer.

Sunflower has enjoyed a rapid growth in Zambia in recent years and is today the country's major oilseed crop. Despite its widespread acceptance by small-scale farmers, on-farm yields remain low. Management and soil constraints must be overcome through appropriate research and education. Even small gains on the sunflower yield ladder should lead to self-sufficiency in cooking oil in Zambia in the near future.

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INFLUENCE OF AGRONOMIC PRACTICES ON PERFORMANCE OF SOYABEANS IN ZAMBIA

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Introduction

Although the area under soybean cultivation has increased rapidly, yield per hectare still remains low ranging between 1000 to 1800 kg/ha. According to Prior (1976) the low soyabean yields per hectare are largely due to poor management. He explained that "whilst there is room for improvement in Zambia in the provision of better genetic material, there is no doubt that management is of overriding importance at the present stage. The present varieties of soya in Zambia, are good enough to out perform the mean yields obtained in America and approach the yields obtained by the better farmers. There will be a gradual increase in productivity in our soils if good management practices are followed." The following is a review of the influence of some agronomic practices on the performance of soyabeans in Zambia. The effect of variety, time of planting fertilizer, inoculation, lime, row spacing, weed control, disease and pest control, and harvesting on soyabean yield is discussed.

Variety Selection

A lot of work has been done in Zambia on varietal selection. This has been going on since the 1950's. All of the recommended varieties grown in Zambia are introductions from neighboring countries or from distant countries with similar latitudes as Zambia. In addition, a large number of the Zambian varietal collection is from the United States of America.

Varietal trials done during the 1950-60 period involved almost exclusively the "Hernon" strains. It was in 1968 when the move to diversify and increase the varietal collection was initiated. In 1968, the collection consisted of only 159 varieties. Today's collection includes varieties from over 14 different countries.

Table 1 shows the recommended varieties. The majority of Zambian varieties fall in the medium - late maturity group taking about 100 to 120 days to mature.

Although the soyabean plant is classified as a short day plant, photoperiod per se may not be as critical as the distribution of rain during the growing season in determining the adaptability of the soyabean in Zambia. Variations in soyabean yields observed at different locations or latitudes within Zambia are largely due to differences in amounts and distribution of

rainfall. Another important factor affecting the adaptability of soyabean varieties in Zambia is soil acidity. Soyabeans are very sensitive to low soil pH. This factor is responsible for the low productivity of this crop reported in the high rainfall areas of Zambia.

Table 1: Characteristics of Recommended Soyabean Varieties 1982/83.

Variety	Origin	Yield Kg/ha	Days to 95% mat -urity	Days to 50% flowering	Height at mat -urity	100 seed weight (gm)	Shatt ering score
Santa Rosa	Brazil	2045	106	47	48	14.4	1.3
Kaleya	Brazil	1950	113	49	50	15.5	1.0
Magoye	Australia	1638	114	52	38	11.8	1.3
Hernon 147	Tanzania	1590	108	47	39	18.8	1.5
Tunia	Colombia	1825	107	44	49	19.1	1.2
Jupiter	U.S.A.	1470	121	52	68	16.5	1.4

Source: Joshi et al 1983

Shattering score 10 days after maturity
1 = no shattering
2 = less than 10%
3 = 10 - 25%
4 = 25 - 50%
5 = over 50% pods

Table 2 shows photoperiods expected at latitudes 10deg. 15deg. and 20deg. during the growing season commencing from November to May. The data show little change in photoperiod across most of Zambia. Similarly, the difference in daylength during the growing season is too small to influence productivity of soyabeans.

It is generally recognized that the recommended varieties in Zambia are good enough to produce high yields similar to those reported in other soyabean growing countries. If a variety is able to produce sufficient growth under Zambian conditions then it is likely to be a suitable variety. According to Hartwig (1970), a variety that takes a 45 - day period from emergence to early bloom approaches the minimum to permit plants to make adequate growth for producing moderate seed yields. Data presented in table 1 show that recommended varieties meet this requirement.

The problem of adaptation in Zambia lies in finding varieties able to produce sufficient growth and flowering such that when planted at or near the beginning of the rainy season it w.ll flower and fruit at an appropriate time or period for harvesting to be done at the end of the rains. After maturity, a variety with minimum shattering is preferred. Shattering has been reported to cause yield losses ranging from 100 kg to 300kg per hectare of seed. Although lodging tolerance is another important factor a good variety should posses, it is very rare that a crop of soyabeans planted at the right population, will present lodging problems in Zambia. Plants on the average, do not grow excessively tall to pose any lodging problems.

Table 2. Photoperiods at Latitudes 10deg, 15deg, and 20deg from November to May

Location (latitude)	Nov	Dec	Jan	Feb	Mar	Apl	May	Range +/- hrs
Kasama (10deg)	1322	1330	1322	1308	1252	1236	1226	1.04
Kabwe (15deg)	1334	1350	1334	1315	1255	1228	1206	1.44
Zimbabwe (20deg)	1345	1410	1345	1322	1258	1218	1148	2.22
Range +/-	0.23	0.40	0.23	0.14	0.06	0.18	0.38	

Source: adapted from Harturig 1970

Time of Planting

Time of planting is probably the most important management practice which holds the key to successful production of soyabeans in Zambia. For soyabeans grown for seed, early planting is necessary to obtain maximum yields (Table 3).

With the majority of varieties grown in Zambia, planting during the last week of November to mid - December gives the best yields. Delaying planting till January can result in yield reduced by as much as half.

Table 3. Effect of Planting date on Soyabean (Hernon 147) Yield (kg/ha) Mount Makulu 1958-60.

Year	Late Nov.	Mid Dec.	Late Dec.	Mid Jan.	Late Jan.
1958-59	4592	3529	2458	190	865
1959-60	3557	3599	2892	1107	860

Source: Smartt, 1960.

The recommended time of planting however, is mid-December. This timing coincides well with the establishment of reliable rains. Also, planting earlier may result in the crop maturing at a time when the weather is still too wet for pod drying (McPhillips, 1974).

Planting date should be matched with the variety planted and location. Late maturing varieties can be planted earlier than early maturing varieties even in the northern regions of the country where the duration of the rainy-season is longest.

In soyabean growing regions at higher Latitudes (30deg and above) the time of planting is governed to larger extent by the photoperiodic response of the varieties planted. Planting very early in spring results in yield reduction due to low soil temperature and too short photoperiods. Planting too late also results in low yields because soyabeans grow under short photoperiods.

This influence of photoperiod on planting time is not as significant in Zambia. A variety planted at different dates during the same season or planted at different latitudes in Zambia, flowers at about the same time of physiological maturity.

Table 4 shows the response of "Hernon 147" to planting at different latitudes and dates. The data showed that the variety flowered after 50-60 days after planting at different latitudes despite the differences in planting time. If photoperiod was influencing flowering, the days to flower could have been more at Magoye because of higher latitudes and earlier planting than at Misamfu which is at a lower latitude with later planting.

In summary, it is evident that the changes in photoperiod during the growing season are too small to influence the choice of planting time. The important consideration to make is how the date of planting matches with availability of soil moisture

during the critical stages of growth. The effect of low temperatures may be important in higher altitudes such as Mbala. Stress of any kind that is imposed on plants during and after flowering is likely to reduce yield and its components. This in itself suggests that latitude or calendar date of planting has little influence on photoperiod hence, the no response of Zambia varieties to photoperiod.

Table 4. Days to flower of Hernon 147 planted at different latitudes and dates.

Approximate Latitude (deg.S)		Date of Planting	Date of flowering	Days to flowering	Approx. 1) Photoperiod (hrs)
10 deg.	Misamfu	Dec 12	Feb 13	54	13.08
12.5deg.	Mufurila	Dec 27	Feb 22	57	13.05
15deg.	Golden Valley	7	Jan 26	52	13.20
16deg.	Magoye	Dec 6	Jan 25	50	13.25

Source: Joshi et al 1984

1) Adapted from Hartwig 1970

Fertilizer, Inoculation and Lime

Soyabean like any other crops needs large amounts of nitrogen, phosphorus and potassium (Table 5) McPhillips (1974) reported that yield increases were recorded, with increased phosphorus applications. Potassium, although required in quantity by the crop did not increase yield. He explained that Zambian soils are generally well supplied with potassium and hence the lack of response to rates of application of this element.

The soyabean plant, being a legume, is capable of acquiring most of its nitrogen requirements by biologically fixing atmospheric nitrogen. However, under conditions of low soil pH, drought, inefficient or insufficient inoculum, the soyabean plant may not fix sufficient nitrogen. The consequence of this is poor plant growth and low yields.

Generally, a well nodulated soyabean crop does not respond to high nitrogen applications. This has led to fertilizer recommendations favoring lower nitrogen application than that for most other crops.

Javaheri (1977) stated that some farmers are not satisfied with the performance of locally produced inoculum. He explained that this might have been due to insufficient amounts of active bacteria getting into the soil rather than the efficiency of the strains.

McPhillips (1974) suggested that until this problem of conflicting results with inoculations has been resolved, farmers should apply high rates of nitrogen fertilizer.

Table 5 Amounts of nutrients (N,P,K,) removed from the soil by a soyabean crop yielding about 1600 kg/ha.

Plant Part	Kg/ha Dry Matter	N	P_2O_5	K_2O
Grain	2640	193.6	44.0	61.6
Straw	3080	61.6	17.6	39.6
Roots and Stubble	1320	30.8	8.8	22.0
Total	7040	286	70.4	123.2

He recommended to use 300-400 kg/ha of 'R' mixture 20:20:0 of percent N,P, and K respectively, on high potassium soils and 300 kg/ha of 'D' compound 10:20:10 of percent N,P, and K respectively plus 300 kg/ha of ammonium nitrate (34%N) on medium to low potassium soils.

Table 6 shows data collected from a two-year field experiment by Temba et al. (1985) conducted to determine the response of three recommended varieties to liming, fertilizer rates and inoculations. Yields of all three varieties were increased by doubling the amount of 'D' compound from 200 kg/ha to 400 kg/ha. "Hernon 147" produced the highest yield among the three varieties when no lime was applied. A positive response to inoculation was observed during the 1984-85 season only. This was attributed to a more efficient inoculum used in that season suggesting that the innoculum being produced at Mount Makulu now is better than that produced in the previous years. The data also showed that yields obtained with 400 kg/ha of 'D' compound could be achieved by applying 200 kg/ha of D compound to an inoculated crop. Inoculation in that case could be equated to 200 kg/ha of 'D' compound.

Varieties like "Hernon 147" and "Magoye" are capable of utilizing indigenous strains of Rhizobium thus minimizing the dependence on commercial inoculum. The superior performance of "Hernon 147" when compared with other varieties under low management practices is partially explained by this special characteristic of this variety. In addition, "Hernon 147" yields relatively high under soil conditions that are too acidic for other varieties. The variety is particularly suitable as a LIMA crop because of its low requirement for expensive inputs.

Table 6 Effect of liming, fertilizer, and inoculation on yield of three varieties of soyabeans. UNZA 1983-85

Liming	Fertilizer	Variety: Hernon 147	Santa Rosa	Magoye
		-- Kg/ha --		
		1983-84		
None	200 'D'	2030	1578	1349
	400 'D'	2704	2126	1418
1 tonne/ha	200 'D'	1801	2199	1675
	200 'D' + Inoculum	1473	1481	1341
	400 'D'	2394	2435	2254
		1984-85		
None	200 'D'	2733	2939	1761
	400 'D'	3511	3039	1744
1 tonne/ha	200 'D'	2839	2711	1700
	200 'D' + Inoculum	3583	3200	3000
	400 'D'	3406	3159	1828

Row Spacing

Soyabeans can be grown in a range of row spacings from 30cm to 100cm. McPhillips (1974) explains that whichever row spacing, the aim should be to obtain a final stand of 420 000 plants per hectare. This is best achieved by planting at 45cm between rows and 3-5cm between plants within a row. To achieve this, 70-80 kg of seed will be required per hectare. He cautioned that planting at more than 5-6 cm within row is not recommended.

Data obtained earlier by Smartt (1960) showed that the highest seed yield with "Hernon 147" was obtained in 30 cm rows with plants spaced at 15cm within the row. Yields obtained from 45cm rows with plants spaced at 7.5cm or 15cm within a row were not different from the highest yield. Smartt's results suggested that the current plant population recommended could be on the

high side. Table 7 shows results obtained from two varieties planted in four row spacings.

In making a seeding rate recommendation, it is common practice to start with a higher rate than is required to compensate for percent germination and other factors that might reduce plant population. Under field conditions plant stands can be reduced drastically by soil crusting, losses at cultivation, cutworms, drought and in some cases the seed quality may not be guaranteed. As security against these losses, planting rates are usually higher than what data from a controlled experiment may suggest.

Table 7. Effect of Row spacing on yield of soyabean. UNZA 1979-80.

Variety	Row spacing (cm)	Yield Kg/ha	Plant Population Harvested (X 100)	Plant Height (cm)	Lodge score	Pods per plant
Improved Pelican	15	2422	712	79	4	23
	30	2535	664	79	5	25
	45	2264	476	70	3	28
	60	2372	378	80	4	32
Williams	15	1806	544	33	1	16
	30	2177	627	33	1	13
	45	1600	387	38	1	15
	60	1447	287	35	1	19

Source: Nissly and Temba UNZA 1979-80

The determining factor as to which row spacing should be adopted is the method of weed control. Smart (1960) explained that even though narrow rows had higher yields than wide rows, rows narrower than 75cm could not be practical at that time. Soyabean should be sown in intertilled rows spaced as closely as the method of cultivation could permit.

Until recently, unavailability of adequate planting equipment and effective weed control methods have been the major problems with planting in rows narrower than 75cm apart. Today, a wide range of drills specifically designed for soyabean planting together with effective herbicides have made narrow row soyabean planting a feasible practice.

For some varieties planting in narrow rows when planting is delayed offsets the yield loss associated with late planting. Table 8 show this yield compensation by planting in 45cm rows

when planting was delayed until January 24. Yields were higher in 45cm compared with that in 75cm in the late planted soyabeans.

Table 8. Effect of narrow rows on yield of late planted soyabeans.

Variety	Date of Planting			
	December 24 1973		January 24 1974	
	45cm	75cm	45cm	75cm
	kg/ha			
Clark 63	1466	1157	837	655
Willet 1	1910	1569	864	807

Source: Taha, et al. 1975

Weed Control

Heavy infestation of weeds can suppress soyabean yields as much as 50% and reduce harvest efficiency. Early control of weeds is important to obtain high soyabean yields. Many agronomists believe that improved weed control is the factor most responsible for recent soyabean yield increases.

Research data show that the most critical period to keep weeds under control is the first two months. Data in Table 9 show that continuous weeding done past the seventh week is not as profitable as that done before this time. After the seven-week period the complete canopy of leaves should help smother weeds between and within rows. This however, depends on the row spacing used. Varieties recommended in Zambia will have more than 80% of their canopies closed at eight weeks of growth if planted in rows less or equal to 50 cm apart (Javaheri and Mkumbula, 1984).

Most good weed control programs in soyabeans include a combination of cultural, mechanical and chemical practices. A good seedbed does not only help crop germination but discourages weed infestation. Preplant herbicides can be a part of the normal seedbed preparation. The common preplant herbicide used in Zambia is Treflan (trifluralin). Other preplant herbicides that can be applied include Basalin, Prow, Lasso and Dual.

Delaying planting after the onset of rains can reduce problems. Preplanting cultivations eliminate several flushes of weeds and the later applications of preemergence and postemergence herbicides result in longer control of slower and later germinating annual weeds.

Table 9. Effect of timing of weeding on yield of soyabeans. Mufurila. 1984.

Weeding treatment	Variety		
	Santa Rosa	Hernon 147	Kaleya
	kg/ha		
No weeding	766	958	1116
Weed first 4 weeks	987	1200	1420
Weed first 7 weeks	1041	1179	1316
Weed first 10 weeks	1004	1083	962
Weed free	1112	1408	1541

Source: Javaheri and Nkumbula, 1984.

Postemergence herbicides on the market in Zambia are Basagran and Blazer for controlling annual broad-leaf weeds. Hoelon and Poast are used to control annual grasses and volunteer maize.

With the current high prices of herbicides it is only wise to use them in combination with cultural and mechanical methods. It is due to this reason that wide rows that will permit the use of tractor-mounted cultivators should be adopted.

Diseases and pests

A number of diseases attack soyabeans but the most common ones are bacterial blight (caused by Psendomona gglycinea) and bacterial pustule (caused by Xanthomonas phaseoli). All recommended varieties have acceptable tolerance to these diseases therefore no serious yield losses occur.

The "disease-free" situation is probably due to the small hectarage that is currently under soyabeans. With more land being cleared for soyabeans the disease situation may change.

This concern has been amplified by the re-appearance of the red leaf blotch disease caused by Pyrenochaeta glycines. This is a disease which so far is restricted to Zimbabwe and Zambia. It was reported in Ethiopia in 1957. The disease can cause serious defoliation thus reducing yield. No variety has been reported to be resistant to the disease. Worse still there is no effective chemical or cultural control for this disease.

Limited research done in Zambia showed that the development of the disease can be slowed down by spraying Brestan at the rate of 1.0 kg/ha. Planting after mid - December reduces the incidence.

The same situation described for diseases in soyabeans is true for insects. No severe insect problems occur at present

Insects that may attack soyabeans include cutworms, loopers, stink bugs, grasshoppers and snout beetles. The attack is usually minor and control measures need only be undertaken if an attack is severe.

Harvesting

One major factor to success in soyabean production is efficient harvesting. Timely harvesting is important. The crop is ready for harvesting when 95% of the pods have reached their mature pod colour. Five to 10 days of drying weather may be required after this stage before the soyabeans reach the 15% moisture required for harvesting.

Harvesting too early means harvesting seeds that may be of higher moisture content than 13%. In that case artificial seed drying will be required before storage. On the other hand delaying harvesting to less than 13% moisture causes increased pre-harvest shatter loss, sickle-bar shatter loss during harvest, and increased number of split beans.

Days from maturity to the beginning of shattering varies between varieties and are affected by climatic conditions. "Magoye" will shatter seven days after maturity while "Hernon 147" will take 10 to 14 days before it shatters. The other recommended varieties take longer to shatter than "Hernon 147".

Soyabeans can be harvested either by hand or by combine. It has been estimated that one man should be able to produce up to one 90 kg bag of clean seed per day.

Mechanized harvesting needs experience and capital. However, if considerable area of soyabean is to be grown, it is obvious that harvesting will have to be done with some speed or the crop will be lost through shattering. The combine therefore, is the most suitable harvester for large commercial soyabean growers.

Sometimes a swather is used if the combine cannot harvest all the crop in a safe short time. Cut plants in a swath will not shatter as early as the standing crop. Also, sometimes it is necessary to extend the harvesting period. This can be achieved by planting different varieties of different maturities. Planting the same variety at different times may not give the same result.

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AGROTECHNOLOGY TRANSFER - THE CASE OF WHEAT

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The domestication of plant species about 10,000 years ago opened an important chapter in man's quest for providing a steady supply of food for himself. Early man's change of life style from hunter-gather to a more sedentary one, was instrumental in plant domestication. The process of domestication involved recognition that a particular plant species had something to offer, which followed the development of methods of cultivating the plant together with method of processing the crop. This led to the beginning of scientific agriculture.

With the better understanding of genetics, biology and plant nutrition coupled with the introduction of mechanization in agriculture, plant breeders and agronomists have achieved tremendous improvements in the yielding capacity and quality of many crops and thereby contributed to increased food production in the world (Burton, 1981). One would safely state that the over four billion people inhabiting the earth today, have more food than the eight million people who made up the total world population some 10,000 to 8,000 BC. This is on an average however. Beneath this average, is a food problem of chronic hunger and malnutrition that is endemic in the economically underdeveloped third world countries (Borlaug, 1981).

The Role of Agrotechnology Transfer

Progress in food production during the past 15-20 years has been achieved in many third world countries of Asia and Latin America, but Africa has lagged behind in this respect for several reasons. Agricultural productivity is a multifaceted undertaking. It requires not only genetically improved crop varieties, improved scientific crop production techniques but also an efficient extension service, adequate financial resources for necessary inputs and above all, a right pricing policy by the Government as an incentive to the farmers. Non availability of some or all of these equally important components of production may be considered predominantly responsible for the present state of chronic food shortages in the African continent. The fundamental component in any production system, however, is the availability of an improved production technology. Developing technologies through research is both slow and expensive and many countries do not have the resources necessary.

Agrotechnology transfer has had a tremendous impact on improving food production in many third world countries. The development of dwarf wheat varieties at the International Maize and Wheat Improvement Centre , CIMMYT in Mexico and later of dwarf rice varieties at the International Rice Research Institute (IRRI) in the Philippines and their subsequent adoption in many third world countries, are two very outstanding examples of the

value of agrotechnology transfer in improving food production in the world. The widespread introduction of high yielding wheat varieties in the third world is what was popularly called "The Green Revolution". In India for example, wheat production tripled between 1961 and 1980, largely as a result of the adoption of high yielding varieties rather than the expansion of the area planted to the cereal. Wheat production soared from 11.4 million tons in 1967 to 26.4 million tons in 1972 and reached 34.7 million tons in 1979 (Plucknett and Smith 1982). Production surpassed 45 million tons in 1984-85 season (personal communication). In Pakistan wheat production increased from 4 million tons in 1968 to 9 million tons in 1978 (Borlaug, 1978). Bangladesh has recently come within a few thousand tons of it's requirement. Mexico exports wheat in some years, a major turn around considering its rapidly growing population and the fact that it had been importing substantial quantities of wheat for decades. The Philippines, which imported rice for decades, has only occasionally had to buy rice since 1980, the Philippines exported 250,000 tons of rice. Indonesia's food picture is much brighter now that more hectares are being planted to high yielding rice varieties (Plucknett and Smith, 1982).

The Green Revolution among other things, was, not only due to the adoption of high yielding, disease resistant, dwarf Mexican wheat varieties but equally important was the development of improved production technologies eg. proper and timely sowing, proper irrigation and fertilizer application etc, which enabled full exploitation of the yield potential of these varieties. Judicious transfer of available technology can give quick results particularly in situations, where resources both financial and human to develop such technologies locally are scarce or not available. This is particularly true of the African continent, who must rely heavily on imported technology. It should be added however, that since agriculture production is location specific, there will be need for adaptive research to improvise imported technologies. In this presentation, the improved production package for wheat developed elsewhere will be reviewed and discussed in relation to its applicability under Zambian condition including research carried out in Zambia to develop such technologies.

Wheat in Zambia

There is a high potential for wheat production in Zambia particularly during the dry season under irrigation (May to October). Yields of over 5 tons per hectare in farmers fields are generally obtained. However, despite this, total hectarage under wheat has remained at about 3,000 hectares producing only about 8-10% of the country's annual requirements of over 150,000 tons. What has arrested progress in wheat production is the cost of irrigation. Available irrigation technology using sprinklers is expensive and beyond the means of peasant and emergent farmers. Hence it is only large scale farmers who are growing wheat in Zambia. For the country to become self sufficient in

wheat, an area of around 40,000 hectares under irrigated wheat is needed (Sisodia, 1983a).

In an effort to increase wheat production in Zambia, the government launched a rainfed wheat research program with the assistance of the Canadian government. The growing season of rainfed wheat is from January-February to April-May. The anticipated benefits of rainfed wheat are obvious and will result in decentralization of wheat production from the hands of a few large scale farmers to many small scale farmers. So far, however, results have shown that yields under rainfed conditions are not satisfactory. The low yields are mainly due to high temperatures, which reduce tillering and disease attack especially Helminthosporium sativum (Moono, 1979). The acid soils ausing aluminium toxicity in the high rainfall areas of the Northern Province of Zambia, targeted for rainfed wheat production, is another serious problem. Rainfed wheat, therefore, is still in an experimental stage and research is continuing to solve some of the problems referred above. The first rainfed wheat variety 'Whydah' released last year, is showing some promise for a commercial rainfed wheat crop but it is too early to tell whether its going to popularize ainfed wheat production. Yields up to 2.8 t/ha of Whydah were reported in trials at Mbala, where rainfed wheat research is concentrated. One farmer, in an areas of about 140 ha, averaged yield of 2t/ha (Wheat Coordinator's Report, 1984). It may be added that Whydah is an introduction from Brazil, where soil and climatic conditions are somewhat similar to those experienced during the rainfed season in Zambia. The variety, however, lacks required level of resistance/tolerance to both soil acidity and Helminthosporium and therefore increasing use of introductions from Brazil is being made in the selection and breeding program for the development of a more suitable rainfed wheat variety.

Improved Production Technology-Irrigated Wheat.

Zambia has benefited from agrotechnology transfer through the various wheat screening nurseries she receives from CIMMYT and from the International Center for Agricultural Research in Dry Areas (ICARDA) in Syria. Lines in these nurseries are screened diseases, adaptability and yield potential under Zambian conditions. The selected lines are then entered in yield trials for 3-4 years to assess their yield potential. Only high yielding, disease resistant lines are released for commercial production. The specific production recommendations for wheat are arrived at through agronomic research conducted in Zambia.

Varieties

Three varieties are currently recommended for production. These are Loerie, Canary and Emu's'. All these varieties have been selected from germplasm received from CIMMYT, Mexico. Loerie is a Veery selection. A number of Veery lines have been selected by CIMMYT from a spring x winter wheat cross. These

lines are proving to be very high yielding and widely adapted in many countries. Canary was selected in the University of Zambia wheat Program. It is a tip awned variety. Both Canary and Emu are resistant to stem and leaf rusts and are very high yielding. Canary has strong straw and does not lodge even when heavily fertilized.

Seed rate, time and method of sowing

A seed rate of 100 kg/ha is recommended. Studies done at the University of Zambia and the National Irrigation Research Station (NIRS) have shown that this seed rate is optimum for high yields as long as the seed is of high percent germination. Table 1 shows the effect of sowing date and seed rate on yield and yield attributes of two wheat varieties (Mbewe, 1975).

Table 1. Effect of sowing date, seed rate and variety on mean grain yields and yield components of spring wheat. (Source: Mbewe, 1975).

	YIELD AND YIELD COMPONENTS				
Treatment	Grain Yield (Kg/ha)	No. of heads/m	No. of grains /head	Grain Wt/ head	1000 Grain wt.
Sowing date					
April, 19	4137.2b	120.8a	32.4a	0.80a	39.4a
May, 3	5475.8a	129.3a	40.9b	0.80a	38.8a
May, 20	5395.4a	130.4a	48.9c	0.79a	36.2b
CV%	30.3	13.9	22.1	9.7	3.5
Seed rate					
40 kg/ha	4932.3ab	180.9a	42.8b	0.80a	38.2a
80 kg/ha	4858.8b	125.6a	39.7a	0.81a	38.2a
120kg/ha	5217.2a	146.1b	39.7a	0.78a	38.1a
CV%	7.5	15.6	9.7	7.9	3.4
Variety					
Tokwe	5279.3a	132.1a	39.9a	0.87a	41.2a
Mtalikwe	4726.2b	121.6b	41.5b	0.74b	35.1b
CV%	10.7	5.9	15.1	14.8	10.3

Means followed by same letter are not significantly different from each other.

A seed rate of 120 kg/ha gave overall higher yields for the two varieties. Results also show that the best yields were obtained with the first week of May Planting. The yield components,

number of heads per meter and grain weight per spike were not affected by the date of sowing. However, the number of grains per head and 1000 grain weight were affected by the sowing date. Later plantings gave more grains/head but reduced grain weight. Seed rate did have an effect on number of heads per meter and number of grains per spike. There was an increase in the number of heads per meter but a reduction in the number of grains per spike with the increase in seed rate. There was, however, no observable effect of seed rate on grain weight per head and 1000-grain weight. The yield components showed inter component compensation (Adam, 1967).

Results in table 2 on the effect of sowing date and seed rate show that yield was higher at the seed rate of 90 kg/ha with a general decline with higher populations.

Table 2. Effect of sowing date and seed rate on yield of wheat varieties at N.I.R.S. in tonnes per ha. (Source: MAWD annual report, 1977-78).

Seed rate kg/ha	Sowing Date			Mean
	28/4/77	19/5/77	8/6/77	
90	4.80	3.82	4.10	4.24
120	4.34	3.79	3.90	4.01
150	4.76	3.84	3.52	4.03
Mean	4.61	3.82	3.84	

In an another experiment carried out at UNZA for two seasons - 1982 and 1983, no effect of population densities on yield was observed (Table 3; Sisodia and Patel, unpublished); only in 1983, there was a marginal increase in yield at D3 level but it was statistically at par with the others. The experiment involved three population densities: 200 (D1), 300 (D2) and 400 (D3) seeds/m^2 and six wheat + one durum + one triticale varieties. These population densities corresponds approx. 80, 120 and 160 kg/ha seed rate respectively. In both years, the yield components, no. of spikelets, grains/ spike and 1000 grain wt. decreased with increasing population densities as expected and also reported by several workers. Of particular interest is the tillering pattern at different densities. Tiller count is from two, one meter long rows and the initial count was taken six weeks after planting and final count at harvest.

Table 3. Effect of population density on yield and yield components in wheat genotypes (Sisodia and Patel; unpublished)

Density	Yield (kg/ha)	No. of spike-lets/ spike	Grains per spike	1000 grain wt	Initial tiller no.	Final tiller no.	Tiller survival (%)
				1982 season			
D1	5190	20.31a*	46.16	45.58a	226.9a	152.3	66.5
D2	5129	19.31b	44.33	44.70ab	271.1b	157.6	58.1
D3	5114	19.10b	43.05	43.91b	293.1c	161.3	55.0
CV%	7.3	8.5	12.2	3.6	10.9	7.9	-
LSD.05	N.S.	0.97*	N.S.	0.94**	16.8**	N.S.	-
				1983 season			
D1	4306	19.50	51.9a	51.3a	259.4a	157.8a	60.8
D2	4396	19.4	49.5b	48.2b	301.6b	169.8b	56.3
D3	4434	19.0	47.4c	49.9ab	325.8c	183.7c	56.4
CV%	5.5	5.8	7.0	7.3	7.7	10.0	-
LSD.05	N.S.	N.S.	2.0***	2.1*	13.3***	9.9***	

* Similar letters indicate no significant difference between those treatments. (* ...) refers to significance level P.05, P.001 respectively)

Even in initial tiller counts, relative differences in population densities are not reflected indicating that competition between plants at higher plant densities starts quite early in the growth stage. Such a competition continues till maturity as reflected by relatively narrow gap between tiller numbers at different plant densities; this advantage is diluted by the corresponding reduction in other yield components and net result is no increase in yield. At a lower plant density, the tiller survival percentage is higher as expected.

Summarising, these and several other results confirm that the recommended seed rate of 100 kg/ha is a proper seed rate and should provide adequate insurance against any unforseen problem in germination and/or seedling mortality. Interestingly enough, in many countries, this seed rate is recommended and it may be considered an 'international' seed rate for wheat.

As far as sowing date is concerned, it is more location specific depending upon climate and cropping system followed. Under Zambian conditions, best yields were obtained in the last

week of April (Table 2) and toward late May sowing (Table 4). Considering that irrigated wheat in Zambia is rotated with soyabean, which is harvested toward late April, first three week of May are recommended for sowing wheat. This allows the crop to reach tillering stage, when temperatures cool down in June. The chilling effect of low June temperatures promote tillering, which is necessary for high yields.

Table 4. Effect of sowing date on yield (average of four varieties) at N.I.R.S. in tonnes per ha. (Source: MAWD Annual Report, 1977-78).

Sowing Date		
6/5/78	26/5/78	18/6/78
4.83	5.87	3.08

There is a need to develop varieties that will have a longer grain filling period. An extension in the grain filling period would only be achieved by developing varieties that will tiller well in warm temperatures so that they can be planted early, say mid-April wherever cropping sequence permits. This way the grain filling period would be extended since this stage would fall during the cool temperatures in July. In August, temperatures begin to rise and higher temperatures enhance crop maturity and leaf senescence. Hence extension of the grain filling period can only be done by early planting.

As regards row spacings, 15-22 cm is recommended. Similar row spacings are generally followed in many countries, where wheat is grown under high input conditions. Correct seeding depth is important for the high yielding dwarf wheat varieties. At an early stage in the introduction of dwarf Mexican varieties in India, it was discovered that seeding depth beyond 6-7 cm affects seedling emergence because these varieties have relatively short coleoptile (Bhardwa, 1978). Recommendation for seeding depth, therefore, is 5-6 cm, which is being followed in many countries.

Fertilizer:

Fertilizer recommendations are more location specific depending upon soil type. Soil fertility status, crop rotations in use etc. Fertilizer recommendations also need to be in relation to the level of yields expected in a given environment. In Zambia, nitrogen response up to 180 kg N/ha has been reported (Table 5), whereas no significant response beyond 60 kg N/ha was observed in an experiment carried out at UNZA over three year period 1981-83 (Gill et al unpublished). At present, general recommendations are 100-130 kg N, 60-80 kg P_2O_5 30-40 kg K_2O and a minimum of 20 kg sulphur per hectare. Boron application is

also recommended.

Table 5. Nitrogen response in wheat cv. Jupateco at NIRS, (averaged over seed rates; Source: MAWD Annual Report , 1977-78)

	N in kg per ha				
	0	60	120	180	Mean
Yield (kg/ha)	2.13	3.60	3.86	4.76	3.59

Soil tests are recommended to adjust fertilizer rates. Liming is recommended where soil pH is low. It should be added that generally similar level of fertilizer recommendations exist in India, where the crop duration (120-140 days) and yield level (approx. 5t/ha) are similar to Zambia.

In Zimbabwe, where the growing season extends to more than 150 days and yields are higher (1982 national average 5.3t/ha in an area of about 42,000 ha) fertilizer recommendations are 100-180 kg N/ha with corresponding higher levels of P and K (Sisodia, 1983b).

Another aspect of fertilizer recommendation is to recognize the fact that fertilizer response follows the law of diminishing returns. From the results of extensive experiments carried out in India on the Agronomy of dwarf wheats, substantial evidence is available in this respect (Table 6). The results are based on a total of 300 trials involving 10 dwarf + one tall varieties over a period of four years. Considerable differences between varieties were present and of the 11 varieties, only 5 gave marginal response beyong 120 kg N/ha level.

Table 6: Average response kg Grain/kg N in Wheat at different nitrogen levels

No. varieties tested	Dose-Interval (40kg/ha)				
	(0-40)	(40-80)	(80-120)	(120-160)	Total No. of trials
11	16.7	12.3	6.0	0.8	300

Source: Five years of Research on Dwarf Wheats, 1968; Indian Agric. res. Instt., New Delhi.

Thus maximum response is obtained at lower levels diminishing gradually at higher levels of application. Fertilizer is an expensive input, particularly in the African continent, where most of it has to be imported at the ever increasing cost of scarce foreign exchange. Under such

circumstances, "spreading" the use of fertilizer will be overall more beneficial in order to achieve greater production. There is need, therefore, to educate the farmers on the judicious use of fertilizer in "his situation" as well as of some adaptive research to increase fertilizer-use-efficiency.

Irrigation

Irrigation is the most important and expensive input of irrigated wheat. Mainly sprinkler method is used in Zambia. A total of 450-500 mm of water is needed. In an experiment carried out at UNZA in 1981-82, using a sprinkler line source to impose different irrigation regimes, the yield declined in relation to distance from the source and the amount of water applied (Gill et al, 1983). The results are presented in Table 7.

Table 7. Grain yield (kg/ha) at different irrigation levels (average of three varieties).

	Irrigation levels						
	I_1	I_2	I_3	I_4	I_5	I_6	Mean
			1981				
Total water applied (mm)	459	390	328	305	240	183	-
Yield (kg/ha)	3603	3050	2625	2217	1938	1862	2549
			1982				
Total water applied (mm)	505	475	406	332	252	158	-
Yield (kg/ha)	3870	3627	3049	2757	2359	1762	2904

Similar response to irrigation has been reported by many workers and indicate that wheat crop needs adequate irrigation for maximum yield. As regards timing of irrigations, different farmers in Zambia follow somewhat different schedule depending upon soil type and availability of water and irrigation equipment. Generally the following methods are followed:

(i) Dry sowing followed by irrigation or pressuring irrigation up to a depth of 1.2m to bring the soil to field capacity. If dry sowing is practiced, a light irrigation is given after 5-6 days to facilitate seedling emergence. Further irrigations to follow after 4-5 weeks at intervals of 14-18 days for clay-loam soils and after 3-4 weeks at intervals of 10-14 days for sandy-loam soils.

(ii) When resources does not permit initial heavy irrigation as in above, farmers practice either dry

sowing followed by irrigation or pre-sowing irrigation. An irrigation interval of 10-15 days if followed depending upon soil type and stage of crop growth.

Dry sowing is possible only if proper land preparation can be done withough applying water, which will depend upon soil type, previous crop taken, equipment available etc. Generally at each irrigation about 70 mm of water is applied. Irrigation interval is adjusted according to stage of the crop and rate of evapotranspiration. For example, in late August-September, irrigation is applied at mid-dough stage.

As mentioned earlier irrigation is the most expensive input of irrigated wheat and a major constraint to expand it's production in Zambia. At present altogether approx. 20,000 ha area is under irrigation and need to be increased rapidly. This will not only help increasing wheat production but also stablise agriculture production as a whole. However, as pointed out by Sisodia (1983a), the existing method of applying water from the source to the field using pipes and sprinklers needs heavy intial investment, mostly in foreign exchange, which the nation is hardly in a position of afford. Such investment these days would amount to approx. K5-6000/ha and is prohibitive to further irrigation expansion. Therefore, in order to rapidly expand the irrigated area, research on surface irrigation methods is urgently needed on aspects such as best method, suitability of different soils, water-use-efficiency, economics etc. It is appropriate to add here that in many third world countries nearly all the area is surface irrigated. For example, in India nearly 98% of the wheat irrigated area is surface irrigated. In Zambia, Nakambala Sugar Estate and Mpongwe Wheat Scheme are using surface irrigation. Much can be learned, improvised and applied from the experiences of these and other countries.

Another aspect of irrigation is similar to that mentioned about fertilizer i.e it's response follows the law of diminishing returns. Extensive research carried out on dwarf wheat in India has demonstrated that under limited water supply, more production can be obtained by applying irrigation at critical stages only and thereby spreading it's use to cover more area under irrigation. (Table 8). The results shows that irrigating at crown root stage (CRI- about three weeks after planting) was critical for dwarf wheat and difference between three and six irrigations was only 910 kg/ha. From such results, the following irrigation recommendations based on crop growth stages have been developed for adequate and limited water supply conditions (Bhardwaj, 1978) and are practiced by farmers.

Table 8. Effect of irrigation applied at different stages of growth of dwarf wheat cv Sonora 64. (Source: IARI, 1968).

Treat-ment	Stage of growth						Total No. of irriga-tions	Yield (kg/ha)
	Crown root	Late till-ering	Joint-ing	Boot	Flower-ing	Dough		
1	1	1	1	1	1	1	6	5140.0
2	1	1	0	1	1	0	4	5130.0
3	1	1	0	0	1	1	4	5230.0
4	0	1	0	1	1	1	4	4400.0
5	0	1	1	1	1	0	4	4520.0
6	0	1	0	1	1	0	3	4230.0

1 indicates irrigations given; 0 indicates irrigation not given.

(i) Adequate water supply

- Four irrigations: CRI-tiller completion-boot-milk
- Five irrigations: CRI-tiller competion-late jointing-flowering-milk
- Six irrigations: CRI-tiller completion-late jointing-flowering-milk-dough

(ii) Limited water supply

- One irrigation: CRI
- Two irrigations: CRI-Boot
- Three irrigations: CRI-Boot-Milk

Under Zambian conditions, where irrigation is scarce and expensive, research in such direction is needed to get maximum production from the available irrigation resources and thereby increasing water-use-efficiency.

Spreading Scarce Resources

Fertilizer and irrigation are the two scarce and expensive inputs of irrigated wheat in Zambia. In many situations, land is not limiting. In order to achieve maximum production from the existing resources, based on the research results elsewhere and discussed above, it would seem appropriate to spread these to more land area. For example, suppose a farmer has enough water to grow 100 ha of fully irrigated wheat applying about 500 mm water and irrigated wheat 120 kg N + 60. kg P + 30 kg K fertilizer per hectare. Assuming a yield of 5t/ha, his expected total production would be 500 tons of wheat. Instead, suppose he spreads his water and fertilizer to 200 ha area of partially irrigated wheat applying about 250 mm water, and 70-80 kg N +

40 kg P + 20 kg K fertilizer per hectare and gets a yield of 3-3.5t/ha. his total production would be 600-700 tons - amounting to 100-200 tons of increased production. Adaptive research, therefore, is needed to verify application and if necessary improvisation of such a technology under Zambian conditions. The economic aspect of such technology by way of cost/benefit analysis will be required to ensure that beside increase in production, the farmer is also benefitted financially.

Conclusion

In conclusion, it may be stated that the value of agrotechnology transfer at the level of germplasm exchange has benefitted third world countries. Through international testing nurseries these countries have been able to identify high yielding, disease resistant varieties of wheat. Another hitherto unutilized value of international testing is that the results from these tests could be used to identify crop agroecological zones for an international array of environments. Using yield data of the fourth and fifth International Winter Wheat Performance Nursery (IWWPN), Lungu (1978) was able to classify the IWWPN test sites into adaptive zones. He used the genotype X environment interaction effects for each variety to compute a matrix of inter-individual distance coefficients. The distance coefficients were used as measures of similarity and using cluster analysis an international array of environments having similar varietal performance were identified. With this technique pockets of locations with a similar pattern of varietal performance and yet quite apart geographically were identified. The value of such information is that germplasm and production technologies could be exchanged among agroecologically similar locations with only adaptive research needed to utilize the technologies. This would constitute an expanded form of agrotechnology transfer.

With respect to Zambia, agrotechnology transfer through international testing nurseries has been of great benefit to the country. However the country, has a long way to go for becoming self-sufficient in wheat requirement. Irrigated area needs to be expanded and research on surface irrigation methods needed to reduce the cost of irrigation which amounts to approx. K5-6000/ha and is prohibitive to further irrigation expansion.

Both fertilizer and irrigation are scarce and expensive inputs of irrigated wheat in Zambia. Learning from the experiences of other countries, spreading use of these to more land areas would appear to be more effective in increasing total production. Adaptive research however, will be required for the transfer of this technology under Zambian conditions including consideration of economical aspects.

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REVIEW OF THE XI INTERNATIONAL FORUM ON SOIL TAXONOMY AND AGROTECHNOLOGY TRANSFER.

Cuulu Kalima

I was asked to give a short review on the Forum together with some other colleagues who will speak afterwards.

I will review the Forum in the following manner:

1. Lecturers and lecture materials
2. Field tour
   - Pit discussions
   - Participants participation
   - Role of lecturers
3. Organisation
4. Achievements

Lectures and Lecture Material

It is my opinion and that of most others I have talked to that the lecturing standards were high and the lectures easy to follow. Most of the lecturers did not pretend to be custodians of Soil Taxonomy. They come out very strongly for or against aspects of soil taxonomy that they felt did not agree or conform to their, admittedly, world wide experience. To the participants this was perhaps the most enriching experience during the forum the chance to listen to the negative and positive aspects of Soil Taxonomy. This served to mould and consolidate their understanding of Soil Taxonomy and helped wash away all other misconceptions concerning the system.

Lecture Material

I am sure that most of you in here will agree with me if I say that there is a lot of room for improvement in as far as lecture materials are concerned. The organisers of Soil Taxonomy Forum must endevor to prepare visual aid material in form of overheads (transparencies) slides, wall maps etc well in advance of the forum for specific topics (i.e. on epipedons, subsurface horizons, standard relationship of soil properties in soil orders etc.). Once prepared these materials should be sent to those who will be lecturers to study and later on present in their lectures during the forum. The situation where one lecturer shows elaborate slides on his topic and next lecturer labours to propound a theory without slides or any other aids throws participants from one mode to another thereby affecting their ability to learn. Surely all must have an equal chance let alone the participants.

Field tour

Since I was one of the organiser of the field tour I will leave the bulk of the section for other to review. However,

since I believe in self assessment I will make a comment or two.

While it is important that the organisers of Soil Taxonomy leave the local preparation to the host country because they have a better understanding of local logistics, it is important that they provides guidelines related to

1. Basic logistic factors to be considered, timings etc.

2. Providing data on the experience gained by other countries that have organised such forums before.

The organisers of the forum, that is, SMSS, should ensure that during the tour the lecturers should not keep to themselves i.e. in the Bus etc. An atmosphere should be created were the lecturers should freely mix, integrate and talk to the participants at convenient times. In my understanding of a forum, this is a key factor.

Profile Discussions

There should be a very strong control on the proceedings of discussions at the pit sites. For this to happen the lecturers should as much as possible be brought into action at profile pits. It was not nice to see most lecturers ignore, i.e. refuse to notice, pit discussions especially when a participant was asking a question or chairing a profile pit discussion. If this is done less time will be wasted. The most impressive part of all the profile discussion was that there was always somebody who when everybody was lost or there was near confusion would put us all on the correct track with impressive courage and knowledge.

Participants Role / Role of Lecturers

The role of the participants was very clear: that was to learn and this I believe they followed to the provided limit. The only drawback was that the participants did not seem to want to enforce their role. I think it is better to be an active learner rather than a passive learner. I noted that when ever the lecturers resorted to talking and discussing amongst themselves the participants didn't attempt to ask for any help.

Although the role of the lecturers was as clear as that of the participants, the lecturers did not execute their role to its logical conclusion. Most of the time in the field they resorted to grouping together and discussing among themselves. They should have been instead soldiering around and among the participants to help out with profile description and classification problems. In a way the lecturers seemed to take a double role of lecturer/student. This is mainly because some of the soils seemed a little strange to them and they had hence to study them too. All the same they should not have made this too obvious.

General Organisation

Here again I will not say much owning to my position. I will however mention that, I found it a big mistake to split the forum into lectures - field trip - lectures. All lectures should have been conducted at once followed by a field trip to conclude everything. The result of not doing such can be seen in that the last section consisting of lectures has been poorly attended because the trip exhausted most of the participants.

Achievements

The success of the forum can only be seen in the light of its achievements. In this case we have to find out if the objectives of the forum have been achieved. In my opinion objective 1, 3 and 4 have been achieved, while objective 2 has not. If I ran through the objectives one by one I can say the following for each one of them.

- Objective 1 has been the corner stone of the whole forum. It has also been the most successful. The success of objective one alone, I believe is enough for one to say that the whole forum was a success.

- Objective 2 was achieved only to a very limited extend mainly among few very specialised individuals. In my opinion there was usually a one way transfare of knowledge rather than a two way exchange of knowledge.

- Objective 3 was clearly demonstrated during lectures and in the field especially as related to pit description.

- Objective 4 can be seen in the good working relation that will keep on growing between different soil organisation in Zambia and in other Southern African countries.

Lastly, the forum moral is greatly lowered down if lecturers leave before the forum comes to the end. SMSS should ensure that the lecturers stay to the very end, and if possible spend extra days discussing certain aspects of their profession with local workers. It is rare in a life time to have such a congregation of experts as this forum has brought together and I think the local people should be allowed to make full use of such a resource.

REPORT ON FORUM EVALUATION

Kwame Asumadu

Introduction

My evaluation deals with only the field tour and the technical sessions that followed, because these are the activities that I was involved in. This report is in three parts as follows:-

(a) My impressions about Soil Taxonomy before the forum
(b) My present impressions, and
(c) A General over-view of the forum.

My Impressions about Soil Taxonomy before the Forum.

I considered Soil Taxonomy as just another system developed. In my view, the system was very complicated and incorporated long names that were not easy to remember. Having been trained in Australia, I was more comfortable with the Australian system and was happy to use it. However, this view has changed since the forum.

Present Impressions

Soil Taxonomy obliges the soil scientist to look closely at the soil profile since it forms the basis of classification within the Soil Taxonomy system. This obligation requires the soil scientist to give equal attention to field soil properties sust as mineralogical and physico-chemical properties.

It also encourages the soil scientist to look at laboratory analytical results of soils and thus brings about a complete marriage between field and laboratory soil scientists. This approach removes the old dichotomy between the so called field soil scientist and the laboratory soil scientist. Soil Taxonomy has also made soil survey and classification quantitative, thus enabling soil surveyors to make scientific (objective) interpretations from measured soil properties.

General over-view of the Forum.

(a) More emphasis must be placed on teaching the correct procedures for profile description at such forums because one need not emphasise the importance of correct profile description to soil classification.

(b) Extra time must be devoted to the methodology for the calculation of mineralogical and physical chemical data and their interpretation for soil classification and management. Perhaps, guidelines on those aspects of the subject (if they are not already in existence) must be produced and distributed to participants. Such

booklets will be valuable reference material for the post forum learning process of participants.

(c) All technical sessions must proceed field tour to ensure the full participation of both resource personnel and learners.

(d) The key to taxonomy contains too many compound sentences. Perhaps it can be written in simple concise sentences (without ambiguities) to facilitate its use in classification.

(e) Some of the resource persons were protective of the system. They should adopt a more open altitude and accept genuine criticisms of the system. It is only through application of the system outside the USA and accepting its short comings that would enable the system to be improved and perfected.

(f) The whole organisation of the forum was done professionally and a lot of credit must be given to both the organising and steering committees for a job well done.

(g) There was a good marriage between soil science and agronomy topics discussed at the forum. This was a move in the right direction to bring about the much needed multi-disciplinary approach to solving problems of the world. Perhaps, agricultural economists could be invited to present papers at subsequent forums.

In general the forum was a great success and has made us realise the great potential of soil taxonomy, particularly for agrotechnological transfer, and generally for the soil science profession.

EVALUATION REPORT ON THE 11TH INTERNATIONAL FORUM ON SOIL TAXONOMY AND AGROTECHNOLOGY TRANSFER.

R. Masinja

I sincerely extend my full appreciation to the Organisers of the forum, the sponsor organisations and most of all the Resource staff: Dr. Hari Eswaran, Dr. Rudy Dudal, Dr. Frank Moorman, Dr. Stanley Buol, Dr. Rene Tavernier and last but not the least Dr. Goro Uehara, for having made this forum a reality. The most popular system Soil Taxonomy (USDA) can now be applied in our classification system with all confidence in use.

Introduction

This report does not pretend to be complete or to exhaust all the draw backs and successes of the forum, for some people did not bring up their opinions. In here, the report tries to express the ideas and suggestions of those people who would like to see a better organisation of such a forum which is very important in our modern days. Ample time was given to individuals to do the evaluation for themselves. Generally speaking, it is said that no two persons have similar opinions on given events, but this should not be taken so always, other wise people won't be able to differentiate genuine points, from non-genuine ones. It is important that each point is scrutinised seriously.

General

Most participants were happy to attend the forum, for to some people, it was the first time that a formal introduction to Soil Taxonomy was done. It was a chance to those who didn't know the system to get closer to those who already knew the system and get closer to the authors of the book, so as for them to have some points which were not clear to them clarified. The forum has acted as an encouragement to some soil surveyor scientists who were doubting of the usefulness of the system. It has given most people both theoretical and practical insight into taxonomy. Generally for purposes of understanding and transfer of experience between soils in different countries in the agricultural field, the system is more practical for it allows direct interpretation of soil properties for management. Such forums should be encouraged to facilitate exchange of ideas and standardisation of work in a region or even the entire world. With the use of the system, one can easily have a synoptic view of what kind of soil and the management requirements once one gets used to it.

Such forums should be held regularly for people don't only learn soil taxonomy, but learn a lot more from the professors through academic, social interaction because of their vast experiences.

Problems in the system:

While it is clearly understood that the soil taxonomy was compiled by a group of experts, there is a general feeling that the key must be re-written in concise simple sentences. There are too many compound sentences which make it difficult to understand some parts of the key. It is also hoped that, this system should not be exclusive of other widely used systems in the world e.g. FAO/UNESCO etc. It should try to merge other systems, so that, if one knows one system, then he knows all. It should be such that, it becomes a refinement of an intergreted international system. The system should also try to include most tropical soils. This has to be done soon, because it seems most of the soils we have in the tropics do not fit very nicely. This is a discouragement to the people who are just being introduced, for they doubt of its reability. The example to site is that of structure which is not fully illustrated in the system.

System under Zambian Condition

There is all the hope that application of the system in Zambia will succeed, since it is already in use at the present time, but however, its continued use is dependant on some more amendments to the system. Although it is understood that the system is dealing with dynamic processes, until it is developed so as to effectively cater for all soils with little room for doubt left, the system will always be shunned. Apart from it being expensive in the present economic status, is too complicated, its differentiating strength in Zambia is not very great (many great group have only one or two series). Major differentiating parameters for land use (e.g. texture) only occur at relatively low level (subgroup family). What is required is a simplified system that uses soil taxonomy criteria e.g. master horizon and other related characteristics.

Classroom Lectures

Time allocated was enough only that it was not properly spaced. Some topics needed more attention than others, hence emphasis should be laid on such e.g. charge characteristics of soils in tropics. The general intensity of lectures which provided no time for digestion was expressed. Detailed explanation on specialised fields like CEC, BSP and the related subjects in future should be given more time, for they are the main differentiating parameters in the system. Above all, the lecturers were found to be quite informative. The other observation was of the last two hours which were ineffective because lectures were supposed to be ending at 16.00hrs but were being extended.

Field Discussions

In future it should be emphasised that the forum is a training course and not an International Conference and as such

whether one is a Soil Surveyor of 10 years experience or technical officer of 2 years experience, at this time he/she will be under a training situation, so as such, full participation of all level groups was supposed to participate.

No one group of people should be victimised, if so then why did the people have to come to attend the Forum, if they knew everything already.

Time allocation was enough, but a bit too much time was spent on travelling. An average of two pits a day would have been desirable, and also somewhat more variation among pits (very few wetland soils were observed). It is felt that the idea of discussing the classification with the whole group is not always very efficient. If some "super pits" would have been dug, participants could have split up at some sites in small groups who could have made classification amongst themselves (if possible with the aid of a resource person before throwing it in the group as a whole).

While the job done by the professors is highly appreciated, it is felt that, for every pit done, a resource person was supposed to give a detailed characteristics of such a soil systematically, after everyone had a chance to see the pit. This would carter for those who had no chance to discuss with them in the pit and those of whom for some reason or another are shy to ask. It was also noted that, sometimes, some very important topics were not given enough time, instead too much time was given to some irrelevant topics which were sometimes a bit protracted. Topics such as Land Evaluation was over looked when in actual sense all this classification is done for its sake. A lot of calculations were involved in the physioco-chemical data and as such, for the people who are just being introduced to the system, it caused a lot of problems. If a booklet on calculation of mineralogical and physico-chemical data and their interpretation could have been circulated for the benefit of participants, this could have helped a lot. The other problem was that of some data lacking in certain profiles, this led to some inconveniences as far as classification was concerned and this caused some doubt to the people who were just being introduced to the system as to how reliable the system was.

Running of the Forum

The organisers of the forum are highly appreciated for the job well done. The forum was run very well in the beginning, but towards the end most of participants were broke. This was mainly towards the end of the field trip. Most participants thought that at least some money was supposed to have been given to them, just like in any other International Forum, but this was not the case. Participants wondered whether this was one of the conditions set by the sponsor organisations. This question still lingers amongst the participants and clarification may be needed at one time or the other from the organisers, for it was unique

to this forum alone. This led to some participants being isolated, because they could not join their resource persons over a glass of drink. There are usually some very important topics that can be discussed over a glass of drink and indeed this also allows more interaction.

Conclusion

In conclusion, one would say, the forum was run well. All the participants had a chance at the system through the resource persons. There was enough interaction at all levels. The participants of all levels were given the liberty to call the resource persons by their first names, so as to ease communication.

There was a lot that was learnt by all participants. It was a great honour for Zambia to host such a conference, attended by highly recognised scientists in the world. At least every participant can claim to know a lot about the Taxonomy for each one brushed shoulders with the authors of the books, the atmosphere throughout the forum was that one conducive for learning purposes.

Although this might appear as a recommendation, but in actual sense, it is a request to SMSS and ISS. If this Agrotechnological transfer is to materialise, then all field staff who are capable of understanding the literature of soil taxonomy and the related subjects should attend such forums. Otherwise short course should be organised for them for this is the only surest way to add an effective base for Soil Taxonomy. Hope is that, all the participants to this forum will be called upon the next time another international forum will be held in another country within the region to make a follow up.

RECOMMENDATIONS AND COMMENDATIONS

a) Commendation

The participants of the XI International Forum wish to record their appreciation to the Ministry of Agriculture and Water Development of Zambia for hosting the forum and providing logistical support and also the University of Zambia CYPAC. Additional funding and logistical support was provided by the following organizations and their collaboration and cooperation is gratefully acknowledged:

a. Soil Management Support Services, USA
b. NORAD, Norway
c. Belgian Technical Assistance, Belgium
d. Agency for International Development, USA
e. International Benchmark Sites Network for Agrotechnology Transfer

The participants also wish to record their appreciation to the resource persons who attended and contributed to the Forum.

b) Recommendation

1. Realizing the constraints of the soil scientists in the Southern African countries and appreciating the value of a Forum for strengthening institutions in the region, the participants recommend a follow-up forum within a reasonable period. The University of Zimbabwe has indicated its willingness to host such a Forum and it is requested that they take appropriate action to invite the soil Management Support Service and other regional and international organizations of collaborate in its organization.

2. As soil surveys are the basis of agricultural development, the participants recommend that the soil Management Support Services consider organizing training courses in the Southern African region at regular intervals. The subject matter to be covered includes soil survey methodlology, soil survey interpretations, methods of soil characterization, land evaluation and soil management. It is felt that special courses are needed for soil survey and laboratory technicians.

3. The Forum has clearly established the need for universal field manuals on soil surveys, soil survey interpretations, methods of soil analyses and similar texts. There is an urgent need for such publications and the Soil Management Support Service and IBSRAM is urged to develop these for use by scientists in developing countries.

4. Soil acidity is one of the major constraints to soil use in the higher rainfall areas of Zambia and in this respect, the participants welcome the formation of an international network management of acid soils by the International Board for Soil Research and Management (IBSRAM). The participants strongly recommend that IBSRAM considers countries in the Southern African Region to become members of the network.

5. Confronted by similar constraints in the countries of Southern African region, the participants welcome the collaboration of IBSNAT with Zambia but request IBSNAT to evaluate the feasibility of developing a network in this region. With similar aspirations and agricultural problems, agrotechnology transfer will be a very welcome solution and in collaboration with IBSNAT, a network of collaborating agricultural institutions will contribute to the general agricultural development of the region.

CLOSING ADDRESS OF DR. HARI ESWARAN
(PROGRAMM LEADER, SMSS, USA)

Hon. R.C. Kamanga, Member of the Central Committee and Chairman of the Rural Development Committee.
Hon. Minister of Agriculture and Water Development
Hon. director of Agriculture
Distinguished Guests
Ladies and Gentlemen

About two weeks ago, on July 15, the Hon. Member of the Central Committee opened this Forum and made a very impressive speech and I like to cite a few lines. He said, "the need to increase and improve good production has been Zambia's pre-occupation for a long time now. There is a great urgency to seek self-sufficiency in food production in order to fore-stall possible hunger. Agriculture has become the life blood of this country, especially when the country's benefits from copper are declining."

During the last nine days, the participants of this Forum travelled from Mbala in the North to Livingstone in the South. We got a sample of the 75 million hectares of land in Zambia. We have been told that 60% of this is arable of which only 15% is being cultivated. Mr. Joseph Mutelo, Assistant Director of Land Use told us that there are over 10 million hectares of potentially irrigable land though only 20,000 ha. is currently under irrigation. We have been told that the farmers yields of corn and wheat range from 1 and half to 2 tons/ha. while the commercial estates produce 3 to 4 tons. When we look at population projections, it appears that the population of Zambia will double by the end of this century. The member of the central committee also spelled out the Governments strategy to forestall hunger and prepare the country's food production capability for the new century.

While we were at Kasama, the Provincial Permanent Secretary, Mr. Manda and the Provincial Agricultural Officer, Mr. Kampamba, joined us for dinner and asked our opinion on how agricultural Development in the Province can be accelerated. The participants provided a range of options and I like to summarize some of their observations.

Firstly, as we are all soil scientists, moisture stress in the soil was considered the number one constraint to food and fiber production. A short-term solution is to introduce drought resistant varieties but on the long term, government capital investment is crucial. The amount of irrigated land must be increased from the current 20,000 ha. The farmer cannot afford this and consequently the need for massive government investment.

Secondly, many of the soils suffer from Ca deficiency or Al toxicity. Supply of lime and fertilizers to farmers must be

considered as a necessary capital investment just as irrigation.

Thirdly, the goal of the national planners should not be merely one of seeking self-sufficiency. Zambia can and should set a higher goal. Many of us believe that Zambian soils have fewer constraints than many other countries. In addition Zambia has a tremendous water potential. The rivers Zambezi, Kafue, Luangwa and Chambeshi, the lakes Kariba, Mweru, Tanganyika, Iteshi-teshi and Bangweulu offer vast irrigation potentials. Zambia's goal should be to become the bread-basket of Southern African and we believe this can be achieved.

The ground work needed to achieve this goal is already being laid. A first step is the evaluation of the soil resources of the country and the NORAD funded Soil Survey of Zambia Project is preparing this inventory. A second step is research and this is an area which requires much more attention in Zambia. With the stress the government is placing on agricultural development, there is a real need and perhaps an urgency for a Zambian institute of soil research. The soils of the Southern African Plateau on which Zambia is located, extend beyond Zambia and consequently any research conducted by such an institute will have useful applications beyond its borders. A regional centre of excellence in Zambia with capabilities to conduct research, develop training and provide services will be a positive step to increase agricultural production in not only Zambia but also the SADCC countries as a whole. Technical assistance projects have necessarily a short life-span and are necessarily created to solve specific problems. Based on such projects, perhaps the time is ripe to develop an infrastructure that is more permanent and that will pave the way for Zambia to enter into the 21st century.

Mr. Chairman, I have digressed a bit but I believe that most of the foreign participants will share my opinion. Coming back to the Forum, I must say that this has been a delightful experience. When I came here two years ago, to make the initial plans, I had my doubts if it would be successful. The program was ambitious and the nine day field tour was like a nightmare. I can confidently report to you that the forum proceeded with clockwork precession. The field tour was magnificently handled and the whole meeting was very professionally organized. The credit goes to Mr. Robert Magai and his Team. This is the XI Forum I have organized and without doubt, one of the best. The logistics can be perfect, but a Forum is not considered a success if the participants did not participate. Even on this count, I am extremely satisfied. What we taught in these two weeks is what is given in a U.S. University in one year. Yesterday, when we visited the UNZA farm, we could see the rewards of our work. The participants could classify the soil with no help from the resource persons and more importantly, they could derive all the constraints to soil use from the classification.

Mr. Chairman, at this Forum we also talked about Agrotechnology Transfer. The work being done by Dr. Chinene and his colleagues at the UNZA farm is a clear example. They have been able to obtain 8-9 tons of corn per ha. which is well above the national average. UNZA is clearly providing the leadership in research and with backstopping through the Belgian Technical Assistance Program and collaboration with other International Organization, UNZA is clearly destined to be a centre of excellence not only in teaching but also in research.

Mr. Chairman, I am going to leave the pleasant task of thanking all the organizers to my colleague Dr. Rudy Dudal. However, on behalf of the agency for international development and the U.S. Department of Agriculture, I would like to express our deepest appreciation to the government of Zambia for hosting this Forum. I would also like to express our sincere thanks to you Hon. Kamanga and to the Minister of Agriculture and Water Development for your personal interest and support of this Forum. In two days, we will leave this beautiful country and we can assure you that this forum will be a landmark in the history of tropical soils and that all of us will leave with the fondest memories.

Thank you.

CLOSING SPEECH BY HON. R.C. KAMANGA, MCC.
(CHAIRMAN OF THE RURAL DEVELOPMENT COMMITTEE)

Comrade Chairman, Comrade Minister for Agriculture and Water Development, Comrade Permanent Secretary of the Ministry of Agriculture and Water Development, The Royal Belgian Ambassador The NORAD Representative, The USAID Representative, The IBSNAT Representative, The SMSS Representative, Conference Participants, Ladies and Gentlemen

It is my honour and pleasure to host this dinner on the occasion of this International Forum. It is my sincere hope that you had successful technical discussions both in the field and during the lecture sessions held at the Commonwealth Youth Programme Africa Centre.

I am sure that three weeks ago many of you here tonight had little idea of what Soil Taxonomy and Agrotechnology Transfer meant. But now, however, you should be experts.

Quite apart from attending a rigorous course of lectures, you have travelled the length of the country from Mbala, touching Mpulungu, to Livingstone in the company of some of the foremost soil scientists in the world. I am told that the discussions were lively to say the least.

I hope that nobody was shy to venture an opinion, because the informal nature of any discussion held in the field is an ideal forum to pick the brains of the experts. I am informed that our distinguished visitors brains have been well and truly picked during the forum.

On the other hand, I hope that they have learnt a little about Zambian soils and our problems in utilizing them, so that on future forums in other countries they can bring experience gained here to bear on the problems of others. That is what International Co-operation is all about.

Mr. Chairman, the purpose of classification is to organise knowledge so that we can predict the behaviour and performance of the objects we classify. I have been informed that after two weeks of using the Soil Taxonomy Classification intensively, the soil classification system can be viewed from two different angles. First I would like to quote the English philosopher Pope who said that the first law in heaven is that there must be order. Now, where is there more order than in a Soil Taxonomy? In fact, the Soil Taxonomy is full of order, with its ten taxa at the highest level, followed by sub-orders, great groups etc.

To some of us it may resemble disorder, that is the reason I would also like to quote Einstein who said, "what we can observe is determined by theory". This quotation underlines all your quarrels about alfisols, ultisol and numerous others. As long as the theory is not improved the problems of where to draw the line

between different soils will not be solved. I, therefore, urge you to continue the study of Zambian soils and contribute to the improvement of the soil taxonomy.

Mr. Chairman, Zambian Agricultural Development will depend heavily on agricultural technology transfer from other regions of the world. To do this successfully, Zambia will need a precise inventory of its soil and climate resources. Soil taxonomy is the common language that will enable us to make our soil inventory.

It is apparent Mr. Chairman that as we Zambians are learning more about the soil taxonomy system of classifying soils and are applying it here in Zambia more regularly, some of the difficult terminology is gaining popularity. I have just been informed of one enterprising and eager young Zambian soil surveyor who was considering the possibility of naming his born son ustic or mollic Phiri. Both names being from soil taxonomy.

The future of the nation lies in its natural resources, and so far agriculture which is now the cornerstone of our economy is concerned, the primary resource is the soil. To make the optimum use of this resource we need to study the nature and distribution of our soils. To meet this end we have already taken great strides. With the help of NORAD, our soil survey unit is now operating in all the provinces at near capacity. A similar effort is being followed at the university of Zambia utilizing various donor agencies such as USAID and Belgian Administration for Development Cooperation (BADC) and the international Benchmark sites network for agrotechnology transfer (IBSNAT).

We also need to be able to relate our soils to those in other parts of the world so that we can investigate the potential of importing and testing agricultural technologies developed in other parts of the world on soils similar to our own.

The soil taxonomy system will one day be a universal tool for the transfer of knowledge about the worlds soils. At present it is rather country - specific, suiting the USA especially. But once the system has been refined, through forums such as these, it will be a really important tool for use. In the meantime, we must learn the system, and utilize those parts of it that suit our local conditions.

Mr. Chairman, I am informed that during your tour you encountered some problems of our soils that need mentioning. We have long been aware of the need for lime and phosphate, especially in the north of Zambia, if sustained farming is to continue. However, the knowledge of the researchers has sometimes been only slowly implemented due to lack of resources, and sometimes a lack of awareness amongst the administrators of the seriousness of the problem.

During the field tour distinguished visitors, who have

experience far beyond many of our own experts, strongly reiterated the vital necessity to provide our Northern farmers with lime and phosphates.

The natural conditions of the soils in the north dictate that withough these inputs, over and above the standard fertilizers, yields will decline inoxerably, and the promise of production that we see now will wither away.

In Central and Southern provinces the widespread "sandveldt" soils were recognized to be difficult to manage, and above all, year after year our soils are eroding away due to poor and careless management. It will never come back. It is vital that our planning officers go out in the field and implement soil conservation measures wherever necessary.

It is vital that our extension officers clearly understand the processes behind erosion, and the ways to advise farmers to combat it. This can only happen if we greatly increase the training of our field staff. Forums like this are a vital tool in our drive for development.

Mr. Chairman, His Excellency the President announced last week that irrigated agriculture in Zambia has the chance to be revolutionised. He was referring to a simple irrigation design demonstrated by an American farmer in the Zambezi valley. The idea worked out could be applied by small scale farmers in Zambia and could make it possible to extend the nations irrigated lands. I hope your findings will allow us to identify those soils most suitable for irrigating so as to complement rainfed agriculture in the country.

A point worth of mention Mr. Chairman is that this year is the last one of the international womens decade now culminating with the United Nations womens conference in Nairobi. It seems to me that very few women are involved in soil survey in the world and as far as I know, we have none in Zambia. It sometimes takes a special kind of logic-known as womens intuition - to make sense out of the problems which men often create. I wonder if you should not encourage more women to join your profession to sort out your quarrels over soil taxonomy.

On the last note Mr. Chairman I would like to sincerely thank the donor agencies for their considerable financial and technical support, and not to forget the advisory, steering and organizing committees that did a commendable job in bringing about the XI forum on soil taxonomy and agro-technology transfer to its successful conclusion. And I wish both the foreign and local participants continued efforts in solving the world's sustained food production. Bon voyage.

FIELD TOUR GUIDE.

R. N. Magai
Senior Soil Surveyor

INTRODUCTION

This forum is the eleventh in the series organized internationally by the Soil Management Support Services (SMSS), intended to reach as many soil scientists working in Southerr Africa Sub-region. SMSS is a project that provides technical assistance to less developed countries (LDC) in soil classification, use and management of soils.

The objectives of the forum are:

1. To inform soil scientists in the region about Soil Taxonomy and to enable them to correctly use the system for making and interpreting soil surveys.

2. To enable soil scientists and others intersted in the use and management of soils to meet and to exchange information.

3. To assist in the standarization of techniquesa in the making and utilization of soil resource inventories to foster agrotechnology transfer in the region.

4. As a result of objectives 1, 2, and 3, to strengthen national institutions to achieving the common goal of self-sufficiency in food and fibre production.

As an integral part of the Forum, a field tour has been organized to give an insight into soil classification, land use and management aspects of Zambia's soil resources. The field tour will endeavour to give comprehensive data on what are regarded as benchmark soil sites. The soils on the benchmark sites are assumed to be the most representative in their region of occurence. These sites are intended to be used for intensive basic and adaptive research and the results will be utilized to modify the technologies for local use and to validate the technologies developed elsewhere.

This field tour guide briefly describes the activities of the soil survey unit and the soil science department of Zambia; soils; climate; agro-echological zones; geology and some general remarks about Zambia. Profile descriptions of specific sites are included. Detailed chemical and physical analysis and mineralogical and micro-morphological data are also presented.

The forum has been jointly sponsored and organized by the Soil Survey Unit of the Ministry of Agriculture and Water Development; the Department of Soil Science, University of Zambia; SMSS, NORAD, USAID and ABOS. We greatly appreciate the

financial and material support rendered to this forum by these institutions. The forum could not be what it is without the assistance and guidance of the advisory, steering and organizing committees. We greatly acknowledge their time put into the organization of the forum.

It is hoped that the soil scientists and a few available agronomists will take this opportunity for dialogues and for sharing each others' experience.

Some general remarks about Zambia

Zambia is a country in Southern Central Africa (Latitude 8-18deg.S, Longitude 22-34deg.E) with an extent of 75 million ha. Lusaka is the capital, situated in the centre of the country. The total population consists of 6 million people.

Zambia has a climate with three distinct seasons:

a wet season between November and April
a dry cool season between April and August
a dry hot season between August and November

The mean annual temperature ranges from 18 to 24 deg. centigrade; the hottest areas are the Gwembe and Luangwa valleys. The mean annual rainfall ranges between 600 mm in the South to 1500mm in places in Northern Zambia.

Topographically Zambia is a rather flat country. The main part is formed by an old erosion surface (plateau) of Pre-Cambrian age. Only few quarzite and granite ridges and hills stand out on the plateau. The general altitude of the plateau is 1200 m. Along the Tanzania border the plateau rises to about 1600m. In some areas on the plateau, more towards the centre of the country, locally higher places (up to 1400m) occur.

The plateau areas can be roughly divided as follows:

- the western plateau with Kalahari sand soils
- the southern plateau with "sandveld" soils on metamorphic and igneaus soils (partly Basement complex)
- the middle plateau with "red clay" soils on limestone and schist
- the central plateau with "sandveld" soils on metamorphic rocks (Basement Complex)
- the eastern plateau with "red clay" soils on metamorphic and igneous rocks.

- the north-western plateau with "red clay" soils on sedimentary and metamorphic rocks

- the Copperbelt with a variety of soils and a complex geology

- the northern plateau with "leached sandveld" soils on sedimentary and metamorphic rocks

Zambia has two major river systems:

- Zambezi river with the Kafue and Luangwa rivers as main tributaries

- Luapula river with the Chambeshi river as main tributary, forming part of the Zaire (Congo) river system.

The natural vegetation of Zambia is a quite uniform savanna woodland called "Miombo", consisting of Brachystegia-Julbernardia-isoberlinia species. In the major valleys (Gwembe, Luangwa) Mopane woodland is very common (main species is colophospermum mopane). A third major type of vegetation mainly found on red clay soils is the Munga woodland (with Acacia-Cambretum-terminalia species).

The road system, interlinking the main cities consists of good tarred roads. The main cities are found along the "line of rail" (the railway between Livingstone-Lusaka-Copperbelt). Some main cities, apart from Lusaka, are Ndola and Kitwe (Copperbelt), Livingstone (south), Kabwe (central). Important provincial towns are Chipata (east) Kasama (north), Mansa (Luapula), Solwezi (north-west), Mongu (west) Choma and Mazabuka (south). The Tazara railway starts in Kapiri Mposhi and runs via Kasama to Nakonde (Tunduma) on the Tanzania border and then on to Dar-es-salaam (Tanzania).

About 45% of the population lives in the cities. The degree of urbanization is high. Annual population growth is about 3%. Maize is by far the most important crop. The traditional dish is "Nshima" made of mealie meal (maize flour). Beef cattle plays an important role in the southern parts of the country. Occurence of tsetse fly is a main limitation to cattle farming. Fishing is locally very important. Other main crops besides maize are cassava, sorghum, sunflower, sweet potato, millets, soybean, phaseolus bean, cotton, virginia tobacco, rice and groundnuts.

The majority of the famers are small holders. Their farm size is usually less than 2ha. They practice slash and burn (chitemene) in the northern parts of the country. Branches are cut from trees and burnt on large heaps. Finger millet is normally the first crop to be sown in the ash. Cropping lasts for a few years after which the plot goes back to bush fallow. Often cassava is the last crop in the cultivation cycle.

In the southern regions small holders tend to farm their

fields over longer periods. As the soils are more fertile (and less acid) different land use systems are utilised. Cattle often plays an important role. Maize is the major crop together with groundnuts, beans and sunflower.

The total number of small holders in Zambia is about 600,000. Emergent farmers (few thousands) with farm size ranging from 5 to 100 ha form an important group of farmers which tend to change from traditional to improved ways of farming. A special group of farmers in Zambia are the commercial farmers (about 800). Their farm sizes can be very large. Maize is the main crop. The farms are mechanized and they usually have irrigation facilities in the southern part of the country. Irrigation is especially meant to grow wheat during the dry season alternated with soybean in the rainy season. Cattle ranches form an important part of the commercial farm sector.

The University of Zambia

Introduction.

The University of Zambia came legally into being on 12th November 1965. However, the first academic session did not start until 17th March, 1966. The president of the Republic of Zambia Dr. K.D. Kaunda was formally installed as chancellor on 12th of July 1966.

The main role of the University in nation building is to combine practical service with fulfillment of the historic purposes of a university as a seat of learning, a treasure house of knowledge and a creative centre of research. This two fold objective continues to guide the philosophy of the University of Zambia. Its goals are teaching, research and service relevant to the needs of Zambia and a standard of excellence which will ensure that while these needs are properly and adquately served, the University wins and holds international respect as a seat of scholarship. These objectives have been enshrined in the motto SERVICE AND EXCELLENCE.

Development of the University

The University began in 1966 with three schools: Education, Humanities and Social Science, and Natural Science. But as facilities developed and new needs were recognized, new schools were added: Law (1967), Engineering (1969), Medicine (1970), Agricultural Science (1971), Mines (1973), Business and Industrial Studies (1978), Environmental Studies (1981) and Veterinary Medicine (1983). The present student enrolment is about 5000 students. It is envisaged that eventually the total enrolment will level off at about 8000 students. Because such a number could not be accommodated, academically or residentially, at the main campus in Lusaka, it was decided in 1975 that the University would be developed on a federal basis and that it could comprise two constituent institutions; one at Lusaka and

the other at Ndola. The Ndola Campus opened in July 1978 with the establishment of a school of Business and Industrial studies.

The school of Agricultural Science.

The school of Agricultural Sciences was established in 1971 at the Great East Road Campus of the University of Zambia, in Lusaka. It offers a five year undergraduate programme leading to the degree of Bachelor of Agricultural Sciences. Students are given tuition in five Agricultural Science disciplines, namely agricultural engineering, animal science, crop science, soil science and rural economy and extension education. In the fifth year students opt to specialize in any of the five disciplines. All students are required to do a minimum of 30 weeks of farm practicals before they graduate. This is intended to make them gain some farming skills and expose them to the rural community for which they are being trained to serve.

The Soil Science Department.

The Department of Soil Science is one of the five departments in the School of Agricuture Sciences. The main area of teaching and research are soil chemistry and fertility, soil physical, soil classification and land evaluation. The Department is collaborating in the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). In this endeavour research experiments are being conducted on a number of crops to generate data needed to validate crop simulation models provided by IBSNAT. Once validated these models will be used for agrotechnology transfer within Zambia. The University farm serves as the first IBSNAT site. A meteorological station was set up on the site in June 1984.

Organisation of the Soil Survet Unit in Zambia

The Soil Survey Unit is a section of the Land Use Branch, Ministry of Agriculture and Water Development. Since 1976 the Soil Survey Unit is sponsored by the Norwegian Agency for International Development (NORAD). Phase II of the project ends in 1986 and the project may be extended up to 1989. The total number of personnel is about 90 people of which 11 are expatriates.

The Soil Survey Unit is headed by the Senior Soil Surveyor. Its headquarters is at Mt. Makulu Central Research Station, located at Chilanga, 16km south of Lusaka. Headquarters consists of different sections, notably Soil Correlation, Land Evaluation, National Mapping, Soil Chemistry (including a soil survey and soil advisory laboratory), Soil Information and the Lusaka Provincial Team. Each of the other provinces have their own soil survey team. The Soil Survey Unit operates in decentralized way according to the policy of the Ministry.

In recent times there has been a shift in survey work from

ad-hoc detailed and semi-detailed surveys towards smaller scale surveys. A systematic survey at scale 1;100,000 was started some years ago and the first reports are being compiled. Recently also a 1:250,000 mapping program at district level has started. The national mapping program (at scale 1:1,000,000) has finished North-western Province and is now working in the Northern Province.

Soil Taxonomy plays an important role in soil classification in Zambia together with the FAO/UNESCO legend. Soil Taxonomy is being tested and it works satisfactory in the relative younger landscapes. However, problems are envisaged on the more common old plateau landscapes, where ultisols and oxisols dominate. A series classification has been started since 1981 which aim is to get a relatively easy identification of soil types in the detailed surveys, in which a more or less direct relation is put on further interpretation, especially for agricultural land use planning. A first attempt on a new land evaluation method (based on FAO Framework) is being tested.

The laboratory handles soil survey, soil advisory samples as well as samples for the Zamcan Wheat Research Project. Routine analyses include particle size analysis, organic matter, pH, exchangeable cations and aluminium. Extension of the kind of analysis is currently underway. About 5000, samples are analysed yearly.

A data input system for the soils data bank is being developed in which all soil data will be stored in future.

Enviromental data for the excursion route

In table 1 the data on monthly rainfall, air temperature and soil temperature (at 50cm depth) is given. For convenience the summer and winter temperature averages (acc. to soil taxonomy) are indicated as well.

Agro-ecological zones

Agro-ecological zones in Zambia have been defined by:

- length of the growing period at 70% probability
- occurence of drought within the growing period
- mean monthly temperature during the period December to Feb.
- amount of sunshine during the rainy season
- occurence of frost in the dry season

Thirty six major zones have been mapped, although the data base of 29 stations is low, Later on sub-division have been made on basis of occurrence of specific land use systems, local knowledge about climatic characteristics or major physiographic units like floodplains and swamps.

The growing period is determined by the first and the last

ten day period in which rainfall (at 70% probability) i.e. expected 7 out of 10 years) exceeds half of the potential evapotranspiration (according to FAO methodology). For the southern part of the country the actual season is longer at the beginning because of early planting rains. The end of the growing period depends on the available moisture in the soil.

There is a correlation between length of the growing period at 70% probability and at mean values (as is used by FAO). Comparable data are given below (in days)

70% prob.	80	90	100	110	120	130	140	150	160
mean	135	141	147	152	159	166	173	180	188

In table 2 some climatic data are given for the agro-ecological zones, which we pass during the excursion.

Table 1. Rainfall and air/soil temperature data.

Pedon 1 Mbala (1973 - 1984) Alt. 1673m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	18.3	18.5	18.6	18.6	18.4	16.6	16.8	
Soil Temp. deg C	21.0	21.2	21.5	21.6	21.6	21.5	21.3	
Precipitation mm	250	215	222	120	9	2	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	18.2	20.4	20.6	19.3	18.7	18.6	18.5	17.2
Soil Temp. deg C	21.8	24.0	24.3	22.7	21.5	22.0	21.2	21.5
Precipitation mm	0	3	12	143	243	1219		

Pedons 2, 3, 4 Misamfu (1977 - 1984) Alt. 1536m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	20.1	20.2	20.3	20.0	18.0	16.4	15.8	
Soil Temp. deg C	24.3	24.3	24.0	24.5	24.0	22.7	21.9	
Precipitation mm	304	232	261	104	20	0	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	18.3	21.4	22.4	21.4	20.5	19.6	20.3	16.8
Soil Temp. deg C	24.0	25.7	27.9	26.6	24.5	24.5	24.4	22.9
Precipitation mm	0	3	16	128	256	1326		

Pedon 5 Mpika (1973 - 1984) Alt. 1402m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	19.9	19.9	19.8	19.3	17.6	15.4	15.1	
Soil Temp. deg C	22.5	22.1	22.5	22.9	22.2	20.3	18.9	
Precipitation mm	278	226	187	28	4	1	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	17.5	20.9	22.7	22.1	19.9	19.2	19.9	16.0
Soil Temp. deg C	20.7	23.3	26.5	26.5	23.3	22.6	22.6	20.0
Precipitation mm	1	0	7	96	237	1065		

Pedons 7, 9 Kabwe (1977 - 1984) Alt. 1165m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	21.3	21.5	20.8	19.7	17.4	15.5	15.1	
Soil Temp. deg C	25.8	25.3	25.2	24.7	23.9	22.3	21.2	
Precipitation mm	228	186	136	30	7	0	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	19.1	22.6	24.0	22.8	21.8	20.1	21.5	16.6
Soil Temp. deg C	22.7	26.3	28.3	27.9	26.0	25.0	25.7	22.1
Precipitation mm	0	0	22	105	281	995		

Sum = Summer (December - February)
Win = Winter (June - August)

Pedon 6 Serenje (1973 - 1984) Alt. 1384m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	19.9	20.1	20.3	19.3	17.4	15.2	14.8	
Soil Temp. deg C	23.0	22.8	23.2	23.5	23.2	21.3	20.9	
Precipitation mm	241	291	161	32	1	0	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	16.6	20.1	22.0	21.6	20.1	19.0	20.0	15.5
Soil Temp. deg C	21.9	23.9	25.8	25.4	23.3	23.2	23.0	21.4
Precipitation mm	1	1	12	139	280	1159		

Pedon 8 Ndola (1973 - 1984) Alt. 1270m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	20.6	20.6	20.7	20.2	18.8	16.3	16.3	
Soil Temp. deg C	23.9	23.6	24.4	24.5	23.7	21.5	20.8	
Precipitation mm	307	245	183	39	3	1	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	19.0	22.1	23.8	22.5	20.8	20.1	20.7	17.2
Soil Temp. deg C	22.0	25.0	27.3	26.5	24.0	23.9	23.8	21.4
Precipitation mm	1	2	20	131	280	1212		

Pedon 10 Kafue Polder (1973 - 1984) Alt. 978m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	22.7	22.2	22.2	21.0	19.1	16.5	16.6	
Soil Temp. deg C	25.7	25.5	25.1	24.5	23.0	20.8	20.3	
Precipitation mm	197	149	55	18	6	0	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	18.6	23.5	25.7	24.8	22.3	21.3	22.4	17.2
Soil Temp. deg C	21.3	23.4	27.1	26.5	25.3	24.1	25.5	20.8
Precipitation mm	0	2	15	85	250	777		

Pedon 11 Magoye (1977 - 1984) Alt. 1018m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	23.2	22.6	22.1	21.1	18.9	16.5	17.0	
Soil Temp. deg C	26.4	25.7	24.7	25.0	22.7	20.7	19.7	
Precipitation mm	189	170	89	27	3	0	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	19.7	23.8	25.3	24.9	23.7	21.6	23.2	17.7
Soil Temp. deg C	20.8	24.8	26.9	28.1	27.1	24.4	26.4	20.4
Precipitation mm	0	1	18	92	224	813		

Sum = Summer (December - February)
Win = Winter (June - August)

Pedon 12 Livingstone (1973 - 1984) Alt. 986m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	23.8	23.0	22.9	21.5	18.9	15.8	15.7	
Soil Temp. deg C	27.9	27.6	27.4	27.1	25.2	22.1	21.3	
Precipitation mm	178	161	86	24	1	1	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	18.9	23.8	25.9	25.0	23.4	21.6	23.4	16.8
Soil Temp. deg C	23.3	27.2	29.6	29.4	27.6	26.3	27.7	22.2
Precipitation mm	0	1	23	81	171	727		

Pedon 13 Choma (1973 - 1984) Alt. 1278m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	20.8	20.5	19.8	18.8	16.3	13.6	13.9	
Soil Temp. deg C	24.5	24.3	23.7	23.0	21.5	19.1	18.4	
Precipitation mm	200	185	86	23	6	6	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	16.6	20.7	23.1	22.4	20.6	18.9	20.6	14.7
Soil Temp. deg C	19.6	22.1	25.2	25.8	23.8	22.6	24.2	19.0
Precipitation mm	0	1	22	93	209	831		

Pedon 14 Lusaka International Airport (1973 - 1984) Alt. 1154m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	21.4	21.4	20.9	19.5	17.5	14.9	14.7	
Soil Temp. deg C	24.4	24.2	23.9	22.9	21.5	19.1	18.4	
Precipitation mm	226	172	109	39	4	0	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	17.3	20.9	23.6	23.4	21.5	19.8	21.4	15.6
Soil Temp. deg C	20.0	22.8	25.6	26.0	24.5	22.8	24.4	19.2
Precipitation mm	0	2	20	107	233	912		

Pedon 15 Mt. Makulu (1973 - 1984) Alt. 1213m.

	Jan	Feb	Mar	Apl	May	Jun	Jul	
Air Temp. deg C	21.4	21.2	20.9	20.0	18.3	15.5	15.8	
Soil Temp. deg C	24.9	24.5	24.3	23.7	22.3	20.3	19.7	
Precipitation mm	166	179	60	17	5	0	0	
	Aug	Sep	Oct	Nov	Dec	Year	Sum	Win
Air Temp. deg C	18.3	22.3	24.3	23.2	21.4	20.2	21.3	16.5
Soil Temp. deg C	20.7	23.3	26.1	26.4	24.9	23.4	24.8	20.2
Precipitation mm	0	1	15	97	222	762		

Sum = Summer (December - February)
Win = Winter (June - August)

Table 2. Climatic data of relevant agro-ecological zones.

Zone	10 day periods & length at 70% prob. Early Planting	Growing season Start	Growing season end	Length (days) Gr.s.	Length (days) Whole	Mean Annual Rain	Effective Minimum Rainfall
3ses	N3	D1/2	F3/N1	90	105	600-750	200-250
3sec	N3	D1/2	M1	95	110	600-750	200-250
3n	N3	D1	M1	100	110	700-800	200-250
4en	N2/3	D1	M2	110	125	750-850	250-300
4es	N2	D1	M1/2	105	125	750-900	250-300
5	N3	D1	M2	110	120	700-850	275-325
9	N3	D1	M2	110	120	750-850	300-350
11	N3	D1	M2/3	115	125	750-900	300-450
15ew	N2	N3	M3	130	140	900-1000	400-600
15ee	N2	N3	M3	130	140	900-1100	400-600
18	N3	N3	M3/A1	135	135	1050-1200	600-650
24w	N1/2	N1/2	M3	145	145	950-1150	650-700
24e	N3	N3	M3/A1	135	135	1050-1200	650-700
26sw	N3	N3	A1/2	145	145	1000-1200	550-600
29c	N2	N2	A1/2	155	155	1050-1400	700-750
33	N2	N2/3	A2/3	160	165	1000-1200	700-750

Zone	Estimated occurrence drought periods +	Sunshine hours rainy season	No. of frost days	Mean temp. (Dec-Feb Deg. C Min.	Aver.	Max	Altitude (m)
3ses	4-5, thr	high	4-16	18-19	23-24	27-30	900-1100
3sec	4-5, thr	high	4-16	18-19	23-24	27-30	900-1100
3n	4-5, thr	high	4-16	17-18	22-23	26-29	900-1300
4en	3-4, thr	high	4-16	16-17	21-22	26-27	1000-1200
4es	3-4, thr	high	4-16	16-17	21-22	26-27	1200-1400
5	3-4, J2,F1+	high	4-8	17-18	22-23	26-29	1000-1300
9	2-3, J2,F1+	high	2-8	18-19	23-24	27-30	900-1000
11	1-2, J1-2,F2	high	0-8	17-18	22-23	26-29	900-1300
15ew	1-2, F1	high	4-8	17-18	22-23	26-29	1100-1300
15ee	1-2, F1	high	0-4	17-18	22-23	26-29	1200-1400
18	0-1, J2	high	0-2	15-16	19-21	24-26	1400-1600
24w	0-1, var	high	4-16	17-18	22-23	26-29	1100-1300
24e	0-1, var	high	0-4	16-17	21-22	26-27	1100-1500
26sw	0-1, var	medium	0	16-17	21-22	26-27	1200-1500
29c	0	medium	0	16-17	21-22	26-27	1100-1600
33	0-1,F2,M2	low	0	14-15	18-[illegible]	23-24	1500-1800

Notes:
Capital letters refer to months (J = January etc.)
\+ number of dry ten day periods and when they occur within the growing season.
thr throughout
Sunshine hours: high = more than 850 hours
medium = 700 - 850 hours
low = less than 700 hours

Geology

A description of the major rock types is given below:

Cretaceous system: non-marine sediments and Pleistocene sands

Karroo system: continental sediments, locally overlying basalt

Katanga system: shale, tillite, dolomite, sandstone

Mozambique belt: gneiss, granulite, charnockite with granite, syenite and basic intrusions

Kibaran (basement complex): metasediments, migmatite, gneiss

Ubendices: granite

Pre-Katanga basement: mainly granite, gneiss, migmatite, metasedimentary schist.

Plateau series: quartzite

Luapula-Luitikila beds: sandy and clayey sediments with prominent conglomerates and limestone.

Soils

A small scale soil map of Zambia is given in figure 1, together with a descriptive legend outlining the texture, acidity, drainage, degree of leaching, colour, type of parent rock and physiography. Using the great groups of soil taxonomy, including some phases, a soil map is presented in figure 2.

Land Evaluation

The current system of land evaluation in Zambia is the LUB (Land Use Branch) land capability system in which a soil is placed into land capability units, based on topsoil texture, effective soil depth, slope, wetness, subsoil texture, hindrance to cultivation, and erosion. Each land capability unit has its own definition in terms of productivity for arable crops or grazing. The system was mainly designed to cater for soil conservation measures to be taken in order to avoid erosion.

Since 1984 the Soil Survey Unit is working on a new system of land evaluation based on the FAO framework. The main emphasis in the development of a new system has been on crop suitability. Especially Zambia's main crops have been included: maize, sorghum, cassava, finger millet, bulrush millet, rainfed wheat, dryland rice, paddy rice, sunflower, soybean, groundnut, phaseolus bean, cotton and virginia tobacco.

The first step in the development has been the compilation of the soil and climatic requirements of the main crops. These

requirements are defined in a suitability class system i.e. not only the optimal conditions should be known, but also, and probably more relevant, those circumstances where the suitability of a crop in terms of severity of limitation goes from optimal to sub-optimal, from sub-optimal to marginal and from marginal to (almost) unsuitable. Such requirements are difficult to establish, but with existing knowledge in Zambia (and sources outside) and through the preparation of general crop suitability maps of Zambia, the data base for the major crops is being built up. Other crops can then be included by comparison with the major crops.

The suitability class is determined through a complicated way of finding the most limiting constraints in terms of potential suitability and soil sutability for sustained production. The former is mainly determined by climatic factors, but including the available water holding capacity of the soil. These factors are generally non-manageable. The soil factors include all other relevant factors, most of which can be managed, although costs of management differ widely.

The influence of management on suitability is taken in the second stage. It depends on what the most limiting constraint for a particular crop in which management is appropriate. Therefore these constraints have to known before specific management recommendations can be included into the evaluation. For sake of brevity however, two general classes have been designed:

Low input class: sustained crop production with crop rotation, maintenance liming if required, low level of fertilizer (NPK) input, manual labour and only little protection against soil degradation.

High input class: sustained crop production with crop rotation, initial liming if required, recommended fertilizer application, mechanized labour, soil conservation measures, drainage, flood protection, micronutrient application, ripping. Irrigation is taken as a separate input.

In tables 3 and 4 the land qualities used in the new land evaluation methodology are given, together with the meaning of the suitability classes. Some of the land qualities are very detailed. Whether they are significant in the evaluation depends on the final suitability class. For the higher classes they may have an influence on the final class determination, but at least they are mentioned as possible soil constraints which need further investigation. The suitability classes and their meaning are explained in table 4. It is noted that the evaluation only considers rainy season cropping.

Table 3 list of land qualities

Radiation, (sunshine hours during rainy season)
High temprature (during December to February, esp. for wheat)
Low temperature (December to February for rainy season and July for dry season)
Low humidity (by agro-ecological zone)
High humidity (by agro-ecological zone)
Frost (by zone)
Wind (by zone)
Hail (by zone)
Length growing season at 70% probability (by zone and corrected for AWC and soil drainage conditions)
Total effective minimum rainfall at 70% probability (by zone and corrected for AWC and soil drainage conditions)
Critical periods within the growing season (drought periods occuring regularly and which can be mapped by zone) (by zone and corrected for AWC).
Drought hazard (general drought occurrence during the rainy season) (by zone and corrected for AWC and soil drainage conditions)
Oxygen availability (by soil drainage class and soil moisture regime).
Inherent nutrient availability (by amount of weatherable minerals or minimum exchangeable potassium within 50cm depth)
Phosphate fixation (on amount of free iron in topsoil, depending on the clay content)
Calcium (minmum exchangeable calcium within 50cm depth)
Magnesium (minimum exchangeable magnesium within 50cm depth)
Potassium (average exchangeable potassium within 50cm depth)
Calcium/Magnesium ratio (minimum within 50cm depth)
Calcium/Potassium ratio (minimum within 50cm depth)
Boron (either direct measurement or in relation to pH topsoil)
Copper (depending of texture or in relation with pH topsoil)
Iron (depending on texture or in relation with pH topsoil)
Manganese (actual measurements or in relation with pH topsoil)
Zinc (taken as deficient for all soils under sustained production, but also in relation with pH topsoil)
Molybednum (actual measurements or in relation with pH topsoil)
Sulphur (taken as deficient in all soils, except in the Copperbelt, also in relation with pH topsoil)
Nutrient retention (by cation exchange capacity within 50 cm depth and organic matter content)
Rooting conditions (physical) (by soil depth, gravel content, abrupt textural change, bulk density, structure, consistence)
Rooting conditions (chemical) (especially meant for acid soils in an agro-ecological zone with occurence of drought) (by pH, Al-saturation or calcium content of the subsoil, by zone and corrected for AWC)
Germination/establishment (clayey soils by clay content)
Flooding (by regularity of flooding conditions)
Salinity (by EC measurements)
Alkalinity (by ESP measurements)

Aluminium toxicity (by pH or Al-saturation measurements; for wetlands also the organic matter content)
Free calcium carbonate or sulphate (by measurement)
Manganese toxicity (by pH and soil drainage conditions)
Iron toxicity (by parent material and soil drainage conditions)
Acid sulphate conditions (by pH and organic matter content and possibly sulphur determination)
Workability (by topsoil texture, micro-variability in topsoil texture, occurence of rock outcrops, stones, boulders, consistence and structure topsoil)
Potential for mechanization/landpreparation (by soil depth, wetness occurence of rock outcrops, slope, occurence of anthills)
Ease of puddling (especially for paddy rice) (by texture and mineralogy of topsoil)
Water erosion (by soil erodibity in relation to classification and texture of topsoil and by erosivity estimation, using a Zimbabwean system)
Wind erosion (unknown, but probably by agro-ecological zone and texture)
Physical degradation (by classification and zone)
Chemical degradation (by classification and zone)
Biological degradation (by classification and zone)

Table 4 Suitability classes and their meaning

1. High to very potential
   None to slight constraints
   Yields 50 to more than 100% of reference yield

2. Moderate to very high potential
   Slight to moderate constraints
   Yields 25 to 50% of reference yield

3. Moderate to very high potential
   Severe constraints
   Yields 12.5 to 25% of refernce yield

4. Moderate to very high potential
   Very severe constraints
   Yields 0 to 12.5% of reference yield

4b. Low potential
   None to severe constraints
   Yields 12.5 to 25% of reference yield

5a. Conditionally unsuitable
   None to moderate constraint

5b. Unsuitable

Reference yields of the major crops

Maize;	5	t/ha
Sorghum;	3	t/ha
Cassava;	20	t/ha
Finger millet;	2	t/ha
Bulrush millet;	2	t/ha
Wheat; (rainfed)	2.5	t/ha
Dryland rice;	2	t/ha
Paddy rice;	4	t/ha
Sunflower;	1.5	t/ha
Soybean;	1.5	t/ha
Groundnut;	1.5	t/ha
Phaseolus;	0.8	t/ha
Cotton;	1.8	t/ha
Virginia tobacco;	2	t/ha

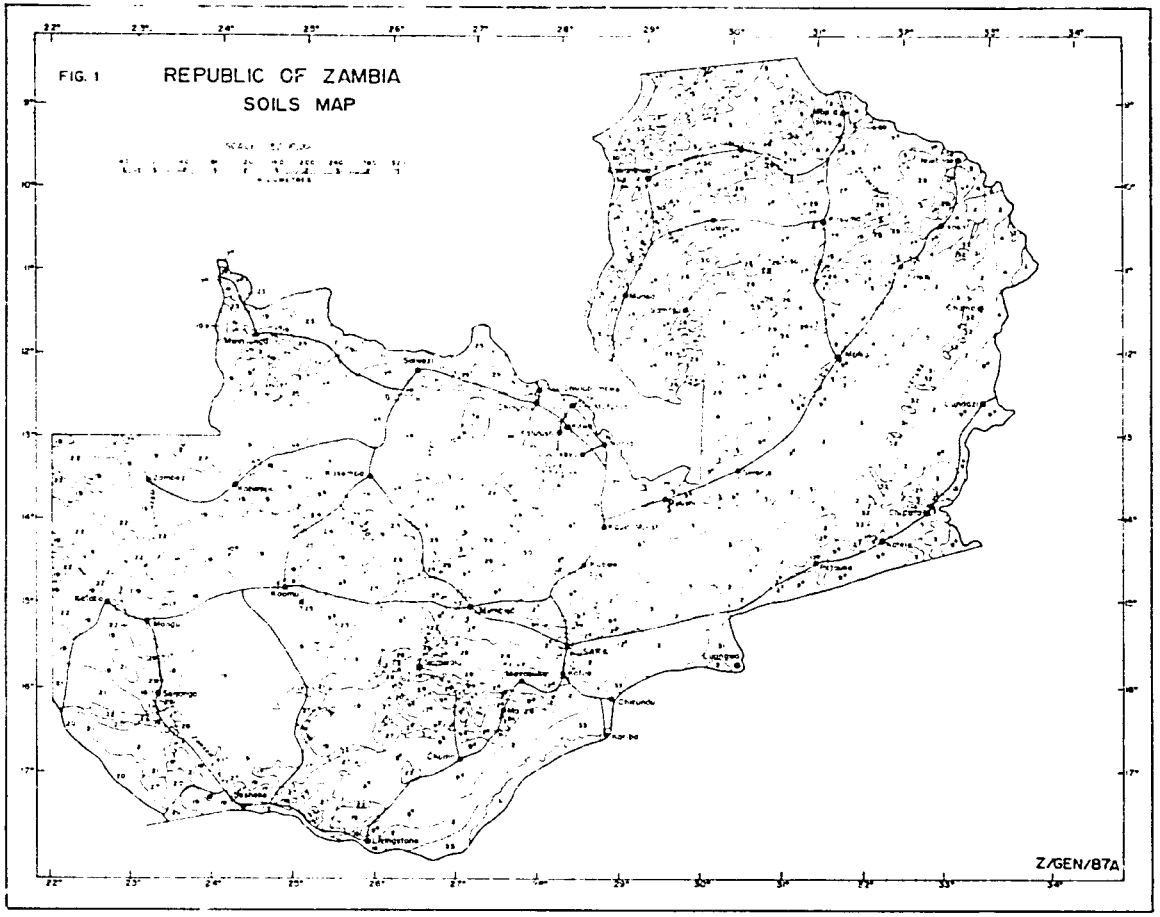


FIG. 1
REPUBLIC OF ZAMBIA
SOILS MAP
Z/GEN/87A

LEGEND OF THE SOIL MAP

2. Shallow and gravely soils derived from acid rocks, occuring in rolling to hilly area, including escarpments ("escarpment zone").

3. Shallow soils derived from acid rocks, occuring on hills or hill ranges.

4. Association of shllow soils occuring on hills (50% unit 2) and moderately leached, strongly to medium acid, reddish to brownish, clayey to loamy soils (with sandy to clayey topsoils) derived from acid to basic rocks (40% unit 9a and 10% unit 10a).

5. Association of shallow soils occuring on hills (50% unit 2 and moderately leached, strongly to medium acid, reddish to brownish, clayey to loamy soils (with coarse to fine loamy topsoils) derived from acid rocks (10% unit 7a)

6. Strongly leached, (very) strongly acid, red, clayey soils (with clayey topsoils) usually with low retention capacity derived from acid rocks.

7a. Strongly leached, strongly to very strongly acid, red to brownish, clayey to loamy soils (with coarse loamy to clayey topsoils) derived from acid rocks (mixture of units 7o snd 7u.

7o. Strongly leached, very strongly acid, red to reddish, clayey and slightly silty soils (with clayey to fine loamy topsoils), usually with low retention capacity, derived from acid rocks.

7u. Strongly leached, strongly to very strongly acid, reddish to brownish, (with clayey to loamy topsoils), derived from acid rocks.

7n. Strongly leached, very strongly acid, red, clayey and slightly silty soils (with clayey topsoils) usually with low retention capacity, derived from acid rocks.

8. Association of strongly (40% unit 7u, 20% unit 7o) and moderately leached (40% unit 9a), red to brownish, strongly to medium acid clayey to loamy soils (with coarse loamy to clayey topsoils), derived from acid rocks.

9a. Moderately leached, strongly to medium acid, reddish to brownish, clayey to loamy soils (with sandy to coarse loamy topsoils), derived from acid rocks.

9b. Moderately leached, strongly to medium acid, yellowish, loamy soils (with sandy to coarse loamy topsoils), derived from acid rocks.

9c. Moderately leached, strongly to medium acid, brownish, clayey soils (with fine loamy topsoils), derived from intermediate to acid rocks occurring in an undulating area.

10a Moderately to strongly leached, strongly to medium acid, red, clayey soils (with clayey topsoils), derived from basic rocks.

10b. Strongly leached, very strongly acid, red, clayey soils (with clayey topsoils), derived from basic rocks.

11. Association of strongly leached, very strongly acid, red to reddish, clayey, slightly silty soils (with fine loamy to clayey topsoils), derived from acid rocks (40% unit 7o) and strongly leached, strongly to very strongly acid, red clayey soils (with clayey topsoils), derived from basic rocks (60% unit 10b).

12a. Slightly leached, medium to slightly acid, red to reddish, clayey soils (with fine loamy to clayey topsoils), derived basic rocks, often in admixture with acid rocks.

12b. Slightly leached, medium to slightly acid, red to reddish, clayey soils (with fine loamy to clayey topsoils), derived from intermediate to basic rocks, occurring in an undulating area.

12x. Shallow, imperfectly drained soils on limestone.

13. Association of slightly leached, strongly to slightly acid, reddish to brownish, clayey to loamy soils (with variable topsoil texture) derived from basic and acid rocks (80% unit 9a and 20% unit 12b).

14. Very strongly leached, very strongly acid, reddish, loamy soils (with fine loamy topsoils), derived from acid rocks.

15. (Very) strongly leached, very strongly acid, dark brownish loamy to clayey soils (with fine topsoils), derived form acid rocks.

16. Shallow soils (with fine loamy to clayey topsoils) on basalt.

17. Reddish, very strongly to medium acid, fine sandy soils (with sandy topsoils) on Kalahari sands.

18. Yellowish, extremely to strongly acid, coarse sandy soils (with coarse sandy topsoils) in a pan area on Kalahari sands.

19. Non to weakly podsolic, very strongly to slightly acid, coarse sandy to coarse loamy soils (with coarse sandy topsoils) on Kalahari sands.

20. Association of moderately leached, probably medium acid to alkalime, reddish to brownish, clayey to loamy soils (with sandy to clayey topsoils), derived from basic rocks, often with acid rock admixture (40% unit 9a or 12a, 10% unit 17) and coarse sandy to coarse loamy, very strongly to slightly acid soils (with coarse sandy topsoils) on Kalahari sands.

21. Poorly to well drained, very strongly acid to alkaline, coarse to fine sandy soils (with coarse sandy topsoils) in large valley dambos or hydromorphic plains.

22. Imperfeclty to very poorly drained, very strongly to medium acid, coarse sandy to coarse loamy soils (with coarse sandy topsoils) in large valley dambos or hydromorphic plains.

23. Association of non to weakly podsolic, very strongly to slightly acid, coarse sandy to coarse loamy soils (with coarse sandy topsoils) on Kalahari sands (65% unit 19 and poorly to very poorly drained, very strongly to medium acid, coarse sandy to coarse loamy soils (with coarse sandy topsoils) in large dambos or plains (35% unit 22).

24. Shallow moderately well to imperfectly drained, loamy soils (with sandy to coarse loamy topsoils) over laterite.

25. Association of moderately to strongly leached, strongly to medium acid, well drained, reddish to yellowish, loamy to clayey soils (with coarse loamy to clayey topsoils) (40% unit 8) and poorly to very poorly drained soils of variable texture and acidity, occurring in large depressions or valleys (60% unit 29).

26. Association of (very) strongly leached, very strongly acid, well drained, brownish to yellowish, loamy to clayey soils (with fine loamy topsoils) (20% unit 14, 60% unit 15) and poorly drained floodplain soils of varible texture and acidity (20% unit 29).

27. Poorly to very poorly drained, clayey, usually alkaline, backswamp soils (with fine loamy to clayey topsoils).

28. Imperfectly to very poorly drained, slightly acid to alkaline clayey floodplain soils (with clayey topsoils).

29. Poorly to very poorly drained floodplain soils of variable texture and acidity.

30. Swamp.

31. (Rift) valley soils of variable texture.

32. Slightly acid to neutral, loamy and clayey, alluvial soils (with coarse to fine loamy topsoils) along tributaries.

33. Slightly acid to alkaline, (rift) valley loamy and clayey soils (with coarse to fine loamy topsoils) in a (gently) undulating area.

NOTES

- Where two textures are mentioned in the description, the first one is dominant in the unit.

- "Coarse sandy" is used in a relative way in comparison with "fine sandy".

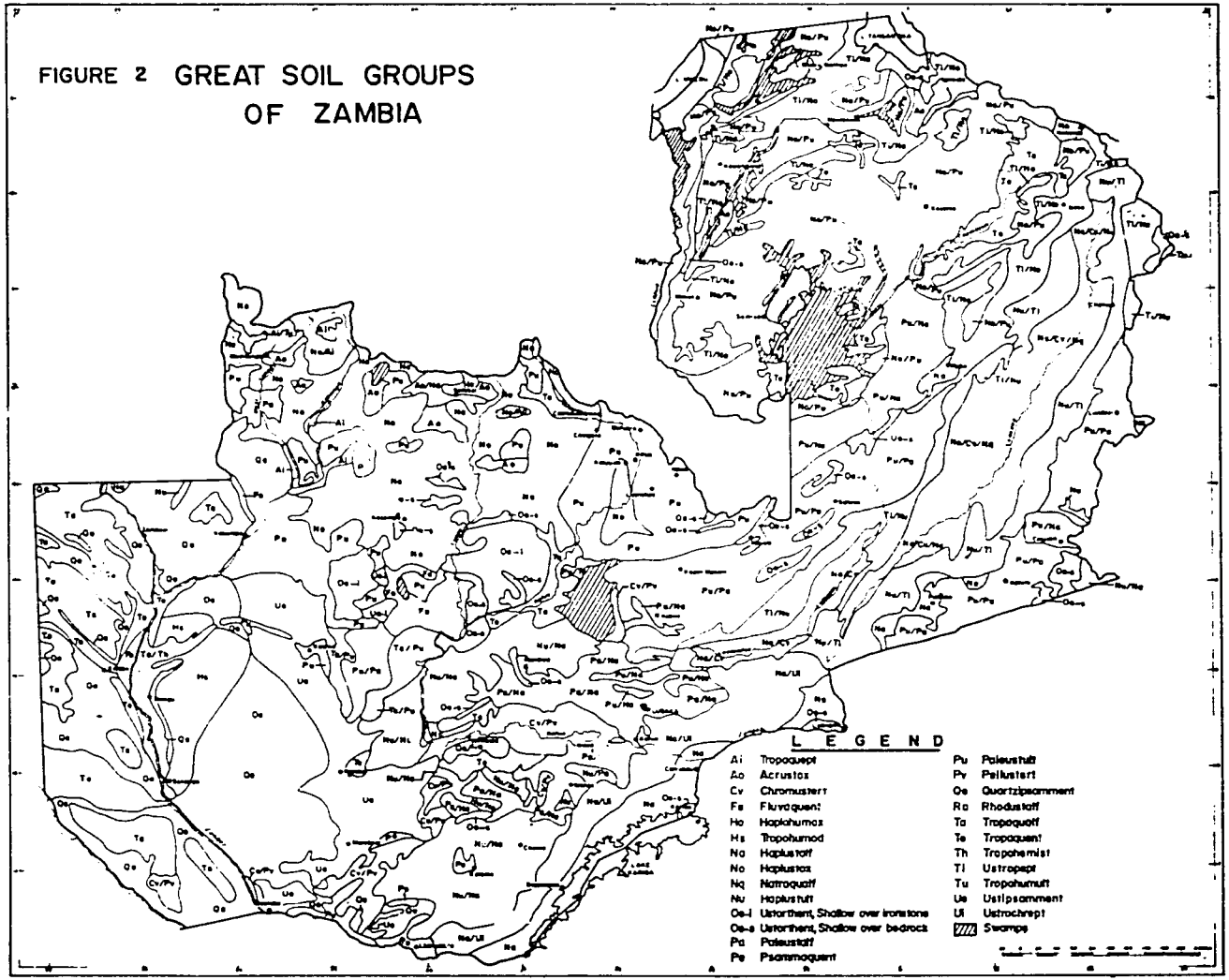
- Soil drainage conditions are only mentioned for units in which hydromorphic soils form a major part of the unit. In other cases it may be assumed that the soils are dominantly well to moderately well drained, with exception of sandy soils, which can be (somewhat) excessively drained.

- The colours of the soils are indicated by the following ranges in colour hue:
  red (2.5YR-10YR),
  reddish to brownish (2.5-7.5YR),
  brownish to yellowish (7.5YR-10YR)
  Yellowish (10YR and yellower)
- The degree of leaching is correlated with the following base saturation values (B-horizon within 1.0m depth):
  Slightly leached (more than 50%)
  Moderately leached (25-50%)
  Strongly leached (10-25%)
  Very strongly leached (less than 10%)

- A low retention capacity means a sum of exchangeable bases and exchange acidity of less than 2.5 me/100g clay.

- Acidity in relation to pH ($CaCl_2$):
  extremely acid (less than 4.0)
  very strongly acid (4.0-4.5),
  strongly acid (4.5-5.0),
  medium acid (5.0-5.5),
  slightly acid (5.5-6.0),
  neutral (6.0-6.5),
  alkaline (6.5-7.5),
  strongly alkaline (more than 7.5)

FIGURE 2 GREAT SOIL GROUPS OF ZAMBIA



Schedule for the field trip

Friday 19

Departure UNZA at 07.00 hrs
Lusaka-Kabwe-Kapiri Mposhi 07.00-09.30
Kapiri Mposhi-Mkushi-Serenje-Kundalila falls 10.00-1300
Night at Kasama FTC

Saturday 20

Departure Kasam FTC at 7.30 hrs
Kasama/Misamfu Regional Research Station 07.30-08.00
Pedon 1 08.00-10.00
Pedon 2 10.30-12.30
Pedon 3 14.00-16.00
Soil Productiviry project 16.15-17.15
Misamfu-Kasama 17.15-17.45
Night at Kasama FTC

Sunday 21

Departure Kasama FTC at 07.30 hrs
Kasama-Mbala 07.30-09.30
Pedon 4 09.30-11.30
Mbala-Mpulungu (Lake Tanganyika) 11.30-12.00
Mpulungu-Mbala 13.00-13.30
Moto moto Museum 13.30-15.00
Mbala-Kasama 15.00-17.00
Night at Kasama FTC

Monday 22

Departure Kasama FTC at 07.30 hrs
Kasama-Mpika 07.30-10.30
Pedon 5 10.30-12.30
Intergrated rural development project 14.00-17.00
Night at ZCA (Zambia Agricultural College, Mpika)

Tuesday 23

Departure ZCA at 07.30 hrs
Mpika-Serenje-Mkushi 07.30-12.00
Pedon 6 13.00-15.00
Mkushi-Kapiri Mposhi-Kabwe 15.30-18.00
Night in Kabwe

Wednesday 24

Departure Kabwe at 07.00 hrs
Kabwe-Kapiri Mposhi-Mpongwe 07.00-09.00
Pedon 7 09.00-11.00
Mpongwe-Kapiri Mposhi 11.00-12.30

Kapiri Mposhi-Mulungushi farm 13.30-14.05
Pedon 8 14.15-15.15
Night in Kabwe

Thursday 25

Departure Kabwe 07.30 hrs
Kabwe-Liteta 07.30-08.30
Pedon 9 08.30-10.30
Liteta-Lusaka 10.30-12.00
Lusaka-Kafue 13.00-14.00
Pedon 10 14.00-16.00
Night at River Motel, Kafue.

Friday 26

Departure River Motel at 07.00 hrs
Kafue-Mazabuka-Magoye 07.00-08.30
Pedon 11 08.30-10.30
Magoye-Mazabuka 10.30-11.00
Nakambala Sugar Estate 11.00-12.30
Mazabuka-Choma-Livingstone 13.30-17.30
Night at Rainbow Lodge

Saturday 27

Departure Rainbow Lodge at 07.30 hrs
Livingstone-Kabuyu 07.30-08.00
Pedon 12 08.00-10.00
Kabuyu-Livingstone 10.00-10.30
Visit to museum 10.30-12.00
Victoria Falls, Culture Village, game park, boat trip 14.00-17.00
Night at Rainbow Lodge

Sunday 28

Departure Rainbow Lodge 08.00 hrs
Livingstone-Choma 08.00-10.00
Pedon 13 10.00-12.00
Choma-Mazabuka-Kafue-Lusaka 13.00-17.00
Night in Lusaka

Monday 2

Lusaka (University)-University farm (30 min.)
Pedon 14

Tuesday 30 (afternoon)

Lusaka (University) - Makeni (30 min.)
Pedon 15

Pedon 1

Print date: 10-21-1987

Pedon: Mufulira NSSL ID #: 84P0507
Soil Survey # S83-FN-990-001
Location: Misamfu Reg. Res. St. 8 km N of Kasama NOP Zambia. Pit located about 250 m E of station headquarters.
Latitude: 10-10- -S Longitude: 031-10- -E
Classification: Clayey, kaolinitic, isohyperthermic Oxic Paleustult
Physiography: Upland slope in plateaus or tablelands
Geomorphic Position: summit interfluve
Microrelief:
Slope Characteristics: .5% plane, southeast facing
Elevation: 1384 m MSL
Precipitation: 1360 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderately rapid
Air Temp. (Centigrade): Ann: 198 Sum: 200 Win: 170
Soil Temp. (Centigrade): Ann: 225 Sum: 221 Win: 205
Drainage: Well drained Land Use:
Stoniness:
Particle Size Control Section: 20 to 70 cm Runoff: Slow
Parent Material: residuum from metamorphic-acidic material
Vegetation Codes: Weather Station: MISAMF
Diagnostic Horizons: , 20 to 153 cm Argillic
Described by: D. Hallbick O. Spaargaren and C. Kalima Date: 11/83

Termite mounds occur at a distance of 10 to 15 m from the pit. Cracks 2 to 3 mm wide extend from the base of the AB horizon downwards 80 to 100 cm apart. Common termite chambers 4 to 5 in diameter connected by 1 cm channels.

A--0 to 10 cm; dark yellowish brown (10YR 4/4) sandy loam; dark yellowish brown (10YR 3/4) moist; weak fine and medium subangular blocky structure; slightly hard, slightly sticky, nonplastic; many fine roots throughout and common medium roots throughout; many very fine and fine interstitial pores; strongly acid (pH=5.5, Hellige-Troug); clear smooth boundary.
In Ah AB Bw1 and Bw2 common termitechambers generally 4 to 5 cm in diameter inter connected by channels about 1 cm in diameter.
84P2778

AB--10 to 20 cm; reddish yellow (7.5YR 6/6) sandy clay; strong brown (7.5YR 4/6) moist; moderate fine and medium subangular blocky structure; hard, very sticky, plastic; common fine roots throughout and few medium roots throughout; many fine and medium continuous tubular and common very fine and fine interstitial pores; few patchy distinct-thin brown to dark brown (7.5YR4/4) organic coats on faces of peds; strongly acid (pH=5.2, Hellige-Troug); clear smooth boundary. Amount of chambers decrease with depth.
84P2779

Bt1--20 to 43 cm; reddish yellow (7.5YR 6/6) clay; strong brown (7.5YR 4/6) moist; weak fine and medium subangular blocky structure; hard, very sticky, plastic; very few very fine roots throughout and very few fine and medium roots throughout; common fine and medium continuous tubular and few very fine and fine interstitial pores; few patchy faint-thin brown to dark brown (7.5YR4/4) organic coats on faces of peds; very strongly acid (pH=5.0, Hellige-Troug); gradual smooth boundary.
Cracks 2 to 3 mm wide extend from the base of the AB horizon downwards 80 to 100 cm apart.
84P2780

Bt2--43 to 71 cm; reddish yellow (7.5YR 6/6) clay; strong brown (7.5YR 5/6) moist; weak fine and medium subangular blocky structure; hard, slightly sticky, plastic; very few fine roots throughout; few to common fine and medium continuous tubular and few very fine and fine interstitial pores; few patchy faint-thin clay films on horizontal faces of peds and clay films between sand grains; extremely acid (pH=4.2, Hellige-Troug); diffuse smooth boundary.
84P2781

Bt3--71 to 132 cm; reddish yellow (7.5YR 6/6) clay; yellowish red (5YR 5/8) moist; weak medium subangular blocky structure; slightly hard, slightly sticky, plastic; very few fine roots throughout; few to common fine and medium continuous tubular and few very fine and fine interstitial pores; extremely acid (pH=4.2, Hellige-Troug); diffuse smooth boundary.
84P2782

Bt4--132 to 153 cm; reddish yellow (5YR 7/8) clay; yellowish red (5YR 5/6) moist; weak C GR structure; slightly hard, slightly sticky, plastic; very few fine roots throughout; few to common fine and medium continuous tubular and few very fine and fine interstitial pores; extremely acid (pH=4.0, Hellige-Troug).
84P2783

S84FN-990-001

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; CLAYEY, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTULT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 507, SAMPLES 84P2778-2783
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- TOTAL CLAY LT .002	-2-- TOTAL SILT .002 -.05	-3-- TOTAL SAND .05 -2	-4-- TOTAL FINE LT .0002	-5-- CLAY CO3 LT .002	-6-- SILT FINE .002 -.02	-7-- SILT COARSE .02 -.05	-8-- SAND VF .05 -.10	-9-- SAND F .10 -.25	-10-- SAND M .25 -.50	-11-- SAND C .5 -1	-12-- SAND VC 1 -2	-13-- COARSE FRACTIONS(MM) WEIGHT 2 -5	-14-- COARSE FRACTIONS(MM) WEIGHT 5 -20	-15-- COARSE FRACTIONS(MM) WEIGHT 20 -75	-16-- COARSE FRACTIONS(MM) WEIGHT .1- 75	-17-- (>2MM) WT PCT OF WHOLE SOIL
			<- - - - - - - - - - - - PCT OF <2MM					(3A1) - - - - - - - - - - - - ->							<- PCT OF <75MM(3B1)->		
84P2778S	0- 10	A	16.7	10.2	73.1	8.7		3.8	6.4	12.7	34.7	21.5	3.8	0.4	--	--	--	60	--
84P2779S	10- 20	AB	29.1	10.6	60.3	15.7		3.9	6.7	11.7	28.0	16.6	3.7	0.3	--	--	--	49	--
84P2780S	20- 43	BT1	45.3	8.6	46.1	25.9		3.1	5.5	10.3	20.3	12.2	2.9	0.4	--	--	--	36	--
84P2781S	43- 71	BT2	48.1	8.8	43.1	27.8		3.2	5.6	9.8	18.0	11.0	3.0	0.5	--	--	--	33	--
84P2782S	71-132	BT3	53.3	8.1	38.6	29.5		3.1	5.0	9.3	16.5	9.3	2.9	0.6	--	--	--	29	--
84P2783S	132-153	BT4	49.4	8.9	41.7	27.0		3.3	5.6	10.0	19.0	9.9	2.3	0.5	TR	--	--	32	--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A	DITH-CIT EXTRACTABLE FE 6C2B	DITH-CIT EXTRACTABLE AL 6G7A	DITH-CIT EXTRACTABLE MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1 PCT	ATTERBERG LIMITS PI 4F <0.4MM	BULK DENSITY FIELD MOIST 4A3A	BULK DENSITY 1/3 BAR 4A1D	BULK DENSITY OVEN DRY 4A1H	COLE WHOLE SOIL 4D1 CM/CM	WATER CONTENT FIELD MOIST 4B4	WATER CONTENT 1/10 BAR 4B1C	WATER CONTENT 1/3 BAR 4B1C	WATER CONTENT 15 BAR 4B2	WRD WHOLE SOIL 4C1 CM/CM
				<- PERCENT	OF <2MM -->							<- - G/CC - - ->				<- - -PCT OF <2MM - ->				
0- 10	0.85	0.053			1.5	0.2	TR	0.22	0.41		NP		1.47	1.54	0.016			10.8	6.8	0.06
10- 20	0.57	0.042			1.8	0.3	TR	0.15	0.33				1.50	1.55	0.011			14.3	9.7	0.07
20- 43	0.37	0.033			2.1	0.4	--	0.11	0.32	37	16		1.47	1.52	0.011			18.2	14.5	0.05
43- 71	0.28				2.1	0.4	--	0.10	0.32				1.45	1.50	0.011			20.0	15.4	0.07
71-132	0.20				2.3	0.5	--	0.10	0.32				1.32	1.37	0.012			21.1	16.8	0.06
132-153	0.18				2.2	0.4	--	0.09	0.32	39	15		1.28	1.32	0.010			18.9	16.0	0.04

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-001
CLASSIFICATION: SND ; CLAYEY, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 507, SAMPLE 84P2778-2783

PRINT DATE 10/19/87

DEPTH (CM)	-1-- (- NH4OAC EXTRACTABLE BASES -) CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID- ITY 6H5A	-7-- EXTR AL 6G9A	-8-- (- - - -CEC - - -) SUM CATS 5A3A	-9-- NH4- OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- -BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- (- - - -PH - - -) KCL IN 8C1G	-19- CACL2 .01M 8C1F 1:2	-20- H2O 8C1F 1:1
	<- - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - ->										<- - - - -PCT - - - ->									
0- 10	0.2	0.4	TR	0.2	0.8	4.1	0.8	4.9	3.7	1.6	50	16	22					4.1	4.3	5.1
10- 20	--	0.3	TR	0.3	0.6	4.5	1.1	5.1	4.3	1.7	65	12	14					4.0	4.2	5.1
20- 43	--	0.3	TR	0.2	0.5	5.7	1.7	6.2	5.1	2.2	77	8	10					4.0	4.2	4.9
43- 71	--	0.2	TR	0.2	0.4	5.4	1.6	5.8	4.8	2.0	80	7	8					4.0	4.2	5.1
71-132	--	0.2	TR	0.2	0.4	5.9	1.8	6.3	5.3	2.2	82	6	8					4.0	4.3	5.0
132-153	--	0.1	TR	0.1	0.2	5.4	2.5	5.6	4.6	2.7	93	4	4					4.0	4.3	5.4

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -) (- - - - - - - CLAY - - - - - - - -)(- - -) -) (- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM (- - - - - <2U - - - -)(- -<2U - -) RES WEATH 7A2I 7A2I 7A2I 7A2I 7A3 7A3 7B1A 7B1A <- RELATIVE AMOUNTS -> <- - - - -PCT - - - ->
0- 10	
10- 20	
20- 43	KK 5 MI 2 GE 1 KK37 99 WE 1
43- 71	KK 5 MI 2 GE 1 KK49 99 WE 1
71-132	
132-153	

AVERAGES, DEPTH 20- 70: PCT CLAY 47 PCT .1-75MM 34

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MI MICA GE GOETHITE WE WEATH MIN

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-001
CLASSIFICATION: SND ; CLAYEY, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 507, SAMPLE 84P2778-2783

PRINT DATE 10/19/87

DEPTH (cm)	FRACTION	X-RAY 7A2i peak size	X-RAY	CLAY MINERALOGY (<.002mm) THERMAL DTA 7A3b	THERMAL TGA 7A4b	ELEMENTAL SiO2	AL2O3	Fe2O3	MgO	CaO	K2O	Na2O	SURF AREA M2/G	INTERPRETATION
20- 43	TCLY	KK 5 MI 2 GE 1	KK37					6.6			1.2			
43- 71	TCLY	KK 5 MI 2 GE 1	KK49					6.7			1.2			

DEPTH (cm)	FRACTION	X-RAY 7A2i Peak Size	X-RAY	SAND - SILT MINERALOGY (2.0-0.002mm) THERMAL DTA 7A3b	THERMAL TGA 7A4b	TOT RE	OPTICAL GRAIN COUNT 7B1a Percent							INTERPRETATION
20- 43	FS					99	RE99	WE 1						
43- 71	FS					99	RE99	WE 1						

KIND OF MINERAL:

KK kaolinite MI mica GE goethite RE resist min WE weath min

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 1 - Micro-morphological observations (L. Chileshe)

Summary of observations concerning samples at 4, 13, 120, and 127 cm depth. Skeleton grains are mainly of small to medium sand fractions and small silt fractions. Determination of the compositions of the grains proved difficult due to the dark coloured matter, probably organic matter and oxides of iron, coating and bridging must of the grains. For proper optical elucidation of the grains, the samples should be pretreated with hydrogen peroxide and hydrochloric acid to remove organic matter and/or iron oxihydrate-clay complexes. The micro structure is some what loose and composed of irregular blocky peds in all samples except in the topmost sample where the bridge structure is common. The related distribution pattern varies from being intertextic in the top horizon to being agglomeraplasmic in the B. horizon. Voids are irregular and ortho with interconnected vughs throughout the profile. A few Glaebules are evedent in the lower part of the profile. The plasmic fabric varies from silasepic in the topmost sample to volskel-masepic fabric in the control section.
The other characteristic feature observed in this profile is the presence in significant amounts of illuviation cutans characterized by crescentic laminations and showing distinctive black extinction bands (under crossed nicols) typical of strongly orientated clay coatings.

PEDON 1 - Land evaluation (W. Veldkamp)

The soil is not very productive for annual cropping. If it is not going to be used for crop production lime applications over several years should be considered; also K and S should be applied, besides the normal NP-application, maybe Zn, B and Mo are necessary. Soil conservation measures to counteract physical and chemical degradation have to be taken.

It would be better to use this soil for perenial, acid tolerant crops like coffee or for acid tolerant grass/legume pasture (provided the tsetse control is effective).

Rating of land qualities; pedon 1

POTENTIAL CONSTRAINTS	low inputs	high inputs
radiation	1	1
high temperature	2	2
high humidity	2	2
lenghth growing season (70% p.)	155	155 (days)
min. eff. rainfall (70% p.)	725	725 (mm)
occurrence drought	x	x
SOIL CONSTRAINTS		
nutrient reserves	1	-
calcium	3	-
magnesium	2	-
potassium	2	-
Ca/Mg	3	-
Ca/K	2	-
boron	2	-
zinc	1	-
Molybdenum	3	1
sulphur	3	-
nutrient retention	3	2
rooting conditions (physical)	1	1
rooting conditions (chemical)	x	-
germination/establishment	1	1
heavy topsoil	2	2
aluminium toxicity	4	3
workability	1	1
mechanization/land preparation	1	1 a/hills
ease of puddling	3	3
physical degradation	3	2
chemical degradation	3	2
biological degradation	2	-

Explanation of ratings:

- no constraint
x special drought constraint
1 slight constraint
2 moderate constraint
3 severe constraint
4 very severe constraint

PEDON 1 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	4a	A	2	A	PKS, lime,degradation protection
Sorghum	3	A	2	G	S, lime, degradation protection
Cassava	3	G	2	W	KS, degradation protection
F/millet	3	G	2	G	S, degradation protection
B/millet	4a	A	3	A	Lime
Wheat	4a	A	3	T	Lime
Dryl. rice	3	G	2	D	S, lime, degradation protection
Paddy rice	5b	P	5b	P	----------
Sunflower	4a	A	3	A	Lime
Soyabean	4a	A	3	A	Lime
Groundnut	3	A	2	G	S,lime,degradation protection
Ph/bean	4a	A	3	A	Lime
Cotton	5b	A	5b	A	---------
V/tobacco	3	Ht,A	3	Ht	(lime)

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 2

Print date: 10-21-1987

Pedon: Misamfu NSSL ID #: 84P0509
Soil Survey # S83-FN-990-003
Location: Misamfu Reg. Res. St. 8 km N of Kasama NOP Zambia. Pit located about 400 m S of station headquarters.
Latitude: 10-10- -S Longitude: 031-10- -E
Classification: Fine-loamy, siliceous, isohyperthermic Typic Haplustox
Physiography: Upland slope in plateaus or tablelands
Geomorphic Position: summit interfluve
Microrelief:
Slope Characteristics: .5% plane, southeast facing
Elevation: 1384 m MSL
Precipitation: 1360 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderately rapid
Air Temp. (Centigrade): Ann: 198 Sum: 200 Win: 170
Soil Temp. (Centigrade): Ann: 225 Sum: 221 Win: 205
Drainage: Well drained Land Use:
Stoniness:
Particle Size Control Section: 25 to 100 cm Runoff: Very slow
Parent Material: residuum from metamorphic-acidic material
Vegetation Codes: Weather Station: MISAMF
Diagnostic Horizons: 0 to 10 cm Ochric, 21 to 146 cm Oxic
Described by: D. Hallbick O. Spaargaren and L. Bustness Date: 11/83

1. Described when dry. 2. Data standard acid. 3. Feel is within range of Oxisols. 4. Has less clay and less red than site 2.

A--0 to 10 cm; brown to dark brown (7.5YR 4/2) sandy loam; dark brown (7.5YR 3/2) moist; weak fine and medium crumb structure; slightly hard, nonsticky, plastic; many fine roots throughout and few medium roots throughout; many fine and medium continuous tubular and many very fine interstitial pores; clear smooth boundary.
84P2790

AB--10 to 21 cm; brown (7.5YR 5/4) sandy loam; strong brown (7.5YR 4/6) moist; I fine and medium subangular blocky structure; slightly hard, nonsticky, plastic; common fine and medium roots throughout and few very coarse roots throughout; many fine and medium continuous tubular and many very fine interstitial pores; clear smooth boundary.
84P2791

Bw1--21 to 48 cm; reddish yellow (7.5YR 6/6) sandy clay loam; yellowish red (5YR 5/6) moist; massive parting to strong very fine granular; slightly hard, slightly sticky, plastic; common fine to coarse roots throughout; many fine and medium continuous tubular and many very fine interstitial pores; clear smooth boundary.
84P2792

Bw2--48 to 80 cm; reddish yellow (7.5YR 6/6) sandy clay loam; yellowish red (5YR 5/6) moist; massive parting to strong very fine granular; slightly hard, slightly sticky, plastic; few fine to coarse roots throughout; few to common fine and medium continuous tubular and many very fine interstitial pores; gradual smooth boundary.
In Bw2 and Bw3 horizons chambers of termites and burrows of beetles occur. Also two bird nests occur in these two horizons.
84P2793

Bw3--80 to 119 cm; reddish yellow (7.5YR 6/6) sandy clay; yellowish red (5YR 5/6) moist; massive parting to strong very fine granular; soft, very sticky, plastic; few fine and medium roots throughout; very few fine and medium continuous tubular and many very fine and fine interstitial pores; gradual smooth boundary.
In Bw3 horizon locally a pan like layer occurs due to termite activity.
84P2794

Bw4--119 to 146 cm; reddish yellow (7.5YR 6/6) sandy clay; yellowish red (5YR 5/8) moist; massive parting to strong very fine granular; soft, slightly sticky, plastic; very few fine and medium roots throughout; very few fine and medium continuous tubular and many very fine and fine interstitial pores.
84P2795

S84FN-990-003

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; FINE-LOAMY, SILICEOUS, ISOHYPERTHERMIC TYPIC KANDIUSTULT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 509, SAMPLES 84P2790-2795
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- TOTAL CLAY LT .002 <- PCT OF <2MM	-2-- TOTAL SILT .002 -.05	-3-- TOTAL SAND .05 -2	-4-- CLAY FINE LT .0002	-5-- CLAY CO3 LT .002	-6-- SILT FINE .002 -.02 (3A1)	-7-- SILT COARSE .02 -.05	-8-- SAND VF .05 -.10	-9-- SAND F .10 -.25	-10- SAND M .25 -.50	-11- SAND C .5 -1	-12- SAND VC 1 -2	-13- COARSE FRACTIONS(MM) WEIGHT 2 -5 <- PCT OF <75MM(3B1)->	-14- 5 -20	-15- 20 -75	-16- >2MM .1- 75 PCT OF WHOLE SOIL
84P2790S	0- 10	A	18.3	3.7	78.0			1.4	2.3	7.5	33.1	30.3	6.7	0.4	TR	--	--	70 --
84P2791S	10- 21	AB	18.8	3.6	77.6			1.3	2.3	7.2	36.5	28.1	5.5	0.3	TR	--	--	70 --
84P2792S	21- 48	BW1	24.7	2.6	72.7			0.3	2.3	7.1	33.5	26.6	5.1	0.4	--	--	--	66 --
84P2793S	48- 80	BW2	29.9	2.7	67.4			0.5	2.2	7.2	28.8	25.1	5.9	0.4	--	--	--	60 --
84P2794S	80-119	BW3	29.7	2.8	67.5			0.5	2.3	7.4	29.3	24.6	5.8	0.4	--	--	--	60 --
84P2795S	119-146	BW4	32.6	4.0	63.4			1.1	2.9	8.5	28.1	21.5	4.8	0.5	--	--	--	55 --

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A <- PERCENT	DITH-CIT EXTRACTABLE FE 6C2B OF	AL 6G7A <2MM -->	MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1 PCT	PI 4F <0.4MM	BULK DENSITY FIELD MOIST 4A3A <-	1/3 BAR 4A1D G/CC -	OVEN DRY 4A1H ->	COLE WHOLE SOIL 4D1 CM/CM	WATER CONTENT FIELD MOIST 4B4 <-	1/10 BAR 4B1C -PCT OF	1/3 BAR 4B1C <2MM	15 BAR 4B2 - ->	WRD WHOLE SOIL 4C1 CM/CM
0- 10	1.50				1.1	0.2	TR	0.30	0.39	20	4		1.36	1.44	0.019			11.6	7.1	0.06
10- 21	0.81				1.1	0.2	TR	0.16	0.36				1.37	1.41	0.010			10.4	6.8	0.05
21- 48	0.39				1.2	0.2	--	0.08	0.32	19	4		1.44	1.44	--			13.7	8.0	0.08
48- 80	0.26				1.3	0.2	--	0.06	0.32				1.38	1.41	0.007			11.6	9.5	0.03
80-119	0.18				1.2	0.2	--	0.05	0.31	27	12		1.36	1.39	0.007			11.6	9.2	0.03
119-146	0.15				1.4	0.3	--	0.05	0.32				1.29	1.36	0.018			13.2	10.5	0.03

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-003
CLASSIFICATION: SND
NATIONAL SOIL SURVEY LABORATORY

; FINE-LOAMY, SILICEOUS, ISOHYPERTHERMIC TYPIC KANDIUSTULT
; PEDON 84P 509, SAMPLE 84P2790-2795

PRINT DATE 10/19/87

DEPTH (CM) -1--	(- NH40AC EXTRACTABLE BASES -) CA 5B5A 6N2E -2--	MG 5B5A 6Q2D -3--	NA 5B5A 6P2B -4--	K 5B5A 6Q2B -5--	SUM BASES -5--	ACID-ITY 6H5A -6--	EXTR AL 6G9A -7--	(- - - -CEC - - -) SUM CATS 5A3A -8--	NH4-OAC 5A8B -9--	BASES + AL 5A3B -10-	AL SAT 5G1 -11-	-BASE SUM 5C3 -12-	SAT-NH4 OAC 5C: -13-	CO3 AS CACO3 <2MM 6E1G -14-	RES. OHMS /CM 8E1 -15-	-16-	COND. MMHOS /CM 8I -17-	(- - - -PH - - -) KCL 1N 8C1G -18-	CACL2 .01M 8C1F 1:2 -19-	H2O 8C1F 1:1 -20-
	<- - - - - - - - - - - -				-MEQ / 100 G	- - - - - - - - - - - -				->	<- - - -		-PCT	- - - ->						
0- 10	1.3	1.3	TR	0.2	2.8	5.1		7.9	5.5			35	51					4.8	4.9	5.9
10- 21	--	0.2	TR	0.1	0.3	4.6	1.1	4.9	3.1	1.4	79	6	10					4.2	4.2	5.2
21- 48	--	0.2	TR	--	0.2	3.2	0.7	3.4	1.9	0.9	78	6	11					4.0	4.3	5.0
48- 80	--	0.2	TR	--	0.2	2.6	0.6	2.8	1.8	0.8	75	7	11					4.2	4.3	5.1
80-119	--	0.1	TR	--	0.1	2.6	0.6	2.7	1.4	0.7	86	4	7					4.2	4.4	5.4
119-146	--	0.1	TR	--	0.1	2.8	0.6	2.9	1.7	0.7	86	3	6					4.5	4.6	5.5

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - - - -) (- - - - - - - CLAY - - - - - - - - - - -) (- - - - X-RAY - - - -)(- - -) (- - - - - <2U - - - -)(- -DTA - -)(- -<2U - -) 7A21	7A21	7A21	7A21	7A3	7A3	TOTAL RES 7B1A	DOM WEATH 7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT	- - - ->		
0- 10	KK 5	GE 2	VR 1		KK34		99	WE 1
10- 21	KK 5	GE 2	GI 1		KK58	GITR	99	WETR
21- 48								
48- 80								
80-119								
119-146								

AVERAGES, DEPTH 25-100: PCT CLAY 28 PCT .1-75MM 62

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE GE GOETHITE VR VERMICULITE WE WEATH MIN GI GIBBSITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

PRINT DATE 10/19/87

S84FN-990-003 ; FINE-LOAMY, SILICEOUS, ISOHYPERTHERMIC TYPIC KANDIUSTULT
CLASSIFICATION: SND ; PEDON 84P 509, SAMPLE 84P2790-2795
NATIONAL SOIL SURVEY LABORATORY

DEPTH (cm)	FRACTION	X-RAY	7A2i	peak size	THERMAL	DTA	7A3b	Percent	TGA	7A4b	Percent	CLAY MINERALOGY (<.002mm)	SiO2	AL2O3	Fe2O3	MgO	CaO	K2O	Na2O	ELEMENTAL	7C3	SURF AREA	M2/G	INTERPRETATION
21- 48	TCLY	KK 5	GE 2	VR 1								KK34						0.2						
80-119	TCLY	KK 5	GE 2	Gl 1								KK58 Gltr				5.3		0.3						
21- 48	FS																							
80-119	FS																							

DEPTH (cm)	FRACTION	X-RAY	7A2i	Peak Size	THERMAL	DTA	7A3b	Percent	TGA	7A4b	Percent	SAND - SILT MINERALOGY (2.0-0.002mm)	TOT RE	OPTICAL GRAIN COUNT	7B1a	Percent	INTERPRETATION
21- 48													99 RE99	WE 1			
80-119													99 RE99	WEtr			

KIND OF MINERAL:

KK kaolinite GE goethite VR vermiculite RE resist min WE weath min Gl gibbsite

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 2 - Micro-morphological observations (L. Chileshe)

Frequent small to medium sand skeleton grains and rare fine silt fractions of various composition are found. The microstructure is bridge in the topmost sample and irregular blocky in the lower samples, voids are irregular, ortho, interconnected vughs. The related distribution is agglomeroplasmic to intertextic. The plasmic fabric is mixed isotic and asepic with very small (20 um) random domains. The features in this profile are similar to those of pedon 1 except for the absence of plasma separations and textural differences between horizons A and B.

PEDON 2 - Land evaluation (W. Veldkamp)

For crop production an initial lime application if required PKS and probably Zn fertilizers are needed. Maybe Mo has to applied to the legumes. Small applications of lime will maintain the productivity. Fertilizers should be given in small portions if possible.

The drought hazard during the rainy season is probably too high for successful dryland rice cultivation.

Agro-forestry might be useful for this soil in order to recycle leached nutrients

Ratings of land qualities: pedon 2.

POTENTIAL CONSTRAINTS	low inputs	High inputs
radiation	1	1
high temperature	2	2
high humidity	2	2
length growing season (70% prob.)	155	155 (days)
min., eff., rainfall (70% prob.)	725	725 (mm)
occurence drought	%	x
SOIL CONSTRAINTS		
nutrient reserves	3	1
potassium	4	-
calcium	3	-
magnesium	2	-
Ca/Mg	3	-
Ca/K	2	-
nutrient retention	3	2
zinc	1	-
molybdenum	2	-
sulphur	2	-
rooting conditions (chemical)	x	-
aluminium toxicity	3	2
mechanization potential/land prep.	1	1
ease of puddling	3	3
chemical degradation	2	1

Explanation of ratings:

- no constraint
x special drought constraint
1. slightly constraint
2. moderate constraint
3. severe constraint
4. very severe constraint

PEDON 2 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	2	A,N	1	N	PKS,lime, Zn, degradation protection
Sorghum	2	G	1	G,W	PKS,lime, Zn, degradation protection
Cassava	4a	K	1	6s	KS,Ca, degradation protection
F/millet	2	G	1	G,W	S,Ca, degradation protection
B/millet	3	A	1	A	S, lime, degradation protection
Wheat	3	T	3	T	-
Dryl. rice	2	D	2	D	-(with irrigation class: 1-,G,M,H: eff. inputs PKS, lime, lime, Zn, degradation protection)
Paddy rice	5b	P	5b	P	-
Sunflower	3	A	1	N	PKS,lime, degradation protection
Soyabean	3	A	1	N	PKS,lime,Zn,degradation protection
Groundnut	3	Ca	1	G,W	PKS, lime,Zn, (Mo), degradation protection
Ph/bean	3	A	1	A,G,W	PKS,lime,Zn, (Mo), degradation protection
Cotton	5b	A	4b	R	(lime)
V/tobacco	2	G	1	G,W	PKS, lime, degradation protection

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 3

Print date: 10-21-1987

Pedon: Misamfu Red NSSL ID #: 84P0508
Soil Survey # S83-FN-990-002
Location: Miasmfu Reg. Res. St. 8 km N of Kasama NOP Zambia. Pit locacted about 650 m NW of station headquarters.
Latitude: 10-10- -S Longitude: 031-10- -E
Classification: Clayey, kaolinitic, isohyperthermic Typic Haplustox
Physiography: Upland slope in plateaus or tablelands
Geomorphic Position: summit interfluve
Microrelief:
Slope Characteristics: .5% plane Elevation: 1384 m MSL
Precipitation: 1360 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Rapid
Air Temp. (Centigrade): Ann: 198 Sum: 200 Win: 170
Soil Temp. (Centigrade): Ann: 225 Sum: 221 Win: 205
Drainage: Well drained Land Use:
Stoniness:
Particle Size Control Section: 25 to 100 cm Runoff: Very slow
Parent Material: residuum from metamorphic-acidic material
Vegetation Codes: Weather Station: MISAMF
Diagnostic Horizons: 0 to 16 cm Ochric, 37 to 148 cm Oxic
Described by: D. Hallbick O. Spaargaren and L. Bustness Date: 11/83

1. Described when dry. 2. Think is within range of oxisols.

A--0 to 16 cm; reddish brown (5YR 4/4) sandy loam; dark reddish brown (5YR 3/3) moist; weak fine and medium crumb structure; slightly hard, nonsticky, plastic; many fine roots throughout and few medium roots throughout; many very fine and fine interstitial and tubular and common fine to coarse continuous tubular pores; clear smooth boundary.
84P2784

BA--16 to 37 cm; red (2.5YR 4/8) clay; red (2.5YR 4/6) moist; massive parting to strong very fine granular; hard, very sticky, plastic; common fine roots throughout; common to many very fine and fine interstitial and tubular and few to common fine and medium continuous tubular pores; clear wavy boundary.
84P2785

Bw1--37 to 63 cm; red (2.5YR 4/8) clay; dark red (2.5YR 3/6) moist; massive parting to strong very fine granular; slightly hard, very sticky, plastic; common fine roots throughout and few medium and coarse roots throughout; common to many very fine and fine interstitial and tubular and few fine to coarse continuous tubular pores; diffuse smooth boundary.
In Bw1 and Bw2 horizons few termite chambers occur inter connected by channels of 2 to 3 mm wide and conneceted with the surface by channels 5 to 10 mm wide. Some of these vertical channels are partly filled and lined.
84P2786

Bw2--63 to 124 cm; red (2.5YR 4/8) sandy clay; dark red (2.5YR 3/6) moist; massive parting to strong very fine granular; soft, very sticky, plastic; few fine and medium roots throughout; many very fine and fine interstitial and tubular and few fine to coarse continuous tubular pores; gradual smooth boundary.
Horizon split for sampling 63 to 95cm No. 2787 and 95 to 124 cm No. 2788.
84P2787

Bw3--124 to 148 cm; red (2.5YR 5/8) sandy clay; dark red (2.5YR 3/6) moist; massive parting to strong very fine granular; soft, very sticky, plastic; very few fine and medium roots throughout; many very fine and fine interstitial and tubular and very few fine and medium continuous tubular pores.
84P2789

S84FN-990-002

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; MEDIAL OVER CLAYEY, SILICEOUS, ISOHYPERTHERMIC KANDIUSTULT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 508, SAMPLES 84P2784-2789
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	(- - -TOTAL - - -) CLAY LT .002	SILT .002 -.05	SAND .05 -2	(- -CLAY- -) FINE LT .0002	CO3 LT .002	(- -SILT- -) FINE .02 -.02	COARSE .05 -.05	(- - - - - -SAND- - - - - -) VF .10 -.10	F .25 -.25	M .50 -1	C .5 -2	VC 1 -2	(-COARSE FRACTIONS(MM)-)(>2MM) - - - - WEIGHT - - - - 2 -5	5 -20	20 -75	.1- 75	WT PCT OF WHOLE SOIL
			<- - - - - - - - - - - - PCT OF <2MM (3A1) - - - - - - - - - - - - - - ->												<- PCT OF <75MM(3B1)->				
84P2784S	0- 16	A	17.0	6.0	77.0			2.5	3.5	10.6	38.0	23.1	4.9	0.4	--	--	--	66	--
84P2785S	16- 37	BA	26.5	5.5	68.0			2.2	3.3	8.3	31.7	21.6	5.5	0.9	TR	--	--	60	--
84P2786S	37- 63	BW1	31.7	6.0	62.3			2.4	3.6	9.0	29.4	19.0	4.3	0.6	TR	--	--	53	--
84P2787S	63- 95	BW2	32.7	5.9	61.4			2.2	3.7	8.8	29.3	18.0	4.8	0.5	TR	--	--	53	--
84P2788S	95-124	BW2	28.9	5.7	65.4			2.2	3.5	9.0	29.9	20.5	5.5	0.5	--	--	--	56	--
84P2789S	124-148	BW3	26.6	5.7	67.7			2.3	3.4	8.8	32.7	20.6	4.9	0.7	TR	--	--	59	--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A <- PERCENT	(- - DITH-CIT - -) EXTRACTABLE FE 6C2B	AL 6G7A OF <2MM -->	MN 6D2A	CEC 8D1	(RATIO/CLAY) 15 BAR 8D1	(ATTERBERG) - LIMITS - LL 4F1 PCT	PI 4F <0.4MM	(- BULK DENSITY -) FIELD MOIST 4A3A	1/3 BAR 4A1D <- - G/CC	OVEN DRY 4A1H - - ->	COLE WHOLE SOIL 4D1 CM/CM	(- - -WATER CONTENT - -) FIELD MOIST 4B4 <- -	1/10 BAR 4B1C -PCT OF	1/3 BAR 4B1C <2MM	15 BAR 4B2 - ->	WRD WHOLE SOIL 4C1 CM/CM
0- 16	1.22	0.067			2.6	0.3	TR	0.26	0.39	16	2		1.33	1.36	0.007			10.4	6.7	0.05
16- 37	0.48	0.030			3.0	0.3	--	0.10	0.33	21	8		1.42	1.45	0.007			12.2	8.7	0.05
37- 63	0.30	0.023			3.1	0.3	--	0.07	0.32				1.39	1.42	0.007			13.2	10.1	0.04
63- 95	0.19				3.2	0.3	--	0.07	0.31	24	10		1.34	1.37	0.007			12.7	10.2	0.03
95-124	0.15				3.0	0.3	--	0.06	0.33				1.34	1.36	0.005			12.8	9.4	0.05
124-148	0.12				3.0	0.3	--	0.06	0.33				1.35	1.37	0.005			12.2	8.9	0.04

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-002
CLASSIFICATION: SND ; MEDIAL OVER CLAYEY, SILICEOUS, ISOHYPERTHERMIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 508, SAMPLE 84P2784-2789

PRINT DATE 10/19/87

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID-ITY 6H5A	-7-- EXTR AL 6G9A	-8-- SUM CATS 5A3A	-9-- NH4-OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- -BASE SUM 5C3	-13- SAT-NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- PH KCL IN 8C1G	-19- PH CACL2 .01M 1:2 8C1F	-20- PH H2O 1:1 8C1F
	(- NH4OAC EXTRACTABLE BASES -)					ACID-	EXTR	(- - - -CEC	- - -)		AL	-BASE	SAT-	CO3 AS	RES.		COND.	(- - - -PH	- - -)	
	<- - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - ->										<- - - - -PCT - - - ->									
0- 16	1.5	0.8	TR	0.1	2.4	4.2		6.6	4.5			36	53					4.6	4.9	5.7
16- 37	0.5	0.5	TR	TR	1.0	2.8	0.3	3.8	2.6	1.3	23	26	38					4.7	4.8	5.4
37- 63	TR	0.6	TR	0.1	0.7	2.7		3.4	2.3			21	30					4.7	4.9	5.7
63- 95	--	0.3	TR	TR	0.3	3.2		3.5	2.3			9	13					4.4	4.6	5.6
95-124	--	0.2	TR	TR	0.2	2.6		2.8	1.7			7	12					4.3	4.5	5.7
124-148	--	0.1	TR	--	0.1	2.6		2.7	1.5			4	7					4.3	4.5	5.6

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -)							
	(- - - - - - - - CLAY - - - - - - - -)(- - -) -)							
	(- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM							
	(- - - - - <2U - - - -)(- -<2U - -) RES WEATH							
	7A2I	7A2I	7A2I	7A2I	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 16								
16- 37	KK 5	VR 1	GE 1	MI 1	KK33		99	WETR
37- 63								
63- 95	KK 5	GE 2	MI 1	VR 1	KK42		98	WE 2
95-124								
124-148	KK 5	GE 2	MI 1	VR 1	KK34			

AVERAGES, DEPTH 25-100: PCT CLAY 31 PCT .1-75MM 54

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE VR VERMICULITE GE GOETHITE MI MICA WE WEATH MIN

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-002
CLASSIFICATION: SND ; MEDIAL OVER CLAYEY, SILICEOUS, ISOHYPERTHERMIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 508, SAMPLE 84P2784-2789

PRINT DATE 10/19/87

DEPTH (cm)	FRACTION	X-RAY 7A2I peak size				THERMAL DTA	THERMAL TGA	CLAY MINERALOGY (<.002mm) SiO2	AL2O3	Fe2O3	MgO	CaO	K2O	Na2O	SURF AREA M2/G	INTERPRETATION
16- 37	TCLY	KK 5	VR 1	GE 1	MI 1	KK33				11.2			0.4			
63- 95	TCLY	KK 5	GE 2	MI 1	VR 1	KK42				9.7			0.4			
124-148	TCLY	KK 5	GE 2	MI 1	VR 1	KK34				9.2			0.4			

DEPTH (cm)	FRACTION	X-RAY 7A2I Peak Size	THERMAL DTA	THERMAL TGA	TOT RE Percent	OPTICAL GRAIN COUNT 7B1a Percent			INTERPRETATION
16- 37	FS				99	RE99	WEtr		
63- 95	FS				98	RE98	WE 2		

KIND OF MINERAL:

KK kaolinite VR vermiculite GE goethite MI mica RE resist min WE weath min

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 3 - Micro-morphological observations (L. Chileshe)

Skeleton grains of varying sizes and composition with coatings are rare to occasional throughout. The microstructure is mixed granular and irregular blocky. Voids are interconnected vughs. The related distribution pattern is agglomeroplasmic. The plasmic fabric is mixed isotic and weakly asepic fabrics with a uniform distribution pattern of microdomains. Glaebules in the form of nodules are rare. No plasma separations are observable in the sample.

PEDON 3 - Land evaluation (W. Veldkamp)

P,K and S fertilizers (especially when including superphosphate) and maybe Zn are effective. Mo is possibly required for the legumes. Regular small lime applications are needed for sustained production. Protection against chemical degradation is required. Irrigation during the rainy season is not feasible, except for dryland rice. Crop production is possible, probably best with cereal/legumes/tuber crop rotation, alternated with tree, pasture or legumes fallow.

Ratings of land qualities: pedon 3

POTENTIAL CONSTRAINTS	low inputs	high inputs
radiation	1	1
high temperature	2	2
high humidity	2	2
length growing period (70% prob.)	155	155
eff. min. rainfall (70% prob.)	725	725 (mm)
occurence drought	x	x
SOIL CONSTRAINTS		
nutrient reserves	3	1
phosphate fixation	1	-
calcium	3	-
magnesium	1	-
potassium	4	-
Ca/Mg	3	-
Ca/K	2	-
Zinc	1	-
molybdenum	2	-
sulphur	2	-
nutrient retention	3	2
rooting conditions (physical)	1	1
heavy topsoil	2	2
aluminium toxicity	2	1
mechanization/land preparation	1	1 anthills
ease of puddling	3	3
chemical degradation	2	1

Explanation of ratings:
-: no constraint
x: special drought constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 3 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	2	N	1	N	PKS,lime,Zn, degradation protection
Sorghum	2	G	1	G,M	PKS,Ca,Zn, degradation protection
Cassava	4a	K	1	G,Rp,M	KS,Ca degradation protection
F/millet	2	G	1	Ht	S,Ca,degradation protection
B/millet	2	G	1	Ht	S, lime,degradation protection
Wheat	3	T	3	T	-
Dryl. rice	2	D	2	D	-(with irrigation: class 1 -MGH;effective inputs, PKS, Ca, Zn, degradation protection
Paddy rice	5b	P	5b	P	-
Sunflower	2	N	1	N	PKS,Ca,degradation protection
Soyabean	3	Ca,K	1	N	PKS,Ca,Mg,Zn, degradation protection
Groundnut	3	Ca	1	M,G	PKS, lime,Zn,(Mo), degradation protection
Ph/bean	2	G	1	M,A,G	PKS,lime,Zn,(Mo), degradation protection
Cotton	4b	R	4b	R	-
V/tobacco	3	Ht	3	Ht	-

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 4

Print date: 10-21-1987

Pedon: Katito NSSL ID #: 84P0510
Soil Survey # S83-FN-990-004
Location: Mbala State Ranch about 11 km SSE of Mbala Nop Zambia.
Latitude: 08-57- -S Longitude: 312-7 - -E
Classification: Clayey, kaolinitic, isohyperthermic Oxic Paleustult
Physiography: Upland slope in plateaus or tablelands
Geomorphic Position: shoulder interfluve
Microrelief:
Slope Characteristics: .5% plane Elevation: 1800 m MSL
Precipitation: 1250 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderately rapid
Air Temp. (Centigrade): Ann: 197 Sum: 200 Win: 181
Soil Temp. (Centigrade): Ann: Sum: Win:
Drainage: Well drained Land Use:
Stoniness:
Particle Size Control Section: 46 to 96 cm
Parent Material: residuum
Vegetation Codes: Weather Station: MBALA
Diagnostic Horizons: 0 to 20 cm Ochric, 46 to 143 cm Argillic
Described by: D. Hallbick O. Spaargaren and L. Bustness Date: 11/83

1. Pedon would classify as Oxic Paleustult if subgroups are analogous tosubgroups of the Haplustults. Probably leandic.

A--0 to 10 cm; yellowish red (5YR 5/6) sandy clay; dark reddish brown (5YR 3/4) moist; moderate fine and medium granular structure; slightly hard, slightly sticky, plastic; many fine and medium roots throughout and few coarse roots throughout; many fine void between rock fragments and many fine and medium continuous tubular pores; clear smooth boundary.
84P2796

A2--10 to 20 cm; yellowish red (5YR 5/8) sandy clay; yellowish red (5YR 4/6) moist; moderate fine and medium subangular blocky structure; slightly hard, slightly sticky, plastic; many fine and medium roots throughout and few roots throughout; many very fine and fine interstitial and tubular pores; clear smooth boundary.
84P2797

BA--20 to 46 cm; red (2.5YR 5/8) clay; red (2.5YR 4/8) moist; weak coarse and very coarse subangular blocky structure parting to weak medium subangular blocky; slightly hard, slightly sticky, plastic; common fine and medium roots throughout and very few coarse roots throughout; many very fine and fine interstitial and few to common fine and medium continuous tubular pores; few patchy distinct-thin reddish brown (2.5YR4/4) organic coats in root channel and or pores; gradual smooth boundary.
84P2798

Bt1--46 to 77 cm; red (2.5YR 4/8) clay; dark red (2.5YR 3/6) moist; weak medium subangular blocky structure; slightly hard, slightly sticky, plastic; common fine roots throughout; many very fine and fine interstitial and few to common fine and medium continuous tubular pores; common discontinuous faint-thin red (2.5YR4/8) clay films on vertical faces of peds; gradual smooth boundary.
84P2799

Bt2--77 to 123 cm; red (2.5YR 4/8) clay; dark red (2.5YR 3/6) moist; weak medium and coarse prismatic structure parting to weak medium and coarse subangular blocky; slightly hard, slightly sticky, plastic; common fine roots throughout; many very fine and fine interstitial and common medium and coarse continuous tubular pores; common patchy faint-thin red (2.5YR4/8) clay films on vertical faces of peds; gradual smooth boundary.
84P2800

Bt3--123 to 143 cm; red (2.5YR 4/8) clay; dark red (2.5YR 3/6) moist; weak medium and coarse subangular blocky structure; soft, slightly sticky, plastic; few fine roots throughout; many very fine and fine interstitial and few fine and medium continuous tubular pores; few patchy faint-thin red (2.5YR4/8) clay films on vertical faces of peds.
84P2801

S84FN-990-004

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC TYPIC KANDIUSTULT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 510, SAMPLES 84P2796-2801
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	(-TOTAL- CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	CO3 LT .002	(-CLAY-) FINE .002 -.02	(-SILT-) COARSE .02 -.05	VF .05 -.10	(-SAND-) F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	(-COARSE FRACTIONS(MM)-) 2 -5	5 -20	WEIGHT 20 -75	(>2MM) .1-75	WT PCT OF WHOLE SOIL
			<- PCT OF <2MM (3A1) ->												<- PCT OF <75MM(3B1)->				
84P2796S	0- 10	A1	36.3	4.9	58.8			2.7	2.2	4.7	24.5	24.9	4.3	0.4	--	--	--	54	--
84P2797S	10- 20	A2	39.2	4.5	56.3			2.4	2.1	4.5	22.3	24.2	4.6	0.7	TR	--	--	52	--
84P2798S	20- 46	BA	46.5	4.5	49.0			2.4	2.1	4.2	19.4	20.4	4.5	0.5	--	--	--	45	--
84P2799S	46- 77	BT1	48.7	4.2	47.1			2.0	2.2	3.9	17.8	20.3	4.4	0.7	TR	--	--	43	--
84P2800S	77-123	BT2	50.3	4.5	45.2			1.9	2.6	4.4	18.0	18.5	3.6	0.7	TR	--	--	41	--
84P2801S	123-143	BT3	52.6	4.7	42.7			2.4	2.3	4.7	16.9	17.1	3.6	0.4	--	--	--	38	--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A	(- - DITH-CIT - -) EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	(RATIO/CLAY) 15 BAR 8D1	(ATTERBERG) LIMITS LL 4F1	PI 4F	(- BULK DENSITY -) FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1	(- - -WATER CONTENT - -) FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
	PCT	<2MM	PPM	<- PERCENT	OF <2MM -->					PCT <0.4MM		<- - G/CC	- - ->		CM/CM	<- - -PCT OF <2MM	- ->			CM/CM
0- 10	1.20	0.069			2.2	0.3	0.1	0.12	0.36	29	12		1.32	1.40	0.020			18.7	13.0	0.08
10- 20	0.95	0.054			2.3	0.3	0.1	0.10	0.32				1.33	1.39	0.015			15.0	12.6	0.03
20- 46	0.66	0.041			2.4	0.3	0.1	0.08	0.29	32	14		1.38	1.41	0.007			16.7	13.6	0.04
46- 77	0.44				2.5	0.3	TR	0.06	0.28				1.36	1.39	0.007			17.7	13.8	0.05
77-123	0.28				2.5	0.3	TR	0.06	0.29	34	13		1.24	1.27	0.008			18.3	14.6	0.05
123-143	0.22				2.7	0.4	TR	0.06	0.29				1.20	1.23	0.008			18.3	15.3	0.04

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-004 PRINT DATE 10/19/87
CLASSIFICATION: SND ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC TYPIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 510, SAMPLE 84P2796-2801

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID-ITY 6H5A	-7-- EXTR AL 6G9A	-8-- SUM CATS 5A3A	-9-- CEC NH4-OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- BASE SUM 5C3	-13- SAT-NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 81	-18- PH KCL IN 8C1G	-19- PH CACL2 .01M 8C1F 1:2	-20- PH H2O 8C1F 1:1
	(- NH4OAC EXTRACTABLE BASES -)							(- - - -CEC - - -)				-BASE	SAT-	CO3 AS	RES.		COND.	(- - - -PH - - -)		
	<- - - - - - - - - - -MEQ / 100 G - - - - - - - - - - ->										<- - - - -PCT - - - ->									
0- 10	TR	0.3	TR	0.2	0.5	6.9	1.1	7.4	4.4	1.6	69	7	11					4.2	4.5	5.1
10- 20	--	0.2	TR	0.1	0.3	6.1	1.2	6.4	4.1	1.5	80	5	7					4.2	4.4	5.1
20- 46	--	0.2	TR	0.1	0.3	5.5	1.0	5.8	3.9	1.3	77	5	8					4.2	4.3	5.1
46- 77	--	0.3	TR	--	0.3	5.0	0.8	5.3	3.1	1.1	73	5	10					4.2	4.4	5.2
77-123	--	0.2	TR	0.2	0.4	3.9	0.6	4.3	2.8	1.0	60	9	14					4.4	4.4	5.4
123-143	--	TR	TR	0.1	0.1	4.5	0.7	4.6	3.1	0.8	88	2	3					4.2	4.4	5.4

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -)							
	(- - - - - - - CLAY - - - - - - - -)(- - -) -)							
	(- - - - X-RAY - - - -)(- -DTA - -)						TOTAL	DOM
	(- - - - - <2U - - - -)(- -<2U - -)						RES	WEATH
	7A21	7A21	7A21	7A21	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 10								
10- 20								
20- 46	KK 5	GE 2			KK52			
46- 77	KK 5	GE 2			KK61		99	TR
77-123	KK 5	GE 1			KK61		99	TR
123-143								

AVERAGES, DEPTH 46- 96: PCT CLAY 49 PCT .1-75MM 42

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE GE GOETHITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-004
CLASSIFICATION: SND ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC TYPIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 510, SAMPLE 84P2796-2801

PRINT DATE 10/19/87

1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

CLAY MINERALOGY (<.002mm)

DEPTH (cm)	FRACTION	X-RAY 7A2i	X-RAY peak size	THERMAL DTA	THERMAL TGA	ELEMENTAL SiO2	ELEMENTAL AL2O3	ELEMENTAL Fe2O3	ELEMENTAL MgO	ELEMENTAL CaO	ELEMENTAL K2O	ELEMENTAL Na2O	SURF AREA M2/G	INTERPRETATION
20- 46	TCLY	KK 5	GE 2		KK52			7.3			0.2			
46- 77	TCLY	KK 5	GE 2		KK61			7.6			0.2			
77-123	TCLY	KK 5	GE 1		KK61			7.1			0.2			

SAND - SILT MINERALOGY (2.0-0.002mm)

DEPTH (cm)	FRACTION	X-RAY 7A2i	X-RAY Peak Size	THERMAL DTA	THERMAL TGA	THERMAL TOT RE	OPTICAL GRAIN COUNT	OPTICAL Percent	INTERPRETATION
46- 77	FS					100	QZ82	QC17 FE 1	
77-123	FS					100	QZ82	QC17 FE 1	

KIND OF MINERAL:

KK kaolinite GE goethite QZ quartz QC clay-coat qz FE iron oxided

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 4 - Micro-morphological observations (L. Chileshe)

Very frequent fine to coarse skeleton grains observed in both samples. The microstructure is bridge separated by organic coatings in the top sample to mixed granular and irregula in the subsoil sample. The voids are irregular, ortho vughs. The related distribution is intertextic to agglomeroplasmic. The plasmic fabric is asepic with isolated skelsepic fabrics. Glaebular features in the form of pedodes and glaebular holes (segregations) are rare to occasional more so in the subsoil sample. No plasma separations were observed in the samples analysed. Clay skins are present but <1%.

PEDON 4 - Land evaluation (W. Veldkamp)

Under low inputs, this type of soil is not very productivel The main constraints are the soil acidity and the low nutrient content (esp. Ca, K and S, apart from P). With high inputs, especially PKS fertilizers and lime and possibly Zn, B and Mo the soil is suitable for production of sorghum, cassava, sunflower, soybean and phaseolous bean.

For wheat the temperature might be the main constraint to obtain high yields with high inputs; on the other hand the desease pressure on this crop (helmintosporium) is usually the biggest problem. Wheat used to be cultivated on nearby fields during the rainy season.

The suitability for maize is hampered by drought stress, lack of radiation and the low nutrient retention.

Irrigation during the rainy season would only be benificial to increase production of maize.

Rice is not a suitable crop because of low temperature.

Ratings of land qualities; pedon 4

POTENTIAL CONSTRAINTS	low inputs	high inputs
radiation	1	1
high temperature	2	2
high humidity	2	2
length growing period (70% prob.)	155	155 (days)
eff. min. rainfall (70% prob.)	725	725 (mm)
occurence critical periods	1	1
occurence drought	x	x
SOIL CONSTRAINTS		
nutrient reserves	2	-
calcium	3	-
magnesium	2	-
potassium	3	-
Ca/Mg	3	-
Ca/K	2	-
boron	2	-
Zinc	1	-
molybdenum	3	-
sulphur	3	-
nutrient retention	3	2
rooting conditions (chemical)	x	-
heavy topsoil	3	3
aluminium toxicity	3	2
ease of puddling	2	2
chemical degradation	2	1

Explanation of ratings:
-: no constraint
x: special drought constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 4 - Land evaluation classes

CRUP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	3	S	2	N,R,D	PKS,lime, Zn, degradation protection (with irrigation class: 1-N,R)
ghum	3	S	1	G	PKS,lime, Zn, degradation protection
-ava	3	K,S	1	Gs	KS, Ca,degradation protection
llet	3	S	2	Ht	S
B/millet	3	A	2	Ht	lime
Wheat	3	A	2	T	PKS,lime,degradation protection
Dryl. rice	5b	D	5a	D	(PKS, lime, degradation protection; with irrigation class:4b-T)
Paddy rice	5b	D	5b	D	-(with irrigation class; 4b-T)
Sunflower	3	A	1	N,R	PKS, lime, degradation protection
Soyabean	3	A	1	N	PKS,lime,Zn, (Mo) degradation protection
Groundnut	3	A	2	A	S,lime, (Mo), degradation protection
Ph/bean	3	S	1	A,G,Mo	PKS,lime,Zn, (Mo) degradation protection
Cotton	5b	A,R	5a	R	(lime)
V/tobacco	4a	Ht	4a	Ht	-

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 5

Print date: 10-21-1987

Pedon: Malashi NSSL ID #: 84P0511
Soil Survey # S83-FN-990-005
Location: Malashi Res. Subst. 3 km NE of Mpika NOP Zambia. Pit located about 500 m SW of the office.
Latitude: 11-52- -S Longitude: 031-23- -E
Classification: Clayey, kaolinitic, isohyperthermic Oxic Paleustult
Physiography:
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1360 m MSL
Precipitation: 1070 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderate
Air Temp. (Centigrade): Ann: 189 Sum: 198 Win: 150
Soil Temp. (Centigrade): Ann: 221 Sum: 226 Win: 194
Drainage: Well drained Land Use:
Stoniness:
Particle Size Control Section: 8 to 58 cm
Parent Material: residuum from sandstone-siltstone material
Vegetation Codes: Weather Station: MPIKA
Diagnostic Horizons: 0 to 8 cm Ochric, 8 to 154 cm Argillic
Described by: D. Hallbick O. Spaargaren and L. Bustness Date: 11/83

Thought to be Ultisol due to clay increase and probable clay films.

Ap--0 to 8 cm; red (2.5YR 4/6) clay; 35 (2.5YR 3/5) moist; strong fine subangular blocky structure parting to strong medium subangular blocky parting to strong coarse subangular blocky; slightly hard, slightly sticky, plastic; many fine and medium roots throughout; many fine continuous tubular and few medium continuous tubular pores; very few to few fine rounded ironstone nodules; clear smooth boundary. Many very fine interstitial irregular pores.
84P2802

Bt1--8 to 23 cm; red (2.5YR 4/8) clay; dark red (2.5YR 3/6) moist; strong fine subangular blocky structure parting to strong medium subangular blocky parting to strong coarse subangular blocky; slightly hard, slightly sticky, plastic; many fine and medium roots throughout; common fine and medium continuous tubular and many very fine interstitial pores; common discontinuous distinct-thin clay films on ped faces; very few to few fine rounded ironstone nodules; clear wavy boundary.
Coats may not be clay films but pressure faces. Need to check also next three layers.
84P2803

Bt2--23 to 61 cm; red (2.5YR 4/8) clay; dark red (2.5YR 3/6) moist; strong fine subangular blocky structure parting to strong medium subangular blocky parting to strong coarse subangular blocky; slightly hard, slightly sticky, plastic; common fine and medium roots throughout; common fine continuous tubular and many very fine interstitial pores; many discontinuous distinct-thin clay films on ped faces; very few to few fine rounded ironstone nodules; clear smooth boundary.
84P2804

Bt3--61 to 94 cm; red (2.5YR 4/8) clay; dark red (2.5YR 3/6) moist; strong coarse subangular blocky structure; hard, slightly sticky, plastic; common fine and medium roots throughout; few to common fine continuous tubular and common very fine interstitial pores; many continuous distinct-thin clay films on vertical faces of peds; common discontinuous distinct-thin clay films on horizontal faces of peds; very few to few fine rounded ironstone nodules; 1 percent pebbles from sandstone; gradual smooth boundary.
84P2805

Bt4--94 to 154 cm; red (2.5YR 4/6) clay; dark red (2.5YR 3/6) moist; moderate coarse subangular blocky structure parting to strong fine and medium subangular blocky; slightly hard, slightly sticky, plastic; common fine and medium roots throughout; few fine continuous tubular and many very fine and fine interstitial pores; common discontinuous distinct-thin clay films on vertical ped faces; very few to few fine rounded ironstone nodules; 1 percent pebbles from sandstone.
Clod samples between 100 and 120 cm and between 130 and 145 cm. Split for sampling 94 to 120 No. 2806 and 120 to 154 No. 2807.
84P2806

*** PRIMARY CHARACTERIZATION DATA ***

S84FN-990-005 (ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC RHODIC KANHAPLUSTULT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 511, SAMPLES 84P2802-2807
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

			(- - -TOTAL	- - -)	(- -CLAY- -)		(- -SILT- -)		(- - - -	- -SAND- -		- - - -)		(-COARSE FRACTIONS(MM)-)				(>2MM)
			CLAY	SILT	SAND	FINE	CO3	FINE	COARSE	VF	F	M	C	VC	- - - - WEIGHT	- - - -			WT
SAMPLE	DEPTH	HORIZON	LT	.002	.05	LT	LT	.002	.02	.05	.10	.25	.5	1	2	5	20	.1-	PCT OF
NO.	(CM)		.002	-.05	-2	.0002	.002	-.02	-.05	-.10	-.25	-.50	-1	-2	-5	-20	-75	75	WHOLE
			<- - - - -	- - - - -	- - - - -	- - -	PCT OF <2MM	(3A1)	- - - -	- - - -	- - - -	- - - -	- - ->	<- PCT OF	<75MM(3B1)		->	SOIL
84P2802S	0- 8	AP	46.8	24.3	28.9	15.5		15.8	8.5	9.2	12.3	4.5	1.6	1.3	1	--	--	21	1
84P2803S	8- 23	BT1	58.9	19.3	21.8	20.5		12.6	6.7	7.0	8.7	3.1	1.3	1.7	1	--	--	16	1
84P2804S	23- 61	BT2	34.5	22.9	42.6	12.5		14.4	8.5	8.5	12.8	8.3	7.3	5.7	1	--	--	35	1
84P2805S	61- 94	BT3	46.4	30.6	23.0	16.2		20.2	10.4	8.7	8.0	2.9	1.6	1.8	1	--	--	15	1
84P2806S	94-120	BT4	42.8	33.1	24.1	15.6		21.3	11.8	9.7	8.6	2.8	1.3	1.7	1	--	--	15	1
84P2807S	120-154	BT4	43.0	32.3	24.7	17.5		19.6	12.7	9.5	7.7	2.5	1.5	3.5	1	--	--	16	1

	ORGN	TOTAL	EXTR	TOTAL	(- - DITH-CIT	- -)		(RATIO/CLAY)		(ATTERBERG	)	(- BULK	DENSITY -)		COLE	(- - -WATER	CONTENT	- -)		WRD
	C	N	P	S		EXTRACTABLE			15	- LIMITS		FIELD	1/3	OVEN	WHOLE	FIELD	1/10	1/3	15	WHOLE
DEPTH					FE	AL	MN	CEC	BAR	LL	PI	MOIST	BAR	DRY	SOIL	MOIST	BAR	BAR	BAR	SOIL
(CM)	6A1C	6B3A	6S3	6R3A	6C2B	6G7A	6D2A	8D1	8D1	4F1	4F	4A3A	4A1D	4A1H	4D1	4B4	4B1C	4B1C	4B2	4C1
	PCT	<2MM	PPM	<- PERCENT	OF	<2MM	-->			PCT	<0.4MM	<- -	G/CC	- - ->	CM/CM	<- -	-PCT OF	<2MM	- ->	CM/CM
0- 8	1.84	0.104			12.0	0.6	0.1	0.21	0.36	36	14		1.33	1.43	0.024			25.5	16.9	0.11
8- 23	1.04	0.063			12.7	0.7	0.1	0.14	0.31	38	12		1.41	1.41	--			24.0	18.0	0.08
23- 61	0.46	0.031			13.7	1.1	0.1	0.37	0.63				1.30	1.34	0.010			24.4	21.6	0.04
61- 94	0.28				12.9	0.7	0.1	0.11	0.39	40	10		1.23	1.26	0.008			24.8	18.3	0.08
94-120	0.27				13.2	0.6	0.1	0.10	0.44				1.23	1.26	0.008			24.2	18.8	0.07
120-154	0.18				14.2	0.7	0.1	0.10	0.44				1.23	1.27	0.011			25.2	19.1	0.07

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-005
CLASSIFICATION: SND
NATIONAL SOIL SURVEY LABORATORY ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC RHODIC KANHAPLUSTULT
; PEDON 84P 511, SAMPLE 84P2802-2807

PRINT DATE 10/19/87

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACIDITY 6H5A	-7-- EXTRAL 6G9A	-8-- SUM CATS 5A3A	-9-- NH4-OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- BASE SUM 5C3	-13- SAT-NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- PH KCL IN 8C1G	-19- PH CACL2 .01M 8C1F 1:2	-20- PH H2O 8C1F 1:1
	(- NH4OAC EXTRACTABLE BASES -)							(- - - -CEC - - -)												
	<- - - - - - - - - - -				-MEQ /	100 G	- - - -	- - - -	- - - -	- - ->	<- - - -		-PCT	- - - ->						
0- 8	4.6	1.5	TR	0.5	6.6	6.8		13.4	10.0			49	66					5.6	5.6	6.4
8- 23	1.9	0.8	TR	0.2	2.9	6.6		9.5	8.3			31	35					5.2	5.1	6.0
23- 61	0.9	0.5	TR	0.2	1.5	12.3		13.9	12.6			12	13					5.2	5.2	6.0
61- 94	1.5	0.6	TR	0.2	2.4	4.6		7.0	4.9			34	49					5.7	5.6	6.0
94-120	1.6	0.7	TR	0.2	2.5	4.2		6.7	4.3			37	58					5.9	5.9	6.0
120-154	1.4	0.7	TR	0.2	2.3	3.8		6.1	4.1			38	56					6.1	6.0	6.1

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -)							
	(- - - - - - - CLAY - - - - - - - -)							
	(- - - - X-RAY - - - -)(- -DTA - -)						TOTAL	DOM
	(- - - - - <2U - - - -)(- -<2U - -)						REL	WEATH
	7A21	7A21	7A21	7A21	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT		- - - ->	
0- 8								
8- 23								
23- 61								
61- 94	KK 5	GI 2	GE 1		KK42	GI 4	99	WE 1
94-120								
120-154	KK 4	GI 2	HE 2	GE 1	KK40	GI 4	99	WETR

AVERAGES, DEPTH 8- 58: PCT CLAY 42 PCT .1-75MM 29

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE GI GIBBSITE GE GOETHITE WE WEATH MIN HE HEMATITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

PRINT DATE 10/19/87

S84FN-990-005 ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC RHODIC KANHAPLUSTULT
CLASSIFICATION: SND ; PEDON 84P 511, SAMPLE 84P2802-2807
NATIONAL SOIL SURVEY LABORATORY

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

CLAY MINERALOGY (<.002mm) ELEMENTAL

DEPTH (cm)	FRACTION X-RAY	THERMAL DTA	TGA	SiO2	Al2O3	Fe2O3	MgO	CaO	K2O	Na2O	SURF AREA M2/G	INTERPRETATION
	7A2i peak size	7A3b Percent	7A4b	7C3 Percent								
8- 23	TCLY KK 5 GI 2 GE 1	KK42 GI 4					18.6		0.2			
61- 94	TCLY KK 4 GI 2 HE 2 GE 1	KK40 GI 4					21.4		0.2			

SAND - SILT MINERALOGY (2.0-0.002mm)

DEPTH (cm)	FRACTION X-RAY	THERMAL DTA	TGA	TOT RE	OPTICAL GRAIN COUNT	INTERPRETATION
	7A2i Peak Size	7A3b Percent	7A4b	7B1a Percent		
8- 23	VFS			99 RE99 WE 1		
61- 94	VFS			99 RE99 WEtr		

KIND OF MINERAL:

KK kaolinite GI gibbsite GE goethite RE resist min WE weath min HE hematite

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 5 - Micro-morphological observations (L. Chileshe)

Very small to small (2-200 um) skeleton grains of the silt fraction are frequent to very frequent with a tendency to decrease down the profile. The microstructure is well developed granular in the top lower samples whereas it is crumb in the top sample. The related distribution is intertextic to agglomeroplasmic. Compound packing voids characterize the samples. The plasmic fabric is mixed isotic and rare argillasepic. Glaebules in the form of nodules and septaria are frequent in the control section.

PEDON 5 - Land evaluation (W. Veldkamp)

It is assumed that P.fixation is a major problem of this soil. Therefore production of maize is reduced and optimal yields cannot be obtained. For crops like sorghum, sunflower, soybean, groundnut and beans (with lower P requirements) good yields can be expected. Other required inputs to make this soil productive are calcium and zinc. Protection against chemical degradation is required.

The heavy textured topsoil makes this soil less suitable for cultivation of the millets.

Irrigation during the rainy season is only useful for dryland rice.

Ratings of land qualities: pedon 5

POTENTIAL CONSTRAINTS	low inputs	high inputs
radiation	1	1
high temperature	2	2
high humidity	2	2
length growing period (70% prob.)	145	145
eff. min. rainfall (70% prob.)	575	575
occurence critical periods	x	x
SOIL CONSTRAINTS		
nutrient reserves	1	-
phosphate fixation	2	1
calcium	2	-
magnesium	1	-
potassium	2	-
Ca/K	2	-
Zinc	1	-
molybdenum	1	-
sulphur	1	-
rooting conditions (physical)	1	1
heavy topsoil	3	3
workability	1	1 struc.
mechanization/land preparation	1	1 a/hills
ease of puddling	2	2
chemical degradation	2	1
biological degradation	1	-

Explanation of ratings:
-: no constraint
x: special drought constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 5 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	3	Np	2	Np	P, degradation protection
Sorghum	2	G	1	G,M,Np	IP),Ca,Zn, degradation protection
Cassava	3	K	2	W	K
F/millet	2	Ht	2	Ht	-
B/millet	2	Ht	2	Ht	-
Wheat	3	T	3	T	-
Dryl. rice	4b	D	4b	D	-(with irrigation class; 1-G,H,M,Np; effective inputs Ca,Zn, degradation protection)
Paddy rice	5b	D	5b	D	-(with irrigation class; 3-P)
Sunflower	2	G	1	G,M,Np	(P), Ca, degradation protection
Soyabean	2	G	1	G,M,Np	(P),K,Ca,Zn, degradation protection
Groundnut	2	G	1	G,M,Np	(P),Ca,Zn, degradation protection
Ph/bean	2	G	1	G,M,Np	P,Ca,Zn, degradation protection
Cotton	4b	R	4b	R	-
V/tobacco	4a	Ht	4a	Ht	-

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 6

Print date: 10-21-1987

Pedon: Mushemi Acid NSSL ID #: 84P0514
Soil Survey # S83-FN-990-008
Location: Shrosbee's farm 10 km SE of Mkushi Cep Zambia. Pit located about 4 km E of the farmhouse.
Latitude: 13-40- -S Longitude: 029-29- -E
Classification: Fine-loamy, siliceous, isohyperthermic Ultic Haplustox
Physiography: Upland slope in plateaus or tablelands
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1330 m MSL
Precipitation: 930 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderately rapid
Air Temp. (Centigrade): Ann: 201 Sum: 212 Win: 159
Soil Temp. (Centigrade): Ann: 239 Sum: 241 Win: 208
Drainage: Well drained Land Use:
Stoniness: Class 9
Particle Size Control Section: 25 to 100 cm Runoff: Very slow
Parent Material: residuum from metamorphic-acidic material
Vegetation Codes: Weather Station: KABWE
Diagnostic Horizons: 0 to 11 cm Ochric, 11 to 34 cm Albic, 61 to 174 cm Oxic
Described by: D. Hallbick O. Spaargaren C. English and P. Woode
Date: 11/83

Close to clayey family when average 25 to 100 cms control section. Probably kandic

A--0 to 11 cm; grayish brown (10YR 5/2) sandy loam; very dark grayish brown (10YR 3/2) moist; weak fine and medium granular structure; soft, nonsticky, nonplastic; many fine roots throughout and few medium roots throughout; many fine and medium continuous tubular and many fine and medium void between rock fragments pores; clear smooth boundary.
84P2820

EA--11 to 34 cm; very pale brown (10YR 7/3) sandy loam; brown to dark brown (10YR 4/3) moist; massive parting to strong very fine granular; slightly hard, nonsticky, nonplastic; common fine roots throughout and very few medium roots throughout; common fine and medium continuous tubular and many fine interstitial pores; gradual smooth boundary.
84P2821

EB--34 to 61 cm; pink (7.5YR 7/4) sandy clay loam; brown (7.5YR 5/4) moist; massive parting to strong very fine granular; slightly hard, slightly sticky, plastic; very few fine roots throughout; common medium and coarse continuous tubular and many fine interstitial pores; clear smooth boundary.
Cracks of about 0.5 to 1 cm wide occur from the base of the EA down to Bw3. Distance between cracks is 60 to 150 cm.
84P2822

Bw1--61 to 99 cm; 7 (7.5YR /7) clay and A 0 M; strong brown (7.5YR 5/6) moist; strong very fine granular structure; slightly hard, nonsticky, nonplastic; very few fine roots throughout; few medium and coarse continuous tubular pores; gradual smooth boundary.
84P2823

Bw2--99 to 151 cm; reddish yellow (7.5YR 7/6) clay; strong brown (7.5YR 5/6) moist; massive parting to strong very fine granular; hard, very sticky, plastic; very few fine roots throughout; very few medium and coarse continuous tubular pores; gradual smooth boundary.
84P2824

BW3--151 to 174 cm; reddish yellow (7.5YR 7/6) clay; yellowish red (5YR 5/6) moist; massive parting to strong very fine granular; slightly hard, very sticky, plastic; very few medium and coarse continuous tubular pores; very few very fine and fine irregular gibbsite concretions.
White crystals probably gibbsite occurs locally near cracks.
84P2825

S84FN-990-008

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; FINE-LOAMY, SILICEOUS, ISOHYPERTHERMIC TYPIC KANDIUSTALF

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 514, SAMPLES 84P2820-2825
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- TOTAL CLAY LT .002	-2-- TOTAL SILT .002 -.05	-3-- TOTAL SAND .05 -2	-4-- TOTAL FINE LT .0002	-5-- CLAY CO3 LT .002	-6-- SILT FINE .002 -.02	-7-- SILT COARSE .02 -.05	-8-- SAND VF .05 -.10	-9-- SAND F .10 -.25	-10- SAND M .25 -.50	-11- SAND C .5 -1	-12- SAND VC 1 -2	-13- COARSE FRACTIONS(MM) WEIGHT 2 -5	-14- COARSE FRACTIONS(MM) WEIGHT 5 -20	-15- COARSE FRACTIONS(MM) WEIGHT 20 -75	-16- >2MM WT .1-75 PCT OF WHOLE SOIL
			<- - - - - - - - - - - - PCT OF <2MM (3A1) - - - - - - - - - - - - - - ->												<- PCT OF <75MM(3B1)->			
84P2820S	0- 11	A	7.3	7.4	85.3			2.5	4.9	11.4	34.6	27.3	9.3	2.7	TR	--	--	74	TR
84P2821S	11- 34	EA	5.9	7.1	87.0			2.1	5.0	12.7	39.5	23.5	8.7	2.6	TR	--	--	74	TR
84P2822S	34- 61	EB	19.9	7.1	73.0			2.1	5.0	10.2	30.7	20.4	8.5	3.2	TR	--	--	63	TR
84P2823S	61- 99	BW1	37.0	5.2	57.8			1.5	3.7	7.0	21.7	17.1	8.4	3.6	TR	--	--	51	TR
84P2824S	99-151	BW2	35.9	5.6	58.5			1.7	3.9	7.2	21.8	17.4	9.3	2.8	TR	--	--	51	TR
84P2825S	151-174	BW3	36.5	6.5	57.0			1.6	4.9	9.4	23.2	14.2	7.5	2.7	TR	--	--	48	TR

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A <- PERCENT	DITH-CIT FE 6C2B OF	DITH-CIT AL 6G7A <2MM -->	DITH-CIT MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LL 4F1 PCT	ATTERBERG PI 4F <0.4MM	BULK DENSITY FIELD MOIST 4A3A <- -	BULK DENSITY 1/3 BAR 4A1D G/CC	BULK DENSITY OVEN DRY 4A1H - - ->	COLE WHOLE SOIL 4D1 CM/CM	WATER CONTENT FIELD MOIST 4B4 <- -	WATER CONTENT 1/10 BAR 4B1C -PCT OF	WATER CONTENT 1/3 BAR 4B1C <2MM	WATER CONTENT 15 BAR 4B2 - ->	WRD WHOLE SOIL 4C1 CM/CM
0- 11	1.60	0.082			0.3	0.1	0.1	0.70	0.58		NP		1.56	1.57	0.002			6.7	4.2	0.04
11- 34	0.26	0.016			0.2	TR	TR	0.15	0.39				1.55	1.56	0.002			5.0	2.3	0.04
34- 61	0.23	0.017			0.4	0.1	TR	0.08	0.31				1.60	1.61	0.002			8.2	6.1	0.03
61- 99	0.13				0.7	0.2	--	0.07	0.30	37	21		1.60	1.64	0.008			13.6	11.0	0.04
99-151	0.10				0.7	0.1	--	0.07	0.30				1.51	1.54	0.007			13.1	10.7	0.04
151-174	0.09				0.7	0.2	--	0.08	0.29	33	16		1.44	1.47	0.007			13.2	10.6	0.04

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-008 PRINT DATE 10/19/87
CLASSIFICATION: SND ; FINE-LOAMY, SILICEOUS, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 514, SAMPLE 84P2820-2825

DEPTH (CM)	-1-- (- NH4OAC EXTRACTABLE BASES -) CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID- ITY 6H5A	-7-- EXTR AL 6G9A	-8-- (- - - -CEC - - -) SUM CATS 5A3A	-9-- NH4- OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- -BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND.(- - - MMHOS /CM 8I	-18- -PH - - -) KCL IN 8C1G	-19- CACL2 .01M 8C1F 1:2	-20- H2O 8C1F 1:1
	<- - - - - - - - - -				-MEQ /	100 G - - -		- - - - - - - - - -			<- - - - -		-PCT - - - ->							
0- 11	4.0	0.7	TR	0.5	5.2	1.5		6.7	5.1			78	100					5.7	5.7	6.6
11- 34	0.6	0.2	TR	0.2	1.0	--		1.0	0.9			100	100					5.2	5.4	6.3
34- 61	0.5	0.6	TR	0.5	1.6	0.6		2.2	1.6			73	100					5.2	5.6	6.2
61- 99	0.6	0.7	TR	0.3	1.6	1.9	0.3	3.5	2.7	1.9	16	46	59					4.4	4.8	5.2
99-151	0.5	0.5	TR	0.3	1.3	1.9		3.2	2.5			41	52					4.4	4.7	5.6
151-174	0.7	0.6	TR	0.2	1.5	1.9		3.4	2.9			44	52					4.7	4.9	5.8

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -) (- - - - - - - - CLAY - - - - - - - - -)(- - -) -) (- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM (- - - - - <2U - - - -)(- -<2U - -) RES WEATH 7A2I	7A2I	7A2I	7A2I	7A3	7A3	7B1A	7B1A <- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 11														
11- 34														
34- 61														
61- 99	KK 5	MI 3	GE 1		KK54			95	WE 5					
99-151														
151-174	KK 5	MI 3	GE 1		KK56									

AVERAGES, DEPTH 25-100: PCT CLAY 27 PCT .1-75MM 58

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MI MICA GE GOETHITE WE WEATH MIN

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-008
CLASSIFICATION: SND ; FINE-LOAMY, SILICEOUS, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 514, SAMPLE 84P2820-2825

PRINT DATE 10/19/87

DEPTH (cm)	FRACTION	X-RAY 7A2i peak size	X-RAY 7A3b peak size	X-RAY 7A4b peak size	THERMAL DTA Percent	THERMAL TGA Percent	ELEMENTAL SiO2	ELEMENTAL AL2O3	ELEMENTAL Fe2O3	ELEMENTAL MgO	ELEMENTAL CaO	ELEMENTAL K2O	ELEMENTAL Na2O	SURF AREA M2/G	INTERPRETATION
	CLAY MINERALOGY (<.002mm)														
61- 99	TCLY	KK 5	MI 3	GE 1	KK54				5.7			0.8			
151-174	TCLY	KK 5	MI 3	GE 1	KK56				3.6			1.1			

DEPTH (cm)	FRACTION	X-RAY 7A2i Peak Size	X-RAY 7A3b Peak Size	X-RAY 7A4b Peak Size	THERMAL DTA Percent	THERMAL TGA Percent	THERMAL TOT RE	OPTICAL 7B1a Percent	OPTICAL GRAIN COUNT	INTERPRETATION
	SAND - SILT MINERALOGY (2.0-0.002mm)									
61- 99	FS						95 RE95 WE 5			

KIND OF MINERAL:

KK kaolinite MI mica GE goethite RE resist min WE weath min

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 6 - Land evaluation (W. Veldkamp)

This soil needs protection against degradation in the first place. The degradation processes are of biological nature foremost, but physical and chemical degradation are also very important.

Any cultivation of this soil should include measures to counteract the potential degradation. The best would be to alternate arable cropping (with maize, sorghum, millets, sunflower, grain legumes or tobacco) with patures which is in fact the system already in use by the best farmers of the region.

Fertilization programme should include P,K and Ca and possibly Zn. It is best to lime this soil every 4 to 5 years with dolomitic lime. This will supply Ca and Mg, but also will neutralize the acidifying effect of the N-fertilizers. In a crop rotation of maize-legumes-maize-pasture, the compound fertilizer is applied to the maize crop, while lime is most effcetive on the legume.

Soybean establishment might be hampered by capping of the topsoil if not well protected against heavy rain impact.

Erosion may occur on sloping land, especially where compaction in the subsurface soil is severe. The compaction is aggrevated by the use of heavy machinery.

The suitability for cassava is low, because of frost hazard.

Ratings of land qualities: Pedon 6

POTENTIAL CONSTRAINTS	low inputs	high input
high temperature	2	2
high humidity	1	1
frost	2	2
length growing period (70% prob.)	140	140
eff. min. rainfall (70% prob.)	x:550	x:550
occurence critical periods	1	1
occurrence drought	x	x
SOIL CONSTRAINTS		
nutrient reserves	1	-
calcium	2	-
magnessium	2	-
potassium	1	-
Ca/K	2	-
zinc	1	-
molybdenum	1	-
sulphur	1	-
nutrient retention	3	2
rooting conditions (physical)	2	2
germination/establishment	1	1
mechnization/land preparation	1	1
ease of puddling	3	3
physical degradation	2	1
chemical degradation	2	1
biological degradation	3	1

Explanation of ratings:
-: no constraints
x: special constraints
1: slight constraints
2: moderate constraints
3: severe constraints
4: very severe constraints

PEDON 6 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS	
Maize	2	G,N	1	D,Ge,N	PKS,Ca,Mg, protection	degradation
Sorghum	2	G	1	Ge	Ca,Zn, protection	degradation
Cassava	3	F	3	F	-	
F/millet	2	G	1	Ge	Ca, protection	degradation
B/millet	2	G	1	Ge	Ca, protection	degradation
Wheat	3	T,Ge	3	T,Ge	-	
Dryl. rice	5a	D	5a	D	-(with irrigation; class; 1-Ge; effective inputs Ca,Zn, protection)	degradation
Paddy rice	5b	D	5b	D	-(with irrigation; class; 4a-P)	
Sunflower	2	N,G	1	N	PK,Ca, protection	degradation
Soyabean	2	N,Ge	2	Ge	PK	
Groundnut	2	G	1	Ge	Ca,Zn, protection	degradation
Ph/bean	2	G	1	G,M,Rp	PK,Ca,Zn, protection	degradation
Cotton	3	Ge	3	Ge	-	
V/tobacco	2	G	1	G,M	PK,Ca, protection	degradation

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 7

Print date: 10-21-1987

Pedon: MPONGWE NSSL ID #: 84P0515
Soil Survey # S83-FN-990-009
Location: About 14 km WSW of Mpongwe at the GRZ/EEC wheat scheme CoP Zambia.
Latitude: 13-36- -S Longitude: 028-04- -E
Classification: Clayey, kaolinitic, isohyperthermic Typic Eutrustox
Physiography: Upland slope in level or undulating uplands
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1240 m MSL
Precipitation: 1210 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Rapid
Air Temp. (Centigrade): Ann: 197 Sum: 206 Win: 157
Soil Temp. (Centigrade): Ann: 222 Sum: 223 Win: 197
Drainage: Well drained Land Use:
Stoniness:
Particle Size Control Section: 25 to 100 cm Runoff: Very slow
Parent Material: residuum from limestone material
Vegetation Codes: Weather Station: NDOLA
Diagnostic Horizons: 0 to 7 cm Ochric, 24 to 144 cm Oxic
Described by: D. Hallbick O. Spaargaren and S. B. Salama Date: 11/83

1. Classification tentatively Eutrustox based on data of nearby pits. Base saturation however is close to 50% hence soil borders the Haplustox. 2. Weather station located about 100 km to the NE.

A--0 to 7 cm; dark reddish brown (2.5YR 3/4) clay; dusky red (2.5YR 3/2) moist; weak fine and medium granular structure; soft, very friable, slightly sticky, nonplastic; many fine and medium roots throughout; many fine and medium continuous tubular and many fine void between rock fragments pores; clear smooth boundary.
84P2826

AB--7 to 24 cm; dark red (2.5YR 3/6) clay; dusky red (10R 3/4) moist; weak fine and medium subangular blocky structure; slightly hard, very sticky, very plastic; many fine and medium roots throughout; many fine and medium continuous tubular and many fine void between rock fragments pores; few patchy faint-thin clay films in root channels and/or pores; gradual smooth boundary.
The pore coatings in AB Bw1 Bw2 and Bw3 are pressure coatings rather than illuviation coatings.
84P2827

Bw1--24 to 42 cm; red (2.5YR 4/6) clay; dark red (10R 3/6) moist; weak medium and coarse subangular blocky structure parting to moderate very fine granular; slightly hard, very sticky, very plastic; many fine roots throughout; many fine continuous tubular and many very fine and fine interstitial pores; few patchy faint-thin clay films in root channels and/or pores and clay films on faces of peds; gradual smooth boundary.
84P2828

Bw2--42 to 74 cm; red (2.5YR 4/6) clay; dark red (10R 3/6) moist; moderate very fine granular structure; soft, very sticky, plastic; common fine roots throughout; many fine continuous tubular and many very fine and fine interstitial pores; few patchy faint-thin clay films in root channels and/or pores; diffuse smooth boundary.
84P2829

Bw3--74 to 144 cm; red (2.5YR 4/6) clay; dark red (10R 3/6) moist; moderate very fine granular structure; soft, very sticky, plastic; common fine roots throughout; many fine continuous tubular and many very fine and fine interstitial pores; few patchy faint-thin clay films in root channels and/or pores.
Difference between Bw2 and Bw3 is based on very slight color difference and a softer consistence of the Bw3. Horizon split for sampling 74 to 105 No. 2830 and 105 to 144 No. 2831.
84P2830

S84FN-990-009

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC RHODIC KANDIUSTULT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 515, SAMPLES 84P2826-2831
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- TOTAL CLAY LT .002	-2-- TOTAL SILT .002 -.05	-3-- TOTAL SAND .05 -2	-4-- CLAY FINE LT .0002	-5-- CLAY C03 LT .002	-6-- SILT FINE .002 -.02	-7-- SILT COARSE .02 -.05	-8-- SAND VF .05 -.10	-9-- SAND F .10 -.25	-10- SAND M .25 -.50	-11- SAND C .5 -1	-12- SAND VC 1 -2	-13- COARSE FRACTIONS(MM) WEIGHT 2 -5	-14- COARSE FRACTIONS(MM) WEIGHT 5 -20	-15- COARSE FRACTIONS(MM) WEIGHT 20 -75	-16- COARSE FRACTIONS(MM) WEIGHT .1- 75	-17- (>2MM) WT PCT OF WHOLE SOIL
			<- - - - - - - - - - - - PCT OF <2MM (3A1) - - - - - - - - - - - - - - ->												<- PCT OF <75MM(3B1)->				
84P2826S	0- 7	A	35.2	24.0	40.8			13.4	10.6	13.0	16.6	7.3	3.1	0.8	TR	--	--	28	--
84P2827S	7- 24	AB	52.1	16.0	31.9			7.9	8.1	10.0	12.6	5.6	2.7	1.0	TR	--	--	22	--
84P2828S	24- 42	BW1	56.4	13.5	30.1			6.8	6.7	8.9	11.0	5.5	2.9	1.8	TR	--	--	21	--
84P2829S	42- 74	BW2	56.9	13.5	29.6			6.7	6.8	8.9	11.2	5.3	3.1	1.1	TR	--	--	21	--
84P2830S	74-105	BW3	57.3	13.6	29.1			7.2	6.4	8.9	10.8	5.0	3.2	1.2	TR	--	--	20	--
84P2831S	105-144	BW3	57.6	13.3	29.1			6.4	6.9	8.7	10.9	4.8	3.1	1.6	TR	--	--	20	TR

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A	DITH-CIT EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D	15 BAR 8D1	ATTERBERG LIMITS LL 4F1	PI 4F	BULK DENSITY FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1	WATER CONTENT FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
				<- PERCENT OF <2MM -->						PCT <0.4MM		<- - G/CC - - ->			CM/CM	<- - -PCT OF <2MM - ->				CM/CM
0- 7	3.00	0.189			4.9	0.5	0.1	0.42	0.45	39	14		0.96	1.05	0.030			26.5	16.0	0.10
7- 24	1.48	0.086			5.7	0.6	0.1	0.19	0.32				1.17	1.23	0.017			23.2	16.5	0.08
24- 42	0.74	0.055			6.0	0.5	0.1	0.14	0.30	36	14		1.24	1.30	0.016			22.6	17.1	0.07
42- 74	0.37				6.0	0.5	0.1	0.11	0.29				1.26	1.30	0.010			21.9	16.5	0.07
74-105	0.20				6.1	0.5	0.1	0.10	0.29	37	6		1.25	1.27	0.005			22.1	16.7	0.07
105-144	0.13				6.1	0.5	0.1	0.08	0.29				1.23	1.25	0.005			22.6	16.5	0.08

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-009 PRINT DATE 10/19/87
CLASSIFICATION: SND ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC RHODIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 515, SAMPLE 84P2826-2831

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6O2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACIDITY 6H5A	-7-- EXTR AL 6G9A	-8-- SUM CATS 5A3A	-9-- NH4-OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- PH KCL IN 8C1G	-19- PH CACL2 .01M 8C1F 1:2	-20- PH H2O 8C1F 1:1
	(- NH4OAC EXTRACTABLE BASES -)					ACID-	EXTR	(- - - -CEC - - -)			AL	-BASE	SAT-	CO3 AS	RES.		COND.	(- - - -PH - - -)		
	<- - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - ->										<- - - - -PCT - - - ->									
0- 7	8.0	4.6	TR	0.6	13.2	8.0		21.2	14.8			62	89					6.0	6.0	6.4
7- 24	1.8	1.4	TR	0.1	3.3	9.9	0.8	13.2	9.7	4.1	20	25	34					4.6	4.7	5.5
24- 42	1.8	1.3	TR	TR	3.1	8.2		11.3	7.7			27	40					4.7	5.0	5.9
42- 74	1.4	1.0	TR	0.1	2.5	5.7		8.2	6.0			30	42					5.0	5.1	5.6
74-105	1.1	0.9	TR	TR	2.0	5.8		7.8	5.6			26	36					5.0	5.0	5.8
105-144	1.0	1.0	TR	TR	2.0	5.0		7.0	4.8			29	42					5.0	5.1	5.9

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -)							
	(- - - - - - - CLAY - - - - - - - -)(- - -)							
	(- - - - X-RAY - - - -)(- -DTA - -)						TOTAL	DOM
	(- - - - - <2U - - - -)(- -<2U - -)						RES	WEATH
	7A21	7A21	7A21	7A21	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 7								
7- 24								
24- 42	KK 4	GI 2	VR 2	GE 1	KK36	GI 2	99	WE 1
42- 74								
74-105	KK40	GI 2	VR 2	GE 2	KK49	GI 2		
105-144								

AVERAGES, DEPTH 25-100: PCT CLAY 57 PCT .1-75MM 21

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE GI GIBBSITE VR VERMICULITE GE GOETHITE WE WEATH MIN

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-009
CLASSIFICATION: SND ; CLAYEY, KAOLINITIC, ISOHYPERTHERMIC RHODIC KANDIUSTULT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 515, SAMPLE 84P2826-2831

PRINT DATE 10/19/87

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            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

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           FRACT < - - - - - - X-RAY - - - - - -><- - - THERMAL - - - -><- - - - - - - - - ELEMENTAL - - - - - - - -><- -> SURF  INTER
 DEPTH       ION <                              ><- DTA - -><- TGA - -> SIO2 AL203 Fe203  MgO   CaO   K20   Na20 <    > AREA  PRETA
             < - - - - - -  7A2I - - - - - -><- 7A3b - ><- 7A4b - ><- - - - - - - - - - 7C3 - - - - - - - - -><    >         TION
 (cm)      <- - ><- - - - - peak size - - - - -><- - - Percent - - - -><- - - - - - - - - Percent - - - - - - - -><- -><M2/G><- - ->

 24- 42     TCLY  KK 4  GI 2  VR 2  GE 1  HE 1  KK36  GI 2                                12.9                0.4
 74-105     TCLY  KK40  GI 2  VR 2  GE 2  HE 1  KK49  GI 2                                12.2                0.4

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           < - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - >
           FRACT < - - - - - - X-RAY - - -><- - - THERMAL - - - -><- - - - - - - - - OPTICAL - - - - - - - - -><                 > INTER
 DEPTH       ION <                          ><- DTA - -><- TGA - ->TOT RE< - - - - - GRAIN COUNT - - - - - -><                 > PRETA
             < - - - - - 7A2I - - - - -><- 7A3b - ><- 7A4b - ><- - - - - - - - - - 7B1a - - - - - - - - -><                 >  TION
 (cm)      < - -><- - - Peak Size - - -><- - - Percent - - - -><- - - - - - - - - Percent - - - - - - - -><- - - - - - - -><- - ->

 24- 42     FS                                                 99  RE99  WE 1

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KIND OF MINERAL:

KK kaolinite GI gibbsite VR vermiculite GE goethite HC hematite RE resist min
WE weath min MI mica

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 7 - Land evaluation (W. Veldkamp)

This is a relatively good soil, but subject to chemical degradation. A continuous cover and strip cropping would be a suitable way of sustained crop production. Besides degradation protection, P, K, Ca and Zn have to be applied. It is uncertain whether S-deficiency occurs, although the distance to the S-polluting mines is only 100km.

Cereals and legumes can be cultivated satisfactorilly. The temperature will be too high for rainfall wheat. A humidity limitation is assumed for cotton.

At present this soil is used by the GRZ/EEC scheme to produce irrigated (winter) wheat and soybeans. Although the available water holding capacity is relatively high (160-120mm over the upper 1.0 metre) the topsoil tends to dry out quickly. The irrigation water, derived from a nearby sinkhole in the limestone, contains calcium and therefore under irrigation the pH is maintained at the present level.

Ratings of land qualities: pedon 7

POTENTIAL CONSTRAINTS	Low inputs	High inputs
high temperature	2	2
high humidity	2	2
frost	2	2
length growing period (70% prob.)	145	145 (days)
eff. min. rainfall (70% prob.)	675	675 (mm)
occurrence critical periods	x	x
occurrence drought	x	x
SOIL CONSTRAINTS		
nutrient reserves	3	1
phosphate fixation	1	-
calcium	2	-
magnesium	1	-
potassium	2	-
zinc	1	-
molybdenum	1	-
sulphur	1	-
nutrient retention	2	1
heavy topsoil	3	3
ease of puddling	2	2
chemical degradation	2	1
biological degradation	1	-

Explanation of ratings:
-: no constraint
x: special drought constraint
1: slight constraint
2: Moderate constraint
3: severe constraint
4: very severe constraint

PEDON 7 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	2	G	1	N	PK,Zn, degradation protection
Sorghum	2	G	1	G	(PKS),Zn, degradation protection
Cassava	3	F	3	F	-
F/millet	2	Ht	2	Ht	-
B/millet	2	Ht	2	Ht	-
Wheat	3	T	3	T	-
Dryl. rice	4b	D	4b	D	-(with irrigation; class 1-G,H; effective inputs (PKS), Zn, degradation, protection)
Paddy rice	4b	D,P	4b	D,P	-(with irrigation; class; 3-p)
Sunflower	2	G	1	G	PK, (Zn,S), degradation protection
Soyabean	2	G	1	G	PK,Ca,(Mg),Zn,(S,Mo:) degradation protection
Groundnut	2	G	1	G	(PKS),Ca,Zn,(Mo), degradation protection
Ph/bean	2	G	1	G	(PKS),Zn,(Mo), degradation protection
Cotton	2	G,H	2	H	Degradation protection
V/tobacco	4a	Ht	4a	Ht	-

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 8

Print date: 10-21-1987

Pedon: Mukumbi NSSL ID #: 84P0512
Soil Survey # S83-FN-990-006
Location: Mulungushi farm about 19 km N of Kabwe CeP Zambia. Pit located about 1300 m S of the farmhouse.
Latitude: 14-18- -S Longitude: 028-31- -E
Classification: Clayey, kaolinitic, isohyperthermic Oxic Paleustalf
Physiography: Upland slope in level or undulating uplands
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1150 m MSL
Precipitation: 950 mm Ustic moisture regime MLRA: ♦
Water Table Depth: Permeability: Moderately slow
Air Temp. (Centigrade): Ann: 201 Sum: 212 Win: 166
Soil Temp. (Centigrade): Ann: 239 Sum: 241 Win: 208
Drainage: Somewhat poorly drained Land Use:
Stoniness:
Particle Size Control Section: 45 to 95 cm Runoff: Very slow
Parent Material: residuum from gniess material
Vegetation Codes: Weather Station: KABWE
Diagnostic Horizons: 0 to 8 cm Ochric, 45 to 124 cm Argillic
Described by: D. Hallbick O. Spaargaren and P. Woode Date: 11/83

Probably kandic. In BA Bt1 and Bt2 horizons termite chambers from 3 to 6 cm in size generally elepsoidic shaped connected by channels of .5 to 1 cm in diameter. These channels and chambers usually have lined walls and surrounding.

A--0 to 8 cm; brown (10YR 5/3) sandy loam; very dark grayish brown (10YR 3/2) moist; weak medium granular structure; soft, nonsticky, nonplastic; common fine and medium roots throughout; many fine and medium continuous tubular and many fine void between rock fragments pores; clear smooth boundary.
84P2808

AB--8 to 27 cm; light yellowish brown (10YR 6/4) sandy clay loam; brown (7.5YR 5/4) moist; weak massive structure; slightly hard, slightly sticky, plastic; few fine and medium roots in mat at top of horizon and very few very coarse roots in mat at top of horizon; common fine and medium continuous tubular and common fine interstitial pores; very few medium and coarse rounded ironstone nodules; gradual smooth boundary.
84P2809

BA--27 to 45 cm; reddish yellow (7.5YR 6/6) clay; strong brown (7.5YR 5/6) moist; weak massive structure; slightly hard, very sticky, very plastic; very few fine roots throughout; few to common fine to coarse continuous tubular and few fine interstitial pores; few patchy faint-thin organic coats between sand grains; very few medium and coarse ironstone nodules; clear smooth boundary.
84P2810

Bt1--45 to 83 cm; reddish yellow (7.5YR 6/6) clay; strong brown (7.5YR 5/6) moist; moderate medium and coarse subangular blocky structure; slightly hard, very sticky, very plastic; very few fine roots throughout; few to common fine to coarse continuous tubular and common fine and medium void between rock fragments pores; few continuous distinct-thin clay films in root channels and/or pores; few patchy faint-thin clay films on vertical faces of peds; very few medium and coarse rounded ironstone nodules; clear smooth boundary.
84P2811

Bt2--83 to 124 cm; reddish yellow (7.5YR 6/6) clay; strong brown (7.5YR 5/6) moist; weak medium and coarse subangular blocky structure; slightly hard, slightly sticky, plastic; very few fine roots throughout; few to common fine to coarse continuous tubular and common fine and medium void between rock fragments pores; few patchy faint-thin clay films on vertical faces of peds; very few medium and coarse rounded ironstone nodules; clear smooth boundary.
A few cracks occur about 1 mm wide starting at the base of the AB horizon. Distance between cracks is 1 to 1.5 m.
84P2812

Btc--124 to 158 cm; reddish yellow (7.5YR 6/6) clay; strong brown (7.5YR 5/6) moist; weak fine SBL structure; soft, very sticky, very plastic; very few fine roots throughout; few fine and medium continuous tubular and common to many fine and medium void between rock fragments pores; few patchy faint-thin clay films between sand grains; few to common medium and coarse rounded ironstone nodules and few coarse 2 ironstone nodules.
Color of concretions (10YR 7/6) and (2.5YR 5/8) both when dry.
84P2813

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-006 (ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; FINE, KAOLINITIC, ISOHYPERTHERMIC TYPIC KANDIUSTALF

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 512, SAMPLES 84P2808-2813
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

SAMPLE NO.	DEPTH (CM)	HORIZON	(- - -TOTAL - - -) CLAY LT .002	SILT .002 -.05	SAND .05 -2	(- -CLAY- -) FINE LT .002	CO3 LT .002	(- -SILT- -) FINE .002 -.02	COARSE .02 -.05	(- - - - -SAND- - - - - -) VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	(-COARSE FRACTIONS(MM)-) 2 -5	WEIGHT 5 -20	20 -75	(>2MM) .1- 75	WT PCT OF WHOLE SOIL
			<- - - - - - - - - - - - PCT OF <2MM						(3A1) - - - - - - - - - - - - - - ->						<- PCT OF <75MM(3B1)->		
84P2808S	0- 8	A	11.8	6.9	81.3			2.5	4.4	11.8	31.7	29.4	7.3	1.1	TR	--	--	69	TR
84P2809S	8- 27	AB	13.7	7.0	79.3			2.4	4.6	11.3	29.6	28.2	7.9	2.3	1	--	--	68	1
84P2810S	27- 45	BA	29.3	6.5	64.2			2.5	4.0	8.1	19.9	24.1	10.0	2.1	1	--	--	57	1
84P2811S	45- 83	BT1	46.5	5.5	48.0			2.3	3.3	6.1	14.0	17.4	7.5	3.0	1	--	--	42	1
84P2812S	83-124	BT2	41.1	10.8	48.1			5.3	5.5	7.5	15.7	14.9	6.3	3.7	3	TR	--	42	3
84P2813S	124-158	BT3	37.3	13.8	48.9			6.6	7.2	10.5	14.6	13.4	7.3	3.1	7	1	--	43	8

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A <- PERCENT	(- -DITH-CIT - -) EXTRACTABLE FE 6C2B	AL 6G7A OF	MN 6D2A <2MM -->	CEC 8D1	(RATIO/CLAY) 15 BAR 8D1	(ATTERBERG) - LIMITS - LL 4F1 PCT	PI 4F <0.4MM	(- BULK DENSITY -) FIELD MOIST 4A3A <- -	1/3 BAR 4A1D G/CC -	OVEN DRY 4A1H - ->	COLE WHOLE SOIL 4D1 CM/CM	(- - -WATER CONTENT - -) FIELD MOIST 4B4 <- -	1/10 BAR 4B1C -PCT OF	1/3 BAR 4B1C <2MM	15 BAR 4B2 - ->	WRD WHOLE SOIL 4C1 CM/CM
0- 8	1.01	0.063			0.6	0.1	TR	0.30	0.38	16	2		1.37	1.43	0.014			11.1	4.5	0.09
8- 27	0.31	0.031			0.7	0.1	TR	0.18	0.31				1.50	1.54	0.009			7.6	4.3	0.05
27- 45	0.25	0.022			1.1	0.2	TR	0.09	0.29				1.56	1.60	0.008			12.2	8.4	0.06
45- 83	0.20				1.4	0.3	--	0.08	0.29	37	18		1.48	1.50	0.004			15.8	13.5	0.03
83-124	0.15				1.4	0.3	--	0.07	0.33				1.36	1.40	0.010			16.8	13.4	0.05
124-158	0.12				2.0	0.3	--	0.08	0.37	35	14		1.30	1.32	0.005			18.4	13.7	0.06

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-006 PRINT DATE 10/19/87
CLASSIFICATION: SND ; FINE, KAOLINITIC, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 512, SAMPLE 84P2808-2813

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID- ITY 6H5A	-7-- EXTR AL 6G9A	-8-- SUM CATS 5A3A	-9-- NH4- OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- -BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- -PH- KCL IN 8C1G	-19- CACL2 .01M 8C1F 1:2	-20- H2O 8C1F 1:1
	(- NH4OAC EXTRACTABLE BASES -)							(- - - -CEC - - -)				-PCT								
	<- - - - - - - - - - -HEQ / 100 G - - - - - - - - - - ->										<- - - -		- - ->							
0- 8	1.9	0.5	TR	0.2	2.6	1.9		4.5	3.5			58	74					4.9	5.1	5.9
8- 27	0.6	0.3	TR	--	0.9	2.4	0.2	3.3	2.5	1.1	18	27	36					4.4	4.8	5.5
27- 45	0.9	0.4	TR	0.1	1.4	1.4	0.2	2.8	2.5	1.6	13	50	56					4.5	4.9	5.4
45- 83	1.4	0.8	TR	0.2	2.4	2.3		4.7	3.7			51	65					4.9	5.2	5.6
83-124	1.1	0.8	TR	0.2	2.1	1.5		3.6	2.9			58	72					5.6	5.8	6.1
124-158	0.9	0.7	TR	0.4	2.0	1.6		3.6	2.8			56	71					5.8	5.9	6.0

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -)							
	(- - - - - - - CLAY - - - - - - - -)(- - -) -)							
	(- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM							
	(- - - - - <2U - - - -)(- -<2U - -) RES WEATH							
	7A21	7A21	7A21	7A21	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 8								
8- 27								
27- 45								
45- 83	KK 5	MI 2	GE 2	GI 1	KK53	GITR	95	WE 5
83-124								
124-158	KK 5	MI 2	GE 2	GI 1	KK57	GITR		

AVERAGES, DEPTH 45- 95: PCT CLAY 45 PCT .1-75MM 43

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MI MICA GE GOETHITE GI GIBBSITE WE WEATH MIN

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-006
CLASSIFICATION: SND ; FINE, KAOLINITIC, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 512, SAMPLE 84P2808-2813

PRINT DATE 10/19/87

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            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-
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          FRACT < - - - - - - X-RAY - - - - - -><- - - THERMAL - - - -><- - - - - - - - ELEMENTAL - - - - - - - -><- -> SURF  INTER
 DEPTH      ION <                              ><- DTA - -><- TGA - -> SiO2 AL2O3 Fe2O3  MgO   CaO   K2O   Na2O <    > AREA  PRETA
            < - - - - - -  7A2i - - - - - -><- 7A3b - -><- 7A4b - -><- - - - - - - - - 7C3 - - - - - - - - -><    >         TION
 (cm)     <- - -><- - - - - peak size - - - -><- - - Percent - - - -><- - - - - - - - - Percent - - - - - - - -><- -><M2/G><- - ->
 45- 83     TCLY  KK 5  MI 2  GE 2  GI 1        KK53  Gltr                          6.1                0.5
124-158     TCLY  KK 5  MI 2  GE 2  GI 1        KK57  Gltr                          6.4                0.6
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          < - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - >
          FRACT < - - - - - - X-RAY - - -><- - - THERMAL - - - -><- - - - - - - -  OPTICAL - - - - - - - - -><                 > INTER
 DEPTH      ION <                          ><- DTA - -><- TGA - ->TOT RE<- - - - - - GRAIN COUNT - - - - - -><                 > PRETA
            < - - - - - 7A2i - - - - -><- 7A3b - -><- 7A4b - -><- - - - - - - - -  7B1a - - - - - - - - -><                 >  TION
 (cm)     < - -><- - - - Peak Size - - -><- - - Percent - - - -><- - - - - - - - - Percent - - - - - - - -><- - - - - - - -><- - ->
 45- 83     FS                                                    95  RE95  WE 5
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KIND OF MINERAL:

KK kaolinite MI mica GE goethite GI gibbsite RE resist min WE weath min

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 8 - Land evaluation (W. Veldkamp)

This is a problem soil with especially soil physical constraints. Not only is degradation (biological, chemical and physical) of the soil major problem, but also the usually compacted B-horizon. Therefore ripping may be useful if the depth of the compaction can be reached. For sustained crop production soil conservation measures have to be taken. A few years of cropping should be alternated with pasture/legume fallow.

During the cropping period the soil should be fertilized with P,K and Zn. Furthermore small dolomitic lime application is required to supply Ca and Mg and to counteract the acidifying effect of N-fertilizers. The lime is best applied to a legume crop.

It is assumed that after ripping the internal drainage of the soil has been improved, even for Virginia tobacco. The major crops for this soil are maize, sorghum, millet, sunflower, groundnuts, beans, and tobacco.

Ratings of the land qualities; pedon 8

POTENTIAL CONSTRAINTS	low inputs	high inputs
high temperature	2	2
high humidity	1	1
frost	2	2
length growing period (70% prob.)	140	140 (days)
eff. min. rainfall (70% prob.)	x;400	x;400 (rating;mm)
occurrence critical periods	1	1
occurrence drought	x	x
SOIL CONSTRAINT		
oxygen availability (CO2 toxicity)	1	-
nutrient reserves	3	1
calcium	2	-
magnesium	2	-
potassium	4	-
Ca/K	1	-
zinc	1	-
molybdenum	1	-
sulphur	1	-
nutrient retention	3	2
rooting conditions (physical)	3	2
germination/establishment	1	1
aluminium toxicity	2	1
mechanization/land preparation	1	1 (anthills)
ease of puddling	3	3
physical degradation	2	1
chemical degradation	2	1
biological degradation	3	1

Explanation of ratings:
-: no constraint
x: special drought constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 8 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	2	G,N,Rp	1	Ge,N	PK,Mg,Zn, ripping, degradation protection
Sorghum	2	G,Rp	1	Ge	Zn, ripping, degradation protection
Cassava	4a	K	3	F	K
F/millet	2	G	1	Ge	ripping, degradation protection
B/millet	2	G	1	O,Ge	ripping, degradation protection
Wheat	3	Ge,T	3	Ge,T	-
Dryl.rice	5a	D	5a	D	-(with irrigation class 1-Ge; effective inputs Zn, degradation protection
Paddy rice	5b	D,P	5b	D,P	-(with irrigation; class 4a-P)
Sunflower	2	G,N	1	N	PK, degradation protection
Soyabean	3	K	2	Ge	K
Groundnut	2	Ca,G,Zn	1	Ge	K,Ca,Zn, degradation protection
Ph/bean	2	Rp	1	Rp,A,M,G	PK,Zn, ripping, degradation protection
Cotton	3	Ge	3	Ge	-
V/tobacco	4a	O	1	M,G	PK, ripping, degradation, protection

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 9

Print date: 10-21-1987

Pedon: Liteta NSSL ID #: 84P0526
Soil Survey # S83-FN-990-020
Location: Chief Liteta Corp. Farm 5 km N of Liteta Leprosarium along Grear North road between Lusaka and Kabwe CeP Zamb
Latitude: 14-43- -S Longitude: 028-04- -E
Classification: Very-fine, mixed, isohyperthermic Udic Paleustoll
Physiography: Upland slope in level or undulating uplands
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1150 m MSL
Precipitation: 950 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderate
Air Temp. (Centigrade): Ann: 201 Sum: 213 Win: 160
Soil Temp. (Centigrade): Ann: 239 Sum: 241 Win: 208
Drainage: Moderately well drained Land Use: Cropland
Stoniness:
Particle Size Control Section: 39 to 89 cm Runoff: Very slow
Parent Material: residuum from limestone material
Vegetation Codes: Weather Station: Kabwe
Diagnostic Horizons: 0 to 21 cm Mollic, 39 to 144 cm Argillic
Described by: D. Hallbick and O. Spaargaren Date: 11/83

Ap--0 to 21 cm; brown to dark brown (10YR 4/3) clay; very dark grayish brown (10YR 3/2) moist; moderate to strong medium and coarse subangular blocky structure parting to moderate to strong medium granular; slightly hard, slightly sticky, plastic; many fine roots throughout; common to many fine and medium continuous tubular and many very fine and fine void between rock fragments pores; abrupt smooth boundary.
84P2895

AB--21 to 39 cm; brown to dark brown (7.5YR 4/4) clay; dark brown (7.5YR 3/4) moist; strong medium and coarse subangular blocky structure; slightly hard, slightly sticky, plastic; many fine roots throughout; many fine and medium continuous tubular and many fine and medium void between rock fragments pores; few patchy distinct-thin organic coats on vertical faces of peds; clear smooth boundary.
84P2896

Bt1--39 to 70 cm; strong brown (7.5YR 5/6) clay; strong brown (7.5YR 4/6) moist; very few fine faint 48 (7.5YR 4/8) mottles; weak very coarse subangular blocky structure parting to strong medium and coarse angular blocky; hard, very sticky, plastic; common fine roots throughout; many fine and medium continuous tubular and many fine to coarse void between rock fragments pores; many discontinuous distinct-thin clay films on vertical and horizontal faces of peds; very few fine and medium rounded ironstone nodules; gradual smooth boundary.
84P2897

Bt2--70 to 103 cm; strong brown (7.5YR 5/6) clay; strong brown (7.5YR 4/6) moist; few fine faint yellowish red (5YR 4/6) mottles; moderate medium prismatic structure; slightly hard, very sticky, plastic; common fine roots throughout; common fine and medium continuous tubular and many fine to coarse void between rock fragments pores; common discontinuous distinct-thin clay films on vertical faces of peds; few patchy prominent-thin black (N 2/0) manganese or iron-manganese coats on vertical and horizontal faces of peds; few to common fine and medium rounded ironstone nodules; gradual smooth boundary.
84P2898

Bt3--103 to 144 cm; yellowish brown (10YR 5/6) clay; dark yellowish brown (10YR 4/6) moist; few to common fine distinct yellowish red (5YR 4/8) mottles; weak to moderate coarse and very coarse subangular blocky structure; slightly hard, very sticky, plastic; common fine roots throughout; common fine to coarse continuous tubular and many fine to coarse void between rock fragments pores; common discontinuous faint-thin clay films on vertical faces of peds; few patchy prominent-thin black (N 2/0) manganese or iron-manganese coats on vertical and horizontal faces of peds; common fine and medium rounded ironstone nodules; clear smooth boundary.
84P2899

Btco--144 to 179 cm; yellowish brown (10YR 5/6) clay; dark yellowish brown (10YR 4/6) moist; common to many fine and medium prominent red (2.5YR 4/8) mottles; moderate medium and coarse subangular blocky structure; slightly hard, very sticky, plastic; few fine roots throughout; common fine and medium void between rock fragments pores; common patchy faint-thin clay films on vertical faces of peds; few patchy prominent-thin black (N 2/0) manganese or iron-manganese coats on vertical and horizontal faces of peds; many fine to coarse rounded ironstone nodules; 50 percent cobbles from ironstone.
84P2900

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-020 (ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; CLAYEY, MIXED, ISOHYPERTHERMIC UDIC PALEUSTOLL

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 526, SAMPLES 84P2895-2900
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	TOTAL CLAY LT .002	TOTAL SILT .002 -.05	TOTAL SAND .05 -2	TOTAL FINE LT .0002	CLAY CO3 LT .002	SILT FINE .002 -.02	SILT COARSE .02 -.05	SAND VF .05 -.10	SAND F .10 -.25	SAND M .25 -.50	SAND C .5 -1	SAND VC 1 -2	COARSE FRACTIONS(MM) WEIGHT 2 -5	5 -20	20 -75	>2MM .1-75	WT PCT OF WHOLE SOIL
			<- PCT OF <2MM (3A1)												<- PCT OF <75MM(3B1)->				
84P2895S	0- 21	AP	37.4	21.8	40.8	21.9		9.3	12.5	16.5	17.5	4.6	1.6	0.6	--	--	--	24	--
84P2896S	21- 39	AB	49.7	19.3	31.0	31.9		8.4	10.9	13.6	12.2	3.3	1.3	0.6	--	--	--	17	--
84P2897S	39- 70	BT1	56.9	17.5	25.6	37.3		7.7	9.8	11.5	9.6	2.6	0.9	1.0	--	--	--	14	--
84P2898S	70-103	BT2	60.1	16.6	23.3	37.2		8.0	8.6	10.4	9.1	2.2	1.1	0.5	TR	--	--	13	--
84P2899S	103-144	BT3	56.7	18.2	25.1	32.3		9.1	9.1	10.8	10.0	2.2	1.1	1.0	TR	--	--	14	--
84P2900S	144-179	BTCO	56.2	18.6	25.2	30.0		8.8	9.8	11.2	9.5	2.3	1.2	1.0	--	--	--	14	--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A	DITH-CIT EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1	PI 4F	BULK DENSITY FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1	WATER CONTENT FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
				<- PERCENT	OF <2MM -->					PCT <0.4MM		<- - G/CC	- - ->		CM/CM	<- - -PCT OF <2MM	- ->			CM/CM
0- 21	2.03	0.136			3.9	0.5	0.1	0.40	0.36				1.25	1.36	0.029			21.1	13.3	0.10
21- 39	1.41	0.113			4.5	0.7	0.1	0.32	0.33				1.37	1.53	0.038			24.7	16.5	0.11
39- 70	1.11	0.092			4.9	0.7	0.1	0.28	0.33				1.34	1.47	0.031			26.5	18.9	0.10
70-103	0.79				4.9	0.7	TR	0.25	0.32				1.23	1.35	0.032			26.9	19.2	0.09
103-144	0.62				4.6	0.7	TR	0.25	0.33				1.24	1.34	0.026			26.1	18.7	0.09
144-179	0.37				5.0	0.8	TR	0.21	0.33				1.26	1.36	0.026			26.4	18.3	0.10

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-020 PRINT DATE 10/19/8
CLASSIFICATION: SND ; CLAYEY, MIXED, ISOHYPERTHERMIC UDIC PALEUSTOLL
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 526, SAMPLE 84P2895-2900

DEPTH (CM)	-1- (- NH4OAC EXTRACTABLE BASES -) CA 5B5A 6H2E	-2- MG 5B5A 6Q2D	-3- NA 5B5A 6P2B	-4- K 5B5A 6Q2B	-5- SUM BASES	-6- ACID- ITY 6H5A	-7- EXTR AL 6G9A	-8- (- - - -CEC - - -) SUM CATS 5A3A	-9- NH4- OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- -BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- (- - - -PH - - -) NAF 8C1D	-19- CACL2 .01M 8C1F 1:2	-20- H2O 8C1F 1:1
	<- - - - - - - - - - -MEQ / 100 G - - - - - - - - - - ->										<- - - - -PCT - - - ->									
0- 21	5.8	3.9	TR	0.2	9.9	10.3		20.2	15.1			49	66						4.8	5.8
21- 39	6.1	3.8	0.1	0.1	10.1	10.7		20.8	15.7			49	64					9.2	5.0	5.9
39- 70	6.1	3.6	TR	0.1	9.8	9.8		19.6	15.8			50	62					9.3	5.0	6.0
70-103	6.0	3.7	TR	0.1	9.8	9.0		18.8	14.8			52	66					9.5	5.2	5.7
103-144	5.5	3.8	TR	TR	9.3	7.6		16.9	13.9			55	67					9.5	5.4	5.9
144-179	4.6	3.7	TR	TR	8.3	6.8		15.1	11.9			55	70					9.6	5.8	6.2

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -) (- - - - - - - CLAY - - - - - - -)(- - -) -) (- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM (- - - - - <2U - - - -)(- -<2U - -) RES WEATH 7A2I	7A2I	7A2I	7A2I	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 21								
21- 39								
39- 70	KK 3	MT 2	GE 2		KK33		94	EP 3
70-103								
103-144	KK 3	GE 2	MT 2	VR 1	KK35			
144-179								

AVERAGES, DEPTH 39- 89: PCT CLAY 58 PCT .1-75MM 14

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MT MONTMORILL GE GOETHITE EP EPIDOTE VR VERMICULITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-020
CLASSIFICATION: SND ; CLAYEY, MIXED, ISOHYPERTHERMIC UDIC PALEUSTOLL
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 526, SAMPLE 84P2895-2900

PRINT DATE 10/19/87

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            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-
--------- ------------------------------------------------------------------------------------------------------------------------
          < - - - - - - - - - - - - - - - - - - - - - - CLAY MINERALOGY (<.002mm) - - - - - - - - - - - - - - - - - - - - - - - - >
          FRACT < - - - - - - X-RAY - - - - - - -><- - - THERMAL - - - -><- - - - - - - - ELEMENTAL - - - - - - - -><- -> SURF  INTER
 DEPTH      ION <                          ><- DTA - -><- TGA - -> SIO2 AL2O3  e2O3  MgO   CaO   K2O   Na2O <    > AREA  PRETA
            < - - - - - -  7A2i - - - - - -><- 7A3b - ><- 7A4b - ><- - - - -  - - - 7C3 - - - - - - - - -><    >         TION
  (cm)    <- - -><- - - - peak size - - - - -><- - - Percent - - - -><- - - - - - - - - Percent - - - - - - - -><- -><M2/G><- - ->

 39- 70     TCLY  KK 3  MT 2  GE 2              KK33                                14.3                0.4
103-144     TCLY  KK 3  GE 2  MT 2  VR 1  MI 1  KK35                                14.3                0.4
--------- ------------------------------------------------------------------------------------------------------------------------
          < - - - - - - - - - - - - - - - - - - - - - - SAND - SILT MINERALOGY (2.0-0.002mm) - - - - - - - - - - - - - - - - - - - - >
          FRACT < - - - - - - X-RAY - - -><- - - THERMAL - - - -><- - - - - - - - OPTICAL - - - - - - - - -><                > INTER
 DEPTH      ION <                          ><- DTA - -><- TGA - ->TOT RE< - - - - - GRAIN COUNT - - - - - -><                > PRETA
            < - - - - - 7A2i - - - - -><- 7A3b - ><- 7A4b - ><- - - - - - - - - 7B1a - - - - - - - - -><                > TION
  (cm)    < - -><- - - Peak Size - - -><- - - Percent - - - -><- - - - - - - - - Percent - - - - - - - -><- - - - - - - -><- - ->

 39- 70     VFS                                                   94  QZ84  OP 7  EP 3  FK 2  RU 2  TM 1
 39- 70     VFS                                                       BT 1  RAtr
--------- ------------------------------------------------------------------------------------------------------------------------
```

KIND OF MINERAL:

KK	kaolinite	MT	montmorill	GE	goethite	QZ	quartz	OP	opaques	EP	epidote
FK	potas-feld	RU	rutile	TM	tourmaline	BT	biotite	RA	resist-aggre	VR	vermiculite
MI	mica										

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 9 - Land evaluation (W. Veldkamp)

This soil needs some improvements to make it a really productive soil. The potassium status is low. There may be some P-fixation, although it is uncertain. Sulphur and zinc should be applied. Maybe the moderately well drainage conditions can be improved by ditches. Ripping may also be useful, but the prismatic structure of the subsoil will remain a constraint for good rooting conditions.

The workability of the topsoil will be reduced for hoe cultivation, but with mechanization a good tilth might be produced.

Best crops are maize, sorghum, soybean, beans, cotton and especially sunflower.

With irrigation rice can be produced, whereas supplementary irrigation will increase the maize yields.

Ratings of the land qualities; pedon 9

POTENTIAL CONSTRAINTS	Low inputs	High inputs
high temperature	2	2
high humidity	1	1
frost	1	1
length growing season (70% prob.)	125	125 (days)
eff. min. rainfall (70% prob.)	1;350	1;350 (rating; mm)
occurrence critical periods	1	1
occurrence drought	x	x
SOIL CONSTRAINTS		
Oxygen availability (CO_2 toxicity)	1	-
phosphate fixation	1	-
potassium	3	-
zinc	1	-
molybdenum	1	-
sulphur	1	-
rooting conditions (physical)	2	2
heavy topsoil	3	
aluminium toxicity	1	-
workability	2	1 (structure, texture)
chemical degradation	1	-

Explanation of ratings:
-: no constraint
x: special drought constraint
1 slight constraint
2: moderate constraint
3: severe constraint
4: Very severe constraint

PEDON 9 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	2	K,Np,Zn	1	D	P,K,Zn (with irrigation; class 1-Rp)
Sorghum	2	Zn	1	Rp	Zn
Cassava	3	W	3	W	-
F/millet	2	Ht	2	Ht	-
B/millet	2	Ht	2	Ht	-
Wheat	3	T	3	T	-
Dryl. rice	5a	D	5a	D	-(with irrigation; class 1-H; effective inputs PKS, Zn, degradation protection
Paddy rice	5a	D	5a	D	-(with irrigation; class: 1A; effective inputs (PKS, Zn)
Sunflower	1	O	1A	-	PKS, lime, Zn, drainage, degradation protection
Soyabean	3	K	1	Rp	K,Zn,(PS,Mo,lime degradation protection)
Groundnut	2	W	1	W	Zn, mechanized tillage (PKS,Mo, degradation protection
Ph/bean	2	Zn	1	Rp	Zn, drainage, (PKS,Mo, lime degradation protection
Cotton	1	O,Rp	1	Rp	drainage, (PKS,Zn,lime, degradation protection)
V/tobacco	4a	Ht,O	4a	Ht	(drainage)

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 10

Print date: 10-21-1987

Pedon: Kafue NSSL ID #: 84P0520
Soil Survey # S83-FN-990-014
Location: Harthoorn's farm 10 km W of Kafue LuP Zambia. Pit located about 250 m SE of fish farm offices.
Latitude: 15-46- -S Longitude: 027-55- -E
Classification: Fine, montmorillonitic (calcareous), isohyperthermic Udic Chromustert
Physiography: Broad plain in lake Plains
Geomorphic Position:
Microrelief: gilgai, Height: less than 20 cm, Pattern: reticulate
Slope Characteristics: Elevation: 990 m MSL
Precipitation: 780 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Very slow
Air Temp. (Centigrade): Ann: 208 Sum: 225 Win: 160
Soil Temp. (Centigrade): Ann: Sum: Win:
Drainage: Somewhat poorly drained
Land Use: Pasture land and native pasture
Stoniness:
Particle Size Control Section: 25 to 100 cm Runoff: Ponded
Parent Material: lacustrine from sedimentary material
Vegetation Codes: Weather Station: Kafue
Diagnostic Horizons: 0 to 8 cm Ochric, 8 to 133 cm Cambic, 24 to 154 cm Calcic
Described by: D. Hallbick O. Spaargaren and C. Kalima Date: 11/83

Not sure of length of time cracks are open may be Typic. Cracks are 4 cm wide at a depth of 50 cm. Polygon diameter about 90 to 100 cm.

A--0 to 8 cm; dark grayish brown (2.5Y 4/2) clay; very dark grayish brown (2.5Y 3/2) moist; few to common fine prominent yellowish red (5YR 5/8) mottles; strong medium and coarse granular structure; hard, very sticky, very plastic; many fine and medium roots throughout; many very fine and fine void between rock fragments pores; common fine rounded ironstone nodules; clear smooth boundary.
84P2857

Bw--8 to 24 cm; olive (5Y 4/3) clay; dark olive gray (5Y 3/2) moist; few to common fine prominent yellowish red (5YR 5/8) mottles; strong medium and coarse subangular blocky structure; hard, very sticky, very plastic; many fine and medium roots throughout; many fine and medium discontinuous tubular pores; few continuous thin intersecting slickensides on faces of peds; common fine and medium rounded ironstone nodules and few fine and medium rounded lime nodules; clear smooth boundary.
84P2858

Bkl--24 to 74 cm; olive gray (5Y 4/2) clay; dark olive gray (5Y 3/2) moist; strong medium and coarse angular blocky structure; hard; common to many fine roots throughout; few to common very fine and fine discontinuous tubular pores; many thin intersecting slickensides on faces of peds; common fine to coarse rounded lime nodules and common fine and medium rounded ironstone nodules; gradual wavy boundary.
84P2859

Bk2--74 to 133 cm; olive gray (5Y 4/2) clay; dark olive gray (5Y 3/2) moist; strong medium and coarse angular blocky structure; hard, very firm; common fine roots throughout; few to common very fine and fine discontinuous tubular pores; many thin intersecting slickensides on faces of peds; many fine to coarse rounded lime nodules and common fine and medium rounded ironstone nodules; gradual smooth boundary. Horizon split for sampling 74 to 105 cm No. 2860 and 105 to 133 cm No. 2861.
84P2860

BCk--133 to 154 cm; clay; olive (5Y 4/3) moist; moderate medium and coarse angular blocky structure; very firm; few fine roots throughout; few fine discontinuous tubular pores; common thin intersecting slickensides on faces of peds; many fine to coarse rounded lime nodules and many fine rounded ironstone nodules.
84P2862

S84FN-990-014

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; FINE, MIXED, ISOHYPERTHERMIC UDIC CHROMUSTERT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 520, SAMPLES 84P2857-2862
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- TOTAL CLAY LT .002 <-	-2-- TOTAL SILT .002 -.05	-3-- TOTAL SAND .05 -2	-4-- CLAY FINE LT .0002	-5-- CLAY CO3 LT .002	-6-- SILT FINE .002 -.02	-7-- SILT COARSE .02 -.05	-8-- SILT VF .05 -.10	-9-- SAND F .10 -.25	-10- SAND M .25 -.50	-11- SAND C .5 -1	-12- SAND VC 1 -2	-13- COARSE FRACTIONS(MM) WEIGHT 2 -5	-14- COARSE FRACTIONS(MM) WEIGHT 5 -20	-15- COARSE FRACTIONS(MM) WEIGHT 20 -75	-16- COARSE FRACTIONS(MM) WEIGHT .1- 75	-17- (>2MM) WT PCT OF WHOLE SOIL
			PCT OF <2MM (3A1)												PCT OF <75MM(3B1)				
84P2857S	0- 8	A	50.6	19.4	30.0	38.3		9.3	10.1	9.1	12.5	5.8	2.0	0.6	1	TR	--	22	1
84P2858S	8- 24	BW	52.9	21.0	26.1	34.9		11.7	9.3	8.1	10.4	5.1	1.7	0.8	--	--	--	16	--
84P2859S	24- 74	BK1	52.4	20.7	26.9	29.6		11.9	8.8	8.2	10.3	5.2	1.9	1.3	2	1	--	21	3
84P2860S	74-105	BK2	53.8	20.9	25.3	29.1		12.1	8.8	7.5	9.5	4.6	1.9	1.8	1	TR	--	19	1
84P2861S	105-133	BK2	56.0	19.0	25.0	27.7		12.8	6.2	7.7	9.4	4.3	1.7	1.9	1	2	--	20	3
84P2862S	133-154	BCK	56.0	18.6	25.4	25.1		12.8	5.8	7.8	9.5	4.5	1.9	1.7	2	2	--	21	4

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A <- PERCENT	DITH-CIT EXTRACTABLE FE 6C2B	DITH-CIT EXTRACTABLE AL 6G7A OF	DITH-CIT EXTRACTABLE MN 6D2A <2MM -->	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1 PCT	ATTERBERG LIMITS PI 4F <0.4MM	BULK DENSITY FIELD MOIST 4A3A <-	BULK DENSITY 1/3 BAR 4A1D G/CC -	BULK DENSITY OVEN DRY 4A1H - ->	COLE WHOLE SOIL 4D1 CM/CM	WATER CONTENT FIELD MOIST 4B4 <-	WATER CONTENT 1/10 BAR 4B1C -	WATER CONTENT 1/3 BAR 4B1C PCT OF <2MM	WATER CONTENT 15 BAR 4B2 - ->	WRD WHOLE SOIL 4C1 CM/CM
0- 8	2.45	0.186			2.3	0.3	TR	0.61	0.34	48	26		1.70	1.73	0.073			26.5	17.4	0.13
8- 24	0.81	0.067			2.7	0.4	TR	0.55	0.31				1.55	1.93	0.076			23.1	16.2	0.11
24- 74	0.57	0.045			2.6	0.3	TR	0.55	0.33	53	34		1.57	2.10	0.100			23.3	17.2	0.09
74-105	0.56				2.6	0.3	TR	0.53	0.36				1.57	2.03	0.089			24.3	19.1	0.08
105-133	0.47				2.5	0.3	TR	0.50	0.34	56	35		1.53	1.99	0.090			26.1	19.3	0.10
133-154	0.36				2.5	0.3	TR	0.51	0.36				1.53	1.99	0.090			27.0	20.0	0.11

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-014 PRINT DATE 10/19/87
CLASSIFICATION: SND ; FINE, MIXED, ISOHYPERTHERMIC UDIC CHROMUSTERT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 520, SAMPLE 84P2857-2862

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6O2O	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACIDITY 6H5A	-7--	-8-- SUM CATS 5A3A	-9-- NH4-OAC 5A8B	-10- EXCH NA 5B5B PCT	-11- SAR 5E	-12- BASE SATURATION SUM 5C3	-13- NH4OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G PCT	-15- RES. OHMS /CM 8E1	-16- CASO4 AS GYPSUM <2MM 6F1A	-17- <20MM 6F4	-18- PH SAT PASTE 8C1B	-19- CACL2 .01M 8C1F 1:2	-20- H2O 8C1F 1:1
	(- NH4OAC EXTRACTABLE BASES -)							(- -CEC- -)				<- -PCT- ->				<- -PCT ->		(- - - -PH - - -)		
	<- - - - - - - - - -MEQ / 100 G - - - - - - - - - ->																			
0- 8	18.1	11.0	0.2	0.7	30.0	6.1		36.1	30.9	1	1	83	97					6.6	6.2	6.7
8- 24	17.7	10.0	0.6	0.2	28.5	3.5		32.0	29.3	2	2	89	97					7.2	6.8	7.4
24- 74	19.2	12.1	2.5	0.2	34.0				28.6	8	6		100	TR				8.0	7.7	8.4
74-105		15.7	6.0	0.2					28.7	17	13			2	880	--		8.1	8.0	8.5
105-133		16.0	7.6	0.2					27.9	17	10			1		1		7.7	7.9	8.1
133-154		14.5	8.0	0.2					28.5	16	11			1		1		7.8	7.9	8.3

DEPTH (CM)	CA 6N1B	MG 6O1B	NA 6P1B	K 6Q1B	CO3 6I1B	HCO3 6J1B	CL 6K1C	SO4 6L1C	NO3 6M1C	H2O 8A	TOTAL SALTS EST. 8D5	ELEC. COND. 8A3A MMHOS /CM	CLAY X-RAY <2U 7A2I	CLAY X-RAY <2U 7A2I	CLAY X-RAY <2U 7A2I	CLAY X-RAY <2U 7A2I	DTA 7A3	DTA 7A3	TOTAL RES 7B1A	DOM WEATH 7B1A
	(- - - - - - - -WATER EXTRACTED FROM SATURATED PASTE- - - - - - - - -)												(- - - - - - - -MINERALOGY - - - - - - - -)							
	< - - - - - - - - - -MEQ / LITER - - - - - - - - - ->									<- -PCT ->			<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 8	1.9	1.7	1.1	0.1	--	2.6	0.6	1.5	--	60.8	TR	0.51								
8- 24	0.6	0.5	1.3	--	--	1.8	0.3	0.3	--	52.1	TR	0.27								
24- 74	0.5	0.2	3.7	TR	--	3.1	0.4	0.7	--	60.3	TR	0.47	KK 4	MT 3	GE 2	VR 1	KK35		99	BTTR
74-105	1.1	1.2	13.8	TR	--	3.2	0.5	12.9	--	73.7	0.1	1.67								
105-133	19.1	17.2	43.1	0.1	--	1.7	4.7	74.2	--	67.4	0.3	6.19	KK 4	MT 3	GE 2		KK32		99	CBTR
133-154	18.7	17.0	47.7	0.1	--	1.4	3.5	78.1	--	74.9	0.4	6.51								

AVERAGES, DEPTH 25-100: PCT CLAY 53 PCT .1-75MM 20

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MT MONTMORILL GE GOETHITE VR VERMICULITE BT BIOTITE
CB CARB-AGG

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-014
CLASSIFICATION: SND ; FINE, MIXED, ISOHYPERTHERMIC UDIC CHROMUSTERT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 520, SAMPLE 84P2857-2862

PRINT DATE 10/19/87

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            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

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           < - - - - - - - - - - - - - - - - - - - - - - - - CLAY MINERALOGY (<.002mm) - - - - - - - - - - - - - - - - - - - - - - >
           FRACT < - - - - - X-RAY - - - - - -><- - - THERMAL - - - -><- - - - - - - - ELEMENTAL - - - - - - -><- -> SURF  INTER
 DEPTH       ION <                            >< - DTA - -><- TGA -> SIO2 AL2O3 Fe2O3  MgO   CaO   K2O   Na2O <    > AREA  PRETA
             < - - - - -  7A2i - - - - - -><- 7A3b - >< - 7A4b - >< - - - - - - - - - 7C3 - - - - - - - - -><    >        TION
  (cm)     <- - >< - - - - peak size - - - - -><- - - Percent - - - -><- - - - - - - - Percent - - - - - - - -><- -><M2/G><- ->

 24- 74      TCLY  KK 4  MT 3  GE 2  VR 1        KK35                                  9.4                 0.5
105-133      TCLY  KK 4  MT 3  GE 2              KK32                                  9.2                 0.5

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           < - - - - - - - - - - - - - - - - - - - - - - SAND - SILT MINERALOGY (2.0-0.002mm) - - - - - - - - - - - - - - - - - - - - >
           FRACT < - - - - - X-RAY - - -><- - - THERMAL - - - -><- - - - - - - - OPTICAL - - - - - - - - -><                > INTER
 DEPTH       ION <                     >< - DTA - -><- TGA - ->TOT RE< - - - - - GRAIN COUNT - - - - - -><                > PRETA
             < - - - - 7A2i - - - - -><- 7A3b - >< - 7A4b - >< - - - - - - - - - 7B1a - - - - - - - - -><                > TION
  (cm)     < - -><- - - Peak Size - - -><- - - Percent - - - -><- - - - - - - - Percent - - - - - - - -><- - - - - - - - -><- ->

 24- 74      FS                                                 99  QZ92  QC 6  RA 1  HNtr  BTtr
105-133      FS                                                100  QZ95  RA 3  QC 2  EPtr  TMtr  FKtr
105-133      FS                                                     CBtr

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KIND OF MINERAL:

KK	kaolinite	MT	montmorill	GE	goethite	VR	vermiculite	QZ	quartz	QC	clay-coat qz
RA	resist-aggre	HN	hornblende	BT	biotite	EP	epidote	TM	tourmaline	FK	potas-feld
CB	carb-aggreg										

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

The heavy texture and type of clay results in a compact soil with poor internal drainage. In Zambia these soils are only used for extensive grazing, but few years ago some farms and projects have started cultivation on these soils. Irrigated wheat, barley and vegetables have been tried. Some farmers grew maize on slightly elevated places during the "dry" rainy seasons of the last three years.

At further distance from the river sunflower and cotton are important crops. Nearby the river paddy rice is probably the best way of cultivation. A team of North Koreans are helping out a Zambian National Service rice project some 10km to the west, where about 100 ha of paddy rice is grown. Zinc deficiency is the major fertility problem (as was shown at Nanga research station on the southern side of the river). Maybe B and Mn-deficiency can be expected in these soils.

The level of sodium in the subsoil has to be monitored with time. Physical degradation in soils of this type may be an advantage, because the topsoil becomes lighter in texture and lower in pH.

Ratings of the land qualities pedon 10

POTENTIAL CONSTRAINTS	low inputs	high inputs	
high temperature	3	3	
high humidity	1	1	
frost	1	1	
length growing period (70% prob.)	120	120	(days)
eff.min. rainfall (70% prob.)	1;325	1;325	(rating;mm)
occurrence critical periods	1	1	
occurrence drought	1	1	
SOIL CONSTRAINTS			
oxygen availability (CO2 toxicity)	2	1	
potassium	2	-	
boron	1	-	
manganese	1	-	
zinc	2	-	
sulphur	1	-	
rooting conditions (physical)	3	3	
heavy topsoil	3	3	
flooding	1	-	
workability	3	2	(texture, structure)
mechanization/land preparation	1	1	(wetness)
physical degradation	2	1	

Explanation of ratings:
-: no constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 10 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	3	Zn	2	Rp	Zn, (drainage, flood-control)
Sorghum	3	Zn	2	Rp	Zn
Cassava	4a	W	4a	W	-
F/millet	2	Ht	2	Ht	-
B/millet	2	Ht	2	Ht	-
Wheat	5b	T	5b	T	-
Dryl. rice	5b	D	5a	D	Zn, mechanized tillage, (with irrigation: class 1-Rp)
Paddy rice	5b	D	5a	D	Zn, (with irrigation: class 1A, effective inputs mechanization)
Sunflower	2	O	1	O,Rp	Drainage, flood control Zn (mechanized tillage, K,B,S)
Soyabean	3	Zn	2	Rp	Zn, (K)
Groundnut	4a	W	2	W	Mechanized tillage
Ph/bean	3	Zn	2	Rp	Zn, (drainage, flood control, mechanized tillage)
Cotton	2	O	2	Rp	drainage, (flood control, Zn, mechanized tillage)
V/tobacco	4a	Ht,O	4a	Ht,O	-

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Print date: 10-21-1987
Pedon 11

Pedon: Nakambala NSSL ID #: 84P0521
Soil Survey # S83-FN-990-015
Location: Magoye Reg. Res. St. 15 km W of Mazabuka SoP Zambia. Pit located about 500 m E of the offices.
Latitude: 15-49- -S Longitude: 027-45- -E
Classification: Clayey, mixed, isohyperthermic Typic Paleustalf
Physiography:
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1040 m MSL
Precipitation: Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderate
Air Temp. (Centigrade): Ann: 230 Sum: 243 Win: 185
Soil Temp. (Centigrade): Ann: Sum: Win:
Drainage: Well drained
Land Use: Forest land not grazed
Stoniness:
Particle Size Control Section: 21 to 71 cm Runoff: Very slow
Parent Material: residuum from metamorphic material
Vegetation Codes: Weather Station: Mazabu
Diagnostic Horizons: 0 to 8 cm Ochric, 21 to 186 cm Argillic
Described by: D. Hallbick O. Spaargaren and C. Kalima Date: 11/83

Cracks about 1 cm wide extend from base of A down to a depth of about 150 cm. Distance between cracks is 20 to 60 cm.

A--0 to 8 cm; reddish brown (5YR 5/3) sandy loam; dark reddish brown (5YR 3/3) moist; weak fine and medium subangular blocky structure parting to massive; soft, very friable, nonsticky, nonplastic; many fine and medium roots throughout; common to many very fine and fine interstitial and tubular pores; clear smooth boundary.
84P2863

EA--8 to 21 cm; yellowish red (5YR 5/6) sandy clay loam; dark reddish brown (5YR 3/4) moist; massive; slightly hard, slightly sticky, nonplastic; common to many fine and medium roots throughout; common fine and medium continuous tubular and many very fine and fine interstitial pores; clear smooth boundary.
84P2864

Bt--21 to 43 cm; yellowish red (5YR 4/6) clay; dark red (2.5YR 3/6) moist; moderate fine and medium subangular blocky structure; slightly hard, very sticky, plastic; common to many fine and medium roots throughout; common fine and medium continuous tubular and common to many fine and medium void between rock fragments pores; few patchy faint-thin clay films on vertical faces of peds; gradual smooth boundary.
84P2865

Bt2--43 to 112 cm; red (2.5YR 4/6) clay; red (2.5YR 4/6) moist; moderate fine and medium subangular blocky structure; slightly hard, very sticky, plastic; common fine and medium roots throughout; common fine and medium continuous tubular and common to many fine and medium void between rock fragments pores; common discontinuous distinct-thin clay films on vertical and horizontal faces of peds; clear smooth boundary.
Clod 43 to 112 cms bulk samples split. Horizon split for sampling 43 to 75 cm No. 2866 and 75 to 112 cm No. 2867.
84P2866

Bt3--112 to 157 cm; red (2.5YR 5/8) clay; red (2.5YR 4/6) moist; moderate fine and medium subangular blocky structure; slightly hard, very sticky, plastic; few fine and medium roots throughout; few medium continuous tubular and common fine and medium interstitial pores; common patchy distinct-thin clay films on vertical and horizontal faces of peds; gradual smooth boundary.
In Bt3 and Bt4 amount of clay somewhat less than in Bt2.
84P2868

Bt4--157 to 186 cm; red (2.5YR 5/8) clay; red (2.5YR 4/8) moist; weak fine and medium subangular blocky structure; soft, very sticky, plastic; few fine and medium roots throughout; few medium continuous tubular and common fine and medium interstitial pores; few patchy distinct-thin clay films on vertical and horizontal faces of peds.
84P2869

S84FN-990-015

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; FINE-LOAMY, MIXED, ISOHYPERTHERMIC KANDIC PALEUSTALF

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 521, SAMPLES 84P2863-2869
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- TOTAL CLAY LT .002	-2-- TOTAL SILT .002 -.05	-3-- TOTAL SAND .05 -2	-4-- TOTAL FINE LT .0002	-5-- CLAY CO3 LT .002	-6-- SILT FINE .002 -.02	-7-- SILT COARSE .02 -.05	-8-- SAND VF .05 -.10	-9-- SAND F .10 -.25	-10-- SAND M .25 -.50	-11-- SAND C .5 -1	-12-- SAND VC 1 -2	-13-- COARSE FRACTIONS(MM) WEIGHT 2 -5	-14-- COARSE FRACTIONS(MM) WEIGHT 5 -20	-15-- COARSE FRACTIONS(MM) WEIGHT 20 -75	-16-- COARSE FRACTIONS(MM) WEIGHT .1- 75	-17-- >2MM WT PCT OF WHOLE SOIL
			<- - - - - - - - - - - - PCT OF <2MM (3A1) - - - - - - - - - - - - - - ->												<- PCT OF <75MM(3B1)->				
84P2863S	0- 8	A	11.7	12.8	75.5			5.0	7.8	23.0	35.9	13.3	2.9	0.4	--	--	--	52	--
84P2864S	8- 21	EA	16.6	11.7	71.7			4.4	7.3	21.4	34.4	12.8	2.6	0.5	--	--	--	50	--
84P2865S	21- 43	BT1	26.1	12.1	61.8			5.1	7.0	18.9	29.1	10.9	2.5	0.4	--	--	--	43	--
84P2866S	43- 75	BT2	38.1	10.7	51.2			4.7	6.0	17.8	22.3	8.8	2.1	0.2	--	--	--	33	--
84P2867S	75-112	BT2	43.4	10.4	46.2			4.0	6.4	15.7	20.1	8.0	2.1	0.3	--	--	--	30	--
84P2868S	112-157	BT3	40.8	11.4	47.8			4.5	6.9	17.8	20.9	6.9	1.9	0.3	--	--	--	30	--
84P2869S	157-186	BT4	40.5	12.1	47.4			4.6	7.5	18.0	20.5	6.6	1.6	0.7	--	--	--	29	--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTK P 6S3 PPM	TOTAL S 6R3A	DITH-CIT EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1 PCT	PI 4F <0.4MM	BULK DENSITY FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1 CM/CM	WATER CONTENT FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1 CM/CM
				<- PERCENT OF <2MM -->								<- - G/CC - - ->				<- - -PCT OF <2MM - ->				
0- 8	0.88	0.072			1.1	0.1	TR	0.35	0.37	19	1		1.43	1.46	0.007			11.6	4.3	0.10
8- 21	0.74	0.057			1.4	0.2	TR	0.27	0.32				1.46	1.50	0.009			11.0	5.3	0.08
21- 43	0.57	0.022			2.1	0.2	TR	0.22	0.33	24	8		1.45	1.52	0.016			15.9	8.5	0.11
43- 75	0.52				2.8	0.3	TR	0.20	0.32				1.44	1.53	0.020			20.2	12.0	0.12
75-112	0.44				3.3	0.4	TR	0.19	0.31	33	13		1.44	1.53	0.020			20.2	13.4	0.10
112-157	0.27				3.1	0.4	TR	0.19	0.30				1.33	1.43	0.024			21.2	12.2	0.12
157-186	0.22				3.1	0.4	TR	0.20	0.29				1.36	1.44	0.019			20.2	11.9	0.11

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-015 PRINT DATE 10/19/87
CLASSIFICATION: SND ; FINE-LOAMY, MIXED, ISOHYPERTHERMIC KANDIC PALEUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 521, SAMPLE 84P2863-2869

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID-ITY 6H5A	-7-- EXTR AL 6G9A	-8-- CEC SUM CATS 5A3A	-9-- CEC NH4-OAC 5A8B	-10- CEC BASES + AL 5A3B	-11- AL SAT 5C1	-12- BASE SUM 5C3	-13- SAT-NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- PH KCL 1N 8C1G	-19- PH CACL2 .01M 8C1F 1:2	-20- PH H2O 8C1F 1:1
	(- NH4OAC EXTRACTABLE BASES -)					ACID-	EXTR	(- - -	-CEC	- - -)	AL	-BASE	SAT-	CO3 AS	RES.		COND.	(- - -	-PH	- - -)
	<- -MEQ / 100 G ->										<- - - - -PCT - - - ->									
0- 8	1.4	1.4	TR	0.6	3.4	2.7		6.1	4.1			56	83					5.0	5.0	5.8
8- 21	1.1	1.3	TR	0.4	2.8	3.5		6.3	4.4			44	64					4.8	4.9	5.8
21- 43	0.9	1.4	0.5	0.2	3.0	5.8	0.8	8.8	5.7	3.8	21	34	53					4.0	4.3	4.9
43- 75	1.2	2.1	0.1	0.3	3.7	7.9	1.1	11.6	7.8	4.8	23	32	47					4.1	4.3	5.4
75-112	1.4	2.6	TR	0.3	4.3	7.7	0.9	12.0	8.4	5.2	17	36	51					4.2	4.4	5.4
112-157	1.6	2.9	0.1	0.4	5.0	5.8	0.1	10.8	7.8	5.1	2	46	64					4.5	4.8	5.5
157-186	1.6	3.1	0.1	0.3	5.1	5.6	0.1	10.7	8.1	5.2	2	48	63					4.7	4.9	5.6

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -)							
	(- - - - - - - - CLAY - - - - - - - -)(- - -) -)							
	(- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM							
	(- - - - - <2U - - - -)(- -<2U - -) RES WEATH							
	7A2I	7A2I	7A2I	7A2I	7A3	7A3	7B1A	7E1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 8								
8- 21								
21- 43	KK 3	MI 3	TA 2	GE 2	KK15		85	FK15
43- 75								
75-112	KK 4	MI 3	GE 2	TA 2	KK36		81	WE19
112-157								
157-186								

AVERAGES, DEPTH 21- 71: PCT CLAY 33 PCT .1-75MM 38

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MI MICA TA TALC GE GOETHITE FK POTAS-FELD
WE WEATH MIN

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-015
CLASSIFICATION: SND ; FINE-LOAMY, MIXED, ISOHYPERTHERMIC KANDIC PALEUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 521, SAMPLE 84P2863-2869

PRINT DATE 10/19/87

DEPTH (cm)	FRACTION	X-RAY 7A2i peak size				THERMAL DTA 7A3b Percent	TGA 7A4b Percent	ELEMENTAL SiO2	AL2O3	Fe2O3	MgO	CaO	K2O	Na2O	SURF AREA M2/G	INTERPRETATION
		CLAY MINERALOGY (<.002mm)														
21- 43	TCLY	KK 3	MI 3	TA 2	GE 2	KK15				12.3			1.0			
75-112	TCLY	KK 4	MI 3	GE 2	TA 2	KK36				13.2			0.9			

DEPTH (cm)	FRACTION	X-RAY 7A2i Peak Size				THERMAL DTA 7A3b Percent	TGA 7A4b Percent	TOT RE	OPTICAL GRAIN COUNT 7B1a Percent							INTERPRETATION
		SAND - SILT MINERALOGY (2.0-0.002mm)														
21- 43	FS							85	QZ83	FK15	TM 1	OP 1	MStr	RAtr		
21- 43	FS								HNtr	ZRtr	EPtr	RUtr				
75-112	FS							81	RE81	WE19						

KIND OF MINERAL:

KK	kaolinite	MI	mica	TA	talc	GE	goethite	QZ	quartz	FK	potas-feld
TM	tourmaline	OP	opaques	MS	muscovite	RA	resist-aggre	HN	hornblende	ZR	zircon
EP	epidote	RU	rutile	RE	resist min	WE	weath min				

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 11 - Land evaluation (W. Veldkamp)

There is a wide range of suitable crops for this soil. Some minor problems like Zn,S and maybe Mo-deficiency (and a low Ca/K ratio in the third horizon) can be overcome relatively easy. The subsoil is quite compact and ripping might be recommended. The major problem is the relatively acid subsoil, Because droughts may occur during the rainy season in the agro-ecological zone, shallow rooting due to subsoil acidity may cause reductions or even crop failure. Therefore lime is required, initially as a relatively high dose and followed by small and regular lime applications to keep the soil in good condition. The initial lime application should be given before ripping. Sustained crop production is then possible with a fertilizer programme following the normal recommendations.

Irrigation during the dry season is hardly feasible apart from supplementary irrigation in case of dry years.

Ratings of the land qualities: pedon 11

POTENTIAL CONSTRAINTS	low inputs	high inputs
high temperature	2	2
high humidity	1	1
frost	2	2
length growing period (70% prob.)	120	120 (days)
eff. min. rainfall (70% prob.)	1;300	1;300(rating;mm
occurrence critical periods	1	1
occurrence drought	1	1
SOIL CONSTRAINTS		
nutrient reserves	1	-
calcium	2	-
magnesium	1	-
potassium	2	-
Ca/Mg	1	-
Ca/K	2	-
zinc	1	-
molybdenum	2	-
sulphur	2	-
nutrient retention	2	1
rooting conditions (physical	1	-
rooting conditions (chemical)	1	1
heavy topsoil	1	1
aluminium toxicity	2	1
chemical degradation	1	-

Explanation of ratings:
-: no constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4. very severe constraint

PEDON 11 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	2	Ca,S,Zn	1	D,N	Ca,S,Zn
Sorghum	2	Ca,S,Zn	1A	-	Ca,K,S,Zn, degradation protection
Cassava	3	F	3	F	-
F/millet	2	Ca,S	1A	-	Ca,K,S,Zn, degradation protection
B/millet	2	Ca,S	1A	-	Ca,K,S,Zn, degradation protection
Wheat	3	T	3	T	-
Dryl. rice	5a	D	5a	D	-(with irrigation class 1-H; effective inputs lime, Zn,S)
Paddy rice	5a	D	5a	D	-(with irrigation: class 2-P)
Sunflower	2	Ca,S	1	A	PK,S, lime
Soyabean	2	Ca,K,S,Zn	1	A	PKS,Zn,Mo, lime
Groundnut	2	Ca,S,Z	1	A	S,Zn,Mo, lime
Ph/bean	2	Ca,S,Zn	1	A	S,Zn,Mo, lime
Cotton	2	A,Ca,S	1	N	S. lime
V/tobacco	2	Ca,S	1	Ht	Ca,S

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 12

Print date: 10-21-1987

Pedon: Kabuyu NSSL ID #: 84P0523
Soil Survey # S83-FN-990-017
Location: 43 km NE of Livingstone SoP Zambia along road to Lusaka.
Latitude: --- Longitude: ---
Classification: , siliceous, isohyperthermic, coated Typic Ustipsamment
Physiography: Low sand ridge in level or undulating uplands
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1140 m MSL
Precipitation: 880 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Rapid
Air Temp. (Centigrade): Ann: 201 Sum: 227 Win: 157
Soil Temp. (Centigrade): Ann: 243 Sum: 247 Win: 209
Drainage: Somewhat excessively drained
Land Use: Forest land not grazed
Stoniness:
Particle Size Control Section: 25 to 100 cm Runoff: Very slow
Parent Material: eolian sand from sandstone material
Vegetation Codes: Weather Station: Living
Diagnostic Horizons: 0 to 17 cm Ochric
Described by: D. Hallbick O Spaargaren and C. Kalima Date: 11/83

Classification problematic because insufficient data are available yet to justify classification in either Inceptisols because of possible cambic horizon or Alfi/Ultisols because of possible argillic horizon.

O--7 to 0 cm; loamy fine sand; strong brown (7.5YR 4/6) and black (N 2/0) moist; single grain parting to massive; loose, nonsticky, nonplastic; common fine and medium roots throughout; many very fine and fine interstitial pores; abrupt smooth boundary.
84P2876

A--0 to 17 cm; dark reddish gray (5YR 4/2) loamy sand; dark reddish brown (5YR 2/2) moist; massive; soft, nonsticky, nonplastic; common fine and medium roots throughout and few coarse roots throughout; many very fine and fine interstitial and few fine to coarse continuous tubular pores; clear wavy boundary.
84P2877

E--17 to 32 cm; reddish brown (5YR 5/4) loamy sand; dark reddish brown (5YR 3/4) moist; massive; soft, nonsticky, nonplastic; common fine and medium roots throughout; many very fine and fine interstitial and few fine to coarse continuous tubular pores; clear wavy boundary. There is a clay increase from the E to the Bw3 however not sufficient to warrant other PCS than LS.
84P2878

Bw1--32 to 54 cm; yellowish red (5YR 5/6) loamy sand; dark red (2.5YR 3/6) moist; massive; soft, nonsticky, nonplastic; few fine and medium roots throughout; many very fine and fine interstitial and few fine to coarse continuous tubular pores; clear smooth boundary. Many termite burrows are coated with gray thick linings probably a mixture of clay and organic matter.
84P2879

Bw2--54 to 94 cm; red (2.5YR 5/6) loamy sand; dark red (2.5YR 3/6) moist; massive; soft, nonsticky, nonplastic; few fine and medium roots throughout; many very fine and fine interstitial and few fine to coarse continuous tubular pores; clear smooth boundary.
84P2880

Bw3--94 to 167 cm; red (2.5YR 5/6) sandy loam; dark red (2.5YR 3/6) moist; massive; slightly hard, slightly sticky, nonplastic; few fine and medium roots throughout; many very fine and fine interstitial and few fine to coarse continuous tubular pores.
84P2881

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

584FN-990-017 (ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; ISOHYPERTHERMIC USTOXIC QUARTZIPSAMMENT

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 523, SAMPLES 84P2876-2881
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	(- - -TOTAL - - -) CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	CO3 LT .002	(- -CLAY- -) FINE .002 -.02	COARSE .02 -.05	(- -SILT- -) VF .05 -.10	F .10 -.25	(- - - - -SAND- - - - - -) M .25 -.50	C .5 -1	VC 1 -2	(-COARSE FRACTIONS(MM)-) 2 -5	5 -20	WEIGHT 20 -75	(>2MM) .1- 75	WT PCT OF WHOLE SOIL
			<- - - - - - - - - - - - PCT OF <2MM						(3A1)	- - - - - - - - - - - - - - -				->	<- PCT OF <75MM(3B1)->				
84P2876S	0- 17	A	5.9	3.5	90.6	3.3		2.1	1.4	13.8	36.4	22.8	17.2	0.4	--	--	--	77	--
84P2877S	17- 32	E	5.2	2.3	92.5	3.0		1.3	1.0	16.2	38.2	21.9	15.8	0.4	--	--	--	76	--
84P2878S	32- 54	BW1	6.0	1.8	92.2	3.5		1.3	0.5	14.8	36.1	23.1	18.0	0.2	--	--	--	77	--
84P2879S	54- 94	BW2	9.1	1.9	89.0	5.6		1.0	0.9	13.2	35.7	23.9	16.0	0.2	--	--	--	76	--
84P2880S	94-144	BW3	10.5	1.4	88..	6.8		0.9	0.5	12.6	35.4	23.4	16.3	0.4	--	--	--	75	--
84P2881S	144-167	BW3	11.6	1.2	87.2	7.8		0.7	0.6	10.7	29.3	25.5	21.2	0.5	--	--	--	76	--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A	(- - DITH-CIT - -) EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	(RATIO/CLAY) 15 BAR 8D1	(ATTERBERG) LL 4F1	PI 4F	(- BULK DENSITY -) FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1	(- - -WATER CONTENT - -) FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
	PCT	<2MM	PPM	<- PERCENT	OF	<2MM	-->			PCT	<0.4MM	<- -	G/CC	- - ->	CM/CM	<- -	-PCT OF	<2MM	- ->	CM/CM
0- 17	0.84	0.038			0.4	TR	TR	0.70	0.41				1.55	1.60	0.011			8.6	2.4	0.10
17- 32	0.27	0.014			0.4	TR	TR	0.29	0.31				1.73	1.75	0.004			5.8	1.6	0.07
32- 54	0.09	0.008			0.4	TR	TR	0.15	0.28				1.68	1.72	0.008			6.1	1.7	0.07
54- 94	0.05				0.5	TR	TR	0.11	0.27				1.67	1.69	0.004			3.9	2.5	0.02
94-144	0.12				0.5	--	TR	0.11	0.27				1.70	1.72	0.004			4.4	2.8	0.03
144-167	0.09				0.5	--	TR	0.10	0.29				1.68	1.70	0.004			4.7	3.4	0.02

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-017 PRINT DATE 10/19/87
CLASSIFICATION: SND ; ISOHYPERTHERMIC USTOXIC QUARTZIPSAMMENT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 523, SAMPLE 84P2876-2881

DEPTH (CM)	-1-- (- NH4OAC EXTRACTABLE BASES -) CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID- ITY 6H5A	-7-- EXTR AL 6G9A	-8-- (- - - -CEC - - -) SUM CATS 5A3A	-9-- NH4- OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- -BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- (- - - -PH - - -) KCL 1N 8C1G	-19- CACL2 .01M 8C1F 1:2	-20- H2O 8C1F 1:1
	<- - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - ->										<- - - - - -PCT - - - ->									
0- 17	2.9	0.4	TR	0.1	3.4	2.4	TR	5.8	4.1			59	83					4.9	4.8	5.3
17- 32	0.8	0.3	TR	0.1	1.2	1.1		2.3	1.5			52	80					5.0	5.1	5.9
32- 54	0.4	0.2	TR	TR	0.6	1.0	TR	1.6	0.9			38	67					4.4	4.8	5.5
54- 94	0.4	0.3	TR	0.1	0.8	1.1	TR	1.9	1.0			42	80					4.4	4.7	5.5
94-144	0.6	0.4	TR	0.2	1.2	1.1		2.3	1.2			52	100					4.7	5.1	5.6
144-167	0.6	0.4	TR	0.1	1.1	1.3		2.4	1.2			46	92					4.8	5.2	5.9

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -) (- - - - - - - CLAY - - - - - - - -)(- - -) -) (- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM (- - - - - <2U - - - -)(- -<2U - -) RES WEATH 7A2I	7A2I	7A2I	7A2I	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 17								
17- 32								
32- 54	KK 4	MI 2	GE 1		KK12		93	FK 6
54- 94								
94-144	KK 5	MI 2	GE 1		KK28		90	FK 9
144-167								

AVERAGES, DEPTH 25-100: PCT CLAY 8 PCT .1-75MM 76

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MI MICA GE GOETHITE FK POTAS-FELD

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-017
CLASSIFICATION: SND ; ISOHYPERTHERMIC USTOXIC QUARTZIPSAMMENT
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 523, SAMPLE 84P2876-2881

PRINT DATE 10/19/87

DEPTH (cm)	FRACTION	X-RAY 7A2I peak size	THERMAL DTA 7A3b peak size	THERMAL TGA 7A4b peak size	CLAY MINERALOGY (<.002mm) SiO2	Al2O3	Fe2O3	MgO	CaO	K2O	Na2O	SURF AREA M2/G	INTERPRETATION
32- 54	TCLY	KK 4 MI 2 GE 1	KK12				5.6			0.9			
94-144	TCLY	KK 5 MI 2 GE 1	KK28				6.1			0.9			

DEPTH (cm)	FRACTION	X-RAY 7A2I Peak Size	DTA 7A3b Percent	TGA 7A4b Percent	SAND - SILT MINERALOGY (2.0-0.002mm) OPTICAL 7B1a Percent									INTERPRETATION
32- 54	FS													
94-144	FS				93	QZ93	FK 6	BTtr	RUtr	OPtr				
					90	QZ90	FK 9	AMtr	OPtr					

KIND OF MINERAL:

KK kaolinite MI mica GE goethite QZ quartz FK potas-feld BT biotite
RU rutile OP opaques AM amphibole

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

Pedon 12 - Land evaluation (W. Veldkamp)

The southern part of the southern province is an area with regular drought during the rainy season. It is however, difficult to assess the severity of drought in relation to crop growth. The number of weather stations is too small to accurately map agro-ecological zones on basis of occurance of drought in this region. The evaluation of pedon 12 assumes the characteristics of agro-ecological zone 3 in conjunction with the coarse loamy to sandy texture of the soil. The result of the evaluation is that without irrigation in fact none of the major crops is suitable and that only a marginal crop of bulrush crop can be expected.

Under irrigation (which seems not to be feasible due to the high permeability) also PKS fertilizers (preferably including superphosphate and if not, also a small application of dolomitic lime) should be applied. Also Zn and maybe Cu and Mo are required. Furthermore the soil needs to be protected against biological and chemical degradation.

All together not a soil for sustained crop production. Wind erosion is considered to be of importance only in regions with less than 700 mm mean annual rainfall. Its significance at the site of pedon 12 may needs further study.

Rating of the land qualities; pedon 12

POTENTIAL CONSTRAINTS	low inputs	high inputs
high temperature	3	3
low humidity	1	1
frost	3	3
length growing period (70% prob.)	105	105 (days)
eff.min rainfall (70% prob.)	4;225	4;225(rating,mm)
occurrence drought	3	3
occurrence drought	3	3
SOIL CONSTRAINTS		
nutrient reserves	3	1
calcium	3	-
magnesium	2	-
potassium	4	-
Ca/K	2	-
copper	1	-
zinc	1	-
molybdenum	2	-
sulphur	2	-
nutrient retention	3	2
germination/establishment	1	1
ease of puddling	3	3
chemical degradation	2	1
biological degradation	3	1

Explanation of ratings:
-: no constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 12 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	5a	D	5a	D	-
Sorghum	5a	D	5a	D	-
Cassava	5b	F	5b	D	-
F/millet	5a	D	5a	D	-
B/millet	4b	D	4b	D	-
Wheat	5b	D	5b	D	-
Dryl. rice	5a	D	5a	D	-
Paddy rice	5b	D,P	5b	D,P	-
Sunflower	5a	D	5a	D	-
Soyabean	5b	D	5a	D	Ca,K
Groundnut	5b	D	5a	D	Ca,K,S Zn,degradation pro.
Ph/bean	5a	D	5a	D	-
Cotton	5b	D	5b	D	-
V/tobacco	5a	D	5a	D	-

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 13

Print date: 10-21-1987

Pedon: Choma NSSL ID #: 84P0522
Soil Survey # S83-FN-990-016
Location: Mochipapa Reg. Res. St. about 10 km SE of Choma SoP Zambia. Pit located
Latitude: --- Longitude: ---
Classification: Fine-loamy, siliceous, isothermic Oxic Paleustult
Physiography: Upland slope in level or undulating uplands
Geomorphic Position:
Microrelief:
Slope Characteristics: Elevation: 1075 m MSL
Precipitation: 830 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderate
Air Temp. (Centigrade): Ann: 183 Sum: 221 Win: 129
Soil Temp. (Centigrade): Ann: Sum: Win:
Drainage: Moderately well drained
Land Use: Pasture land and native pasture
Stoniness:
Particle Size Control Section: 31 to 81 cm Runoff: Slow
Parent Material: residuum from schist & phyllite material
Vegetation Codes: Weather Station: Choma
Diagnostic Horizons: 0 to 31 cm Ochric, 31 to 185 cm Argillic
Described by: D. Hallbick O. Spaargaren and C. Kalima Date: 11/83

Near pit termite mounds with diameter of 5 m at base occur about 40 to 50 m apart.

Ap1--0 to 19 cm; loamy sand; brown to dark brown (7.5YR 4/4) moist; massive parting to single grain; very friable, nonsticky, nonplastic; common fine and medium roots throughout; very fine and fine total porosity and few fine and medium continuous tubular pores; clear smooth boundary.
84P2870

Ap2--19 to 31 cm; loamy sand; brown to dark brown (7.5YR 4/4) and strong brown (7.5YR 5/6) moist; massive; very friable, nonsticky, nonplastic; common fine and medium roots throughout; very fine and fine total porosity and few fine and medium continuous tubular pores; clear smooth boundary.
84P2871

Bt1--31 to 72 cm; yellowish red (5YR 5/8) sandy clay loam; yellowish red (5YR 4/6) moist; weak coarse and very coarse angular blocky structure; slightly hard, slightly sticky, plastic; few to common fine roots throughout; common very fine and fine interstitial and few fine and medium continuous tubular pores; few patchy faint-thin clay films on faces of peds; common patchy faint-thin clay films between sand grains; gradual smooth boundary.
84P2872

Bt2--72 to 125 cm; reddish yellow (5YR 6/8) sandy clay; yellowish red (5YR 5/8) moist; weak coarse and very coarse angular blocky structure; slightly hard, very sticky, plastic; few fine roots throughout; common very fine and fine interstitial and very few fine and medium continuous tubular pores; few patchy faint-thin clay films on faces of peds; common patchy faint-thin clay films between sand grains; clear smooth boundary.
84P2873

Bt3--125 to 185 cm; reddish yellow (5YR 6/8) clay; yellowish red (5YR 5/8) moist; common medium faint red (2.5YR 5/8) and common medium prominent yellow (10YR 7/6) mottles; moderate medium and coarse subangular blocky structure; hard, very sticky, very plastic; very few fine roots throughout; common very fine and fine interstitial pores; few discontinuous distinct-thin clay films on faces of peds; common patchy faint-thin clay films between sand grains; abrupt wavy boundary.
84P2874

2BC--185 to 198 cm; yellowish red (5YR 5/6) gravelly clay; yellowish red (5YR 5/6) moist; common medium prominent dark red (2.5YR 3/6) and common medium faint strong brown (7.5YR 5/6) mottles; massive; hard, slightly sticky, very plastic; very few fine roots throughout; few very fine and fine interstitial pores; few discontinuous prominent-thin dark red (10R 3/6) clay films on sand and gravel; common medium and coarse irregular soft masses of iron; 25 percent pebbles, 5 percent stones from siltstone.
84P2875

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-016 (ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; FINE-LOAMY, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTALF

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 522, SAMPLES 84P2870-2875
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- TOTAL CLAY LT .002 <- PCT OF <2MM	-2-- TOTAL SILT .002 -.05	-3-- TOTAL SAND .05 -2	-4-- CLAY FINE LT .0002	-5-- CLAY CO3 LT .002	-6-- SILT FINE .002 -.02	-7-- SILT COARSE .02 -.05	-8-- SAND VF .05 -.10	-9-- SAND F .10 -.25	-10-- SAND M .25 -.50	-11-- SAND C .5 -1	-12-- SAND VC 1 -2	-13-- COARSE FRACTIONS(MM) WEIGHT 2 -5 <- PCT OF <75MM(3B1)	-14-- 5 -20	-15-- 20 -75	-16-- >2MM WT .1- 75 PCT OF WHOLE SOIL
84P2870S	0- 19	AP1	5.4	7.6	87.0			3.4	4.2	8.5	25.5	31.6	18.8	2.6	TR	--	--	78 TR
84P2871S	19- 31	AP2	6.0	8.2	85.8			3.6	4.6	9.1	27.2	29.1	18.1	2.3	TR	--	--	77 TR
84P2872S	31- 72	BT1	18.4	6,8	74.8			3.1	3.7	6.5	20.2	28.7	16.9	2.5	1	--	--	69 1
84P2873S	72-125	BT2	24.8	6.1	69.1			2.7	3.4	5.9	16.7	25.0	17.2	4.3	1	--	--	64 1
84P2874S	125-185	BT3	29.3	9.7	61.0			4.7	5.0	7.5	14.2	18.3	16.2	4.8	2	--	--	54 2
84P2875S	185-198	2BC	23.6	16.4	60.0			9.5	6.9	10.2	13.0	15.7	14.6	6.5	13	18	--	65 31

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A <- PERCENT	DITH-CIT EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1 PCT	PI 4F <0.4MM	BULK DENSITY FIELD MOIST 4A3A <-	1/3 BAR 4A1D G/CC	OVEN DRY 4A1H ->	COLE WHOLE SOIL 4D1 CM/CM	WATER CONTENT FIELD MOIST 4B4 <-	1/10 BAR 4B1C -PCT OF	1/3 BAR 4B1C <2MM	15 BAR 4B2 ->	WRD WHOLE SOIL 4C1 CM/CM
0- 19	0.46	0.036			0.3	TR	TR	0.22	0.37		NP		1.63	1.66	0.006			7.0	2.0	0.08
19- 31	0.24	0.019			0.3	0.1	TR	0.15	0.37				1.61	1.65	0.008			8.3	2.2	0.10
31- 72	0.15	0.014			0.7	0.1	--	0.11	0.33	19	7		1.66	1.71	0.010			7.4	6.0	0.02
72-125	0.14				0.9	0.2	--	0.10	0.30				1.54	1.59	0.011			10.3	7.5	0.04
125-185	0.09				1.2	0.2	--	0.09	0.31	31	15		1.64	1.69	0.010			12.6	9.1	0.06
185-198	0.08				2.2	0.2	--	0.17	0.41				1.55	1.59	0.007			19.8	9.6	0.13

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-016 PRINT DATE 10/19/87
CLASSIFICATION: SND ; FINE-LOAMY, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 522, SAMPLE 84P2870-2875

DEPTH (CM)	-1-- CA 5B5A 6N2E	-2-- MG 5B5A 6O2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6O2B	-5-- SUM BASES	-6-- ACID-ITY 6H5A	-7-- EXTR AL 6G9A	-8-- CEC SUM CATS 5A3A	-9-- CEC NH4-OAC 5A8B	-10- CEC BASES + AL 5A3B	-11- AL SAT 5G1	-12- BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- PH KCL IN 8C1G	-19- PH CACL2 .01M 8C1F 1:2	-20- PH H2O 8C1F 1:1
	(- NH4OAC EXTRACTABLE BASES -)					ACID-	EXTR	(- - - -CEC	- - -)		AL	-BASE	SAT-	CO3 AS	RES.		COND.	(- - - -PH	- - -)	
	<- - - - - - - - - - -				-MEQ /	100 G	- - -	- - - - - - - - - -		->	<- - - - -	-PCT	- - - ->							
0- 19	0.7	0.3	TR	0.2	1.2	1.2	TR	2.4	1.2			50	100					4.3	4.4	4.8
19- 31	0.2	0.1	TR	0.2	0.5	1.5	0.2	2.0	0.9	0.7	29	25	56					4.2	4.3	4.7
31- 72	1.3	0.2	0.2	0.2	1.9	2.4		4.3	2.1			44	90					4.7	5.0	5.7
72-125	1.2	0.5	TR	0.2	1.9	1.7		3.6	2.4			53	79					5.0	5.3	5.8
125-185	0.7	0.7	TR	0.1	1.5	2.4		3.9	2.7			38	56					4.8	5.0	5.8
185-198	0.7	0.9	TR	0.2	1.8	3.4		5.2	3.9			35	46					5.0	4.7	5.6

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -)							
	(- - - - - - - CLAY - - - - - - - -)(- - -) -)							
	(- - - - X-RAY - - - -)(- -DTA - -) TOTAL DOM							
	(- - - - - <2U - - - -)(- -<2U - -) RES WEATH							
	7A21	7A21	7A21	7A21	7A3	7A3	7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 19								
19- 31								
31- 72	KK 5	MI 3	GE 1		KK37		86	FK13
72-125								
125-185	KK 5	MI 3	GE 2		KK39			
185-198								

AVERAGES, DEPTH 31- 81: PCT CLAY 20 PCT .1-75MM 68

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MI MICA GE GOETHITE FK POTAS-FELD

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-016
CLASSIFICATION: SND ; FINE-LOAMY, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 522, SAMPLE 84P2870-2875

PRINT DATE 10/19/87

```
            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-
--------- ------------------------------------------------------------------------------------------------------------------------
          < - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
          FRACT < - - - - - X-RAY - - - - - -><- - - THERMAL - - - -><- - - - - - - - ELEMENTAL - - - - - - - -><- -> SURF  INTER
 DEPTH      ION <                            ><- DTA - -><- TGA - -> SiO2 AL2O3 Fe2O3  MgO   CaO   K2O   Na2O <    > AREA  PRETA
            < - - - - - 7A2i - - - - -><- 7A3b - ><- 7A4b -><- - - - - - - - - - 7C3 - - - - - - - -><    >         TION
  (cm)    <- - -><- - - - peak size - - - -><- - - Percent - - - -><- - - - - - - - - Percent - - - - - - - -><- -><M2/G><- - ->
 31- 72     TCLY  KK 5  MI 3  GE 1              KK37                                  6.9                 1.2
125-185     TCLY  KK 5  MI 3  GE 2              KK39                                  7.6                 1.0
--------- ------------------------------------------------------------------------------------------------------------------------
          < - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
          FRACT < - - - - - X-RAY - - -><- - - THERMAL - - - -><- - - - - - - - OPTICAL - - - - - - - -><                > INTER
 DEPTH      ION <                        ><- DTA - -><- TGA - ->TOT RE< - - - - - GRAIN COUNT - - - - -><                > PRETA
            < - - - - 7A2i - - - -><- 7A3b - ><- 7A4b -><- - - - - - - - 7B1a - - - - - - - -><                >  TION
  (cm)    < - -><- - - Peak Size - - -><- - - Percent - - - -><- - - - - - - - Percent - - - - - - - -><- - - - - - - -><- ->
 31- 72     FS                                                  86  QZ86  FK13  MStr  ZRtr  RAtr  OPtr
--------- ------------------------------------------------------------------------------------------------------------------------
```

KIND OF MINERAL:

KK	kaolinite	MI	mica	GE	goethite	QZ	quartz	FK	potas-feld	MS	muscovite
ZR	zircon	RA	resist-aggre	OP	opaques						

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

Without irrigation relatively low yields can be expected. The most drought tolerant crops like millet will perform best. Magnesium, sulphur and calcium should be applied, besides the normal NPK fertilizer.

With irrigation this soil can be made much more productive, although protection against biological and chemical degradation is essential for sustained production. Therefore cropping should be alternated with eg. pasture/legume fallows. PKS fertilizers are required, as well as small dolomitic lime, Zn and maybe Mo, B and Cu applications.

The slightly impeded internal drainage conditions might be improved by ripping, but it is doubtful whether this will have the desired effect (esp. for tobacco).

The main crops under irrigation would be maize, sorghum, millet, sunflower, groundnut, beans and tobacco. In years with well distributed rainfall sorghum, millet, sunflower and tobacco might be grown without irrigation.

Rating of the land qualities; pedon 13

POTENTIAL CONSTRAINTS	low inputs	high inputs
high temperature	2	2
high humidity	1	1
frost	3	3
length growing period (70% prob.)	125	125 (days)
eff.min. rainfall (70% prov.)	3;275	3;275(rating;mm
occurrence critical periods	1	1
occurrence drought	1	1
SOIL CONSTRAINTS		
oxygen availability (CO2 toxicity)	1	-
nutrient reserves	1	-
calcium	3	-
magnesium	3	-
potassium	3	-
Ca/K	2	-
boron	2	-
copper	1	-
zinc	1	-
molybdenum	3	1
sulphur	3	-
nutrient retention	3	2
rooting conditions (physical)	2	1
germination/establishment	2	2
aluminum toxicity	2	1
mechanization/land preparation	1	1(anthills)
ease of puddling	3	3
physical degradation	1	-
chemical degradation	2	1
biological degradation	3	1

Explanation of ratings:

-: no constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 13 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	3	Mg,S	2	D	Mg,S
Sorghum	3	S	2	D	S
Cassava	5b	F	5b	F	-
F/millet	3	S	2	D	S
B/millet	3	S	.	Ge	S,Ca,Mg degradation pro.
Wheat	4b	D,Ge	4b	D,Ge	-
Dryl. rice	5b	D	5b	D	-
Paddy rice	5b	D,P	5b	D,P	-
Sunflower	3	S	2	D	S
Soyabean	3	Ca,Mg,K,S	2	D,Ge	Ca,Mg K,S
Groundnut	3	Ca,S	2	D	Ca,S
Ph/bean	3	S	2	D	S
Cotton	4a	Ge	4a	Ge	-
V/tobacco	4a	O	2	D	S,ripping

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon 14

Print date: 10-21-1987

Pedon: Chelston NSSL ID #: 84P0519
Soil Survey # S83-FN-990-013
Location: Unza farm about 20 km E of Lusaka LuP Zambia. Pit located next to the Met. Station Univ. farm.
Latitude: 15-23- -S Longitude: 028-28- -E
Classification: Clayey, kaolinitic, isohyperthermic Oxic Paleustalf
Physiography: Upland slope in level or undulating uplands
Geomorphic Position: on upper third ofshoulder headslope
Microrelief:
Slope Characteristics: .5% plane, east facing Elevation: 1140 m MSL
Precipitation: 810 mm Ustic moisture regime MLRA:
Water Table Depth: Permeability: Moderately slow
Air Temp. (Centigrade): Ann: 202 Sum: 216 Win: 157
Soil Temp. (Centigrade): Ann: 230 Sum: 234 Win: 203
Drainage: Moderately well drained Land Use: Cropland irrigated
Stoniness:
Particle Size Control Section: 38 to 88 cm Runoff: Slow
Parent Material: residuum from limestone material
Vegetation Codes: Weather Station: LUSAKA
Diagnostic Horizons: 0 to 38 cm Ochric, 38 to 195 cm Argillic
Described by: D. Hallbick O. Spaargaren and Wen T. T. Date: 11/83

Ap1--0 to 24 cm; reddish brown (5YR 4/4) silty clay; dark reddish brown (5YR 3/4) moist; moderate fine and medium subangular blocky structure; slightly hard; few fine roots throughout; few to common micro to fine interstitial and tubular pores; few patchy distinct-thin organic coats on lower surfaces of peds or stones; clear smooth boundary.
Coats occur only in the lower part of the horizon.
84P2851

Ap2--24 to 38 cm; dark reddish brown (2.5YR 3/4) clay; dark reddish brown (2.5YR 3/4) moist; weak coarse and very coarse platy structure parting to moderate fine and medium subangular blocky; hard; few fine roots throughout; few to common micro to fine interstitial and tubular pores; common discontinuous distinct-thin dark reddish brown (5YR 3/3) organic coats on vertical and horizontal faces of peds; abrupt smooth boundary.
84P2852

Bt1--38 to 66 cm; clay; dark reddish brown (2.5YR 3/4) moist; moderate coarse subangular blocky structure; friable; few fine roots throughout; many fine and medium continuous tubular and common fine void between rock fragments pores; few patchy faint-thin clay films on vertical and horizontal faces of peds; few discontinuous faint-thin clay films in root channels and/or pores; gradual smooth boundary.
84P2853

Bt2--66 to 109 cm; clay; dark red (2.5YR 3/6) moist; moderate coarse subangular blocky structure; friable; few fine roots throughout; many fine and medium continuous tubular and common fine void between rock fragments pores; common discontinuous distinct-thin clay films on vertical and horizontal faces of peds; few discontinuous faint-thin clay films in root channels and/or pores; clear smooth boundary.
84P2854

Bt3--109 to 157 cm; clay; red (2.5YR 4/6) moist; weak fine and medium subangular blocky structure; very friable; very few fine roots throughout; common fine and medium continuous tubular and common fine void between rock fragments pores; few patchy distinct-thin clay films on vertical and horizontal faces of peds and clay films in root channels and/or pores; diffuse smooth boundary.
Few termite cavities occur of 8 to 11 cm wide.
84P2855

Bt4--157 to 195 cm; clay; red (2.5YR 4/6) moist; weak fine and medium subangular blocky structure; very friable; very few fine roots throughout; common fine and medium continuous tubular and common fine void between rock fragments pores; few patchy faint-thin clay films on vertical and horizontal faces of peds.
84P2856

S84FN-990-013

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***
(ZAMBIA)

PRINT DATE 10/19/87

CLASSIFICATION: SND ; FINE, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTALF

NSSL - PROJECT 84P 97, ZAMBIA
- PEDON 84P 519, SAMPLES 84P2851-2856
- GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

SAMPLE NO.	DEPTH (CM)	HORIZON	-1-- CLAY LT .002	-2-- SILT .002 -.05	-3-- SAND .05 -2	-4-- FINE LT .0002	-5-- CO3 LT .002	-6-- FINE .002 -.02	-7-- COARSE .02 -.05	-8-- VF .05 -.10	-9-- F .10 -.25	-10- M .25 -.50	-11- C .5 -1	-12- VC 1 -2	-13- 2 -5	-14- 5 -20	-15- 20 -75	-16- .1- 75	-17- PCT OF WHOLE SOIL
			(- - -TOTAL - - -)			(- -CLAY- -)		(- -SILT- -)		(- - - - - -SAND- - - - - -)					(-COARSE FRACTIONS(MM)-)(>2MM)				
			<- - - - - - - - - - - - - PCT OF <2MM (3A1) - - - - - - - - - - - - - ->												<- PCT OF <75MM(3B1)->				
84P2851S	0- 24	AP1	21.7	17.6	60.7			6.5	11.1	24.3	29.4	5.7	1.0	0.3	--	--	--	36	--
84P2852S	24- 38	AP2	28.5	16.8	54.7			6.7	10.1	21.4	27.0	5.0	1.0	0.3	--	--	--	33	--
84P2853S	38- 66	BT1	34.9	15.3	49.8			6.4	8.9	19.8	24.4	4.2	0.9	0.5	--	--	--	30	--
84P2854S	66-109	BT2	41.9	13.8	44.3			5.5	8.3	17.5	21.5	4.1	0.8	0.4	TR	--	--	27	--
84P2855S	109-157	BT3	44.5	13.9	41.6			5.4	8.5	18.2	19.0	3.4	0.8	0.2	TR	--	--	23	--
84P2856S	157-195	BT4	42.0	15.9	42.1			6.4	9.5	20.0	18.5	2.6	0.7	0.3	TR	--	--	22	TR

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MM	EXTR P 6S3 PPM	TOTAL S 6R3A	(- - DITH-CIT - -) EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	(RATIO/CLAY) 15 BAR 8D1	(ATTERBERG) - LIMITS - LL 4F1	PI 4F	(- BULK DENSITY -) FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1	(- - -WATER CONTENT - -) FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
				<- PERCENT OF <2MM -->						PCT <0.4MM		<- - G/CC - - ->			CM/CM	<- - -PCT OF <2MM - ->				CM/CM
0- 24	0.63	0.048			2.1	0.2	TR	0.22	0.35	22	8		1.73	1.76	0.006			11.8	7.6	0.07
24- 38	0.55	0.042			2.5	0.2	TR	0.16	0.33				1.86	1.92	0.011			13.3	9.4	0.07
38- 66	0.49	0.039			3.1	0.2	TR	0.14	0.32	29	14		1.62	1.68	0.012			16.9	11.2	0.09
66-109	0.39				3.6	0.3	TR	0.11	0.32				1.55	1.61	0.013			17.0	13.2	0.06
109-157	0.24				3.8	0.3	TR	0.09	0.31	35	18		1.43	1.49	0.014			18.7	13.7	0.07
157-195	0.18				3.7	0.3	TR	0.09	0.30				1.47	1.54	0.016			17.0	12.8	0.06

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-013 PRINT DATE 10/19/87
CLASSIFICATION: SND ; FINE, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 519, SAMPLE 84P2851-2856

DEPTH (CM)	-1-- (- NH4OAC EXTRACTABLE BASES -) CA 5B5A 6N2E	-2-- MG 5B5A 6Q2D	-3-- NA 5B5A 6P2B	-4-- K 5B5A 6Q2B	-5-- SUM BASES	-6-- ACID- ITY 6H5A	-7-- EXTR AL 6G9A	-8-- (- - - -CEC - - -) SUM CATS 5A3A	-9-- NH4- OAC 5A8B	-10- BASES + AL 5A3B	-11- AL SAT 5G1	-12- -BASE SUM 5C3	-13- SAT- NH4 OAC 5C1	-14- CO3 AS CACO3 <2MM 6E1G	-15- RES. OHMS /CM 8E1	-16-	-17- COND. MMHOS /CM 8I	-18- (- - - -PH - - -) KCL IN 8C1G	-19- CACL2 .01M 8C1F 1:2	-20- H2O 8C1F 1:1
	<- - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - ->										<- - - - - -PCT - - - ->									
0- 24	4.0	1.2	0.1	0.2	5.5	1.8		7.3	4.8			75	100					6.0	6.3	6.7
24- 38	3.3	1.1	TR	0.2	4.6	2.3		6.9	4.6			67	100					5.8	6.2	6.8
38- 66	2.1	1.1	TR	0.2	3.4	3.9		7.3	4.9			47	69					5.1	5.5	6.0
66-109	1.8	1.1	TR	0.2	3.1	4.6		7.7	4.8			40	65					4.8	5.0	5.6
109-157	1.8	1.2	TR	0.1	3.1	3.8		6.9	4.2			45	74					5.1	5.5	5.8
157-195	1.7	1.3	TR	0.1	3.1	2.7		5.8	3.8			53	82					5.6	5.9	6.2

DEPTH (CM)	(- - - - - - - - -MINERALOGY - - - - - - - - -) (- - - - - - - CLAY - - - - - - -) (- - - - X-RAY - - - -)(- -DTA - -) (- - - - - <2U - - - -)(- -<2U - -) 7A21	7A21	7A21	7A21	7A3	7A3	TOTAL DOM RES WEATH 7B1A	7B1A
	<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
0- 24								
24- 38								
38- 66	KK 4	MI 3	GI 1	GE 1	KK25	GITR		
66-109								
109-157	KK 5	MI 3	GI 1	GE 1	KK40	GITR		
157-195								

AVERAGES, DEPTH 38- 88: PCT CLAY 38 PCT 1-75MM 29

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY: KIND OF MINERAL: KK KAOLINITE MI MICA GI GIBBSITE GE GOETHITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S84FN-990-013
CLASSIFICATION: SND ; FINE, MIXED, ISOHYPERTHERMIC TYPIC KANDIUSTALF
NATIONAL SOIL SURVEY LABORATORY ; PEDON 84P 519, SAMPLE 84P2851-2856

PRINT DATE 10/19/87

DEPTH (cm)	FRACTION	-1-- X-RAY 7A2i peak size	-2--	-3--	-4--	-5--	-6-- THERMAL DTA	-7-- TGA	-8-- 7A3b	-9-- 7A4b	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-
		CLAY MINERALOGY (<.002mm)												ELEMENTAL							
38- 66	TCLY	KK 4	MI 3	GI 1	GE 1		KK25	Gltr						11.6			1.5				
109-157	TCLY	KK 5	MI 3	GI 1	GE 1		KK40	Gltr						11.9			1.3				

DEPTH (cm)	SiO2 Percent	AL2O3 Percent	Fe2O3 Percent	MgO Percent	CaO Percent	K2O Percent	Na2O Percent	SURF AREA M2/G	INTERPRETATION

KIND OF MINERAL:

KK kaolinite MI mica GI gibbsite GE goethite

RELATIVE PEAK SIZE: 5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

INTERPRETATION (BY HORIZON):

PEDON MINERALOGY
BASED ON SAND/SILT:
BASED ON CLAY:
FAMILY MINERALOGY:
COMMENTS:

PEDON 14 - Land evaluation (W. Veldkamp)

This soil has a good potential for sustained crop production, but the first place needs ripping to improve the soil structure. Furthermore, P.K. and Zn fertilizers are required.

Physical degradation has not been considered to be a constraint for this soil in the present evaluation. The observed structure deterioration however, might be a sign of physical degradation and the assessment of this hazard may have to change to include soils of this kind.

This soil is suited for irrigated paddy rice, if water is available.

Soi[illegible] pedon 14 should in future be used for rainfed wheat [illegible]n. (NB. Zambia imports about 90% of its wheat requirement[illegible]ere is a reasonably good variety (whydah) available, but [illegible] are limited because of drought (especially during the last [illegible] and diseases (helminthosporim). In the evaluation temp[illegible] is considered to be the main constraint. More research i[illegible] to make wheat cultivation on these soils feasible.

Ratings of the land qualities; pedon 14

POTENTIAL CONSTRAINTS	Low inputs	High inputs
High temperature	2	2
high humidity	1	1
Frost	1	1
[illegible]	[illegible]	[illegible]

PEDON 14 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	2	N,Rp	1	D,N	PK,Zn, ripping (with irrigation class:i-N
Sorghum	2	Rp	1	M,Rp	PK,Zn, ripping
Cassava	3	K	2	F,Gs,W	K (with irrigation: class:2-F,W)
F/millet	2	RP	1	Ht	ripping
B/millet	2	Rp	1	Ht	ripping
Wheat	3	T	3	T	-
Dryl. rice	5a	D	5a	D	-(with irrigation: class 1-M; effective inputs PK,Zn,(ripping?)
Paddy rice	5a	D	5a	D	-(with irrigation: class 1A;effective inputs PKS, Zn)
Sunflower	2	N	1	N	PK
Soyabean	3	K	1	N	PK,Zn,ripping
Groundnut	2	Zn	1	M	PK,Zn,ripping
Ph/bean	2	Rp	1	M,Rp	PK, Zn, ripping
Cotton	2	N	1	N	PK, ripping
V/tobacco	4a	O	3	Ht	ripping

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Pedon: Makeni series, clayey phase
Soil Survey # LP/NM/MM1A/86 (BM-21)
Location: York farm, Makeni (8 km SW of Lusaka)
UTM grid: PN 352880 (sheet 1528A4)
Classification: Udic paleustoll, fine, mixed, isohyperthermic
Physiography: middle section of a long straight slope at the edge of a plateau forming the Lusaka plain; slope 1% (W)
Parent material: dolomitic limestone with minor gabbro inclusions
Elevation: 1280 m.a.s.l.
Climate: tropical savannah with an unimodal rainfall of circa 840 mm/year; mean monthly temperatures range from 16deg. C (June) to 24deg.C (November)
Drainage: well drained
Permeability: rapid when dry; when wet the infiltration in and percolation through the A horizon is very low, rendering trafficability on the farm low
Vegetation and land use: pit is situated outside arable land with an irrigated wheat - rainfed soyabean rotation; heavy fertilizer applications give yields of up to 6.0t wheat/ha, ripping is performed every few years
Groundwater: at about 180 cm during the rainy season, more than 4 m during the dry season
Moisture state: 0 - 125 cm dry, 125 - 180 cm moist, wet below
Surface stones: nil
Rock outcrops: nil
Erosion: no visible evidence
Remarks: lowest part of the pit could not be described in detail as it was still flooded. Very few mica flakes were found below 1 m in a neighboring pit. Few narrow (0.5 cm) cracks have been observed at the end of the dry season from the surface to about 1m depth.
Described by: Wen Ting-tiang and Nsofa C. Mulenga Date: 27.6.86

Ap 0 - 20 cm dark brown (7.5YR 3/3, moist and 7.5YR 3/4, dry) sandy clay with a moderate to strong coarse subangular blocky structure; very hard (dry), friable (moist), slightly sticky and slightly plastic (wet); few very fine, many fine and common medium moisture exped pores; many very fine, common fine and few medium roots; transition smooth and clear

AB 20 - 38 cm dark reddish brown (5YR 3/3, moist and 5YR 3/4, dry) clay with a strong very coarse subangular blocky structure, tending to coarse to very coarse prismatic; very hard (dry), friable (moist), plastic and slightly sticky (wet); patchy moderate cutans; many very fine, few fine and medium mostly inped pores; many very fine, common fine and few medium roots; very few fine ironstone gravel; transition gradual and smooth.

Bt1 38 - 70 cm dark reddish brown (5YR 3/5,moist and 5YR 3/6, dry) clay with a strong very coarse subangular blocky structure, tending to very coarse prismatic; hard (dry),

friable (moist), plastic and sticky (wet); moderate broken cutans; many very fine and few fine inped pores; common very fine and fine roots; very few fine ironstone gravel; transition diffuse and smooth

Bt2 70 - 125 cm dark reddish brown (slightly browner than 7.5YR 3/4,moist and 7.5YR 3/6,dry) clay with a moderate very coarse subangular blocky structure, disintegrating into fine to medium subangular blocky; slightly hard (dry), firm (moist), plastic and sticky (wet); moderate broken cutans; many very fine and common fine inped pores; common very fine and few fine roots; very few fine ironstone gravel; transition diffuse and smooth

Bt3 125 - 180 cm dark reddish brown (slightly browner than 5YR 3/6,moist) clay with a moderate coarse subangular blocky structure, disintegrating into fine to medium subangular blocky; haro (dry), firm (moist), plastic and slightly sticky (wet); patchy thin cutans; many very fine and few fine inped pores; common very fine and few fine roots; frequent fine ironstone gravel, locally very frequent; transition gradual and smooth

BC 180 - 220+ cm matrix colour as in Bt1, with common medium to coarse distinct reddish yellow (7.5YR 6/8, moist) mottles; clay with a weak medium to coarse subangular blocky structure, tending to massive, in which a clear fault pattern is still recognizable; frequent Mn staining along fault lines; slightly plastic and slightly sticky (wet); common very fine roots

ANALYTICAL DATA Profile no. LP/MM1A/86

Particle size distribution (%)

depth (cm)	clay	silt	fine sand	medium sand	coarse sand	textural class	gravel
0 - 20	38	24	30	7	2	clay loam	.
20 - 38	49	19	25	6	2	clay	.
38 - 70	53	18	23	5	2	clay	.
70 -125	53	17	25	4	2	clay	.
125-180	47	21	24	5	4	clay	.
180-220	15	19	57	6	4	sandy loam	.

Chemical data

depth (cm)	pH (H2O)	pH (KCl)	org C (%)	avail. P (ppm)	sol. Al (ppm)	sol. Mn (ppm)	free Fe_2O_3 (%)	lab. number
0 - 20	.	4.9	1.67	3	.	.	7.2	86/2836
20 - 38	.	4.9	1.10	2	.	.	7.4	86/ 37
38 - 70	.	5.0	0.70	.	.	.	7.3	86/ 38
70 -125	.	5.3	0.49	.	.	.	7.3	86/ 39
125-180	.	5.6	0.34	.	.	.	7.3	86/ 40
180-220	.	4.3	.	.	.	.	2.0	86/ 41

depth (cm)	exch. Ca (meq/100g soil)	exch. Mg (meq/100g soil)	exch. K (meq/100g soil)	exch. Na (meq/100g soil)	exch. Al (meq/100g soil)	CEC (meq/100g soil)	CEC (meq/100 g clay)	ECEC (meq/100 g clay)	base sat. (%)	Al sat. (%)
0 - 20	8.3	5.6	0.72	0.08	0.0	20.4	54	38	72	0
20 - 38	6.0	5.1	0.46	0.07	0.0	21.5	44	24	51	0
38 - 70	5.4	5.1	0.37	0.07	0.0	20.5	39	21	53	0
70 -125	4.6	4.8	0.31	0.06	0.0	18.0	34	18	53	0
125-180	3.9	5.2	0.26	0.10	0.0	17.1	36	20	55	0
180-220	0.9	0.4	0.31	0.03	0.2	4.6	31	12	36	11

PEDON 15 - Micromorphological data

Ap macroscopic: Iron rich ped, rim of the ped darker in colour with tongues extending into the interior of the ped, few iron nodules many charcoal particles, very porous with common large pores.
microscopic: Matrix. Undulic plasmic fabric, very locally some insepic plasmic domains, weakly glaesepic around very coarse glaebules; porphyroskelic distribution pattern with abundant sand and silt sized quartz grains, very few undetermined grains and abundant voids. Special features. Very few very fine to medium ferriargillans, the larger ones ruptured; few locally common, iron stained papules; very few very coarse to extremely coarse ferric glaebules, partly weathered; abundant charcoal particles.

AB macroscopic: Iron rich ped (brown colour than in Ap), rim of the ped slightly darker than interior, few large iron nodules, common charcoal particles, particles, very porous with few big pores and some distinct planes.
microscopic: Matrix. Undulic plasmic fabric, strongly glaesepic around very coarse glaebules; porphyroskelic distribution pattern with abundant sand and silt sized quartz grains, very few undetermined grains. Special features. Few, locally common, mostly thin ferriargillans (richer in iron in Ap), some completely filling in voids; very few very coarse very distinct manganiferous glaebules; abundant charcoal particles.

Bt1 macroscopic: Iron rich ped (redder than in AB), with rim darker than interior of the ped, many small charcoal particles, very porous with one very large and many smaller voids and few distinct planes.
microscopic: Matrix; Undulic plasmic fabric; porphyroskelic distribution pattern with abundant mostly silt sized quartz grains and abundant voids. Special features. Common, locally many thin to medium ferriargillans, some completely filling in voids; few coarse discrete manganiferous glaebules with inclusions of quartz particles; many charcoal particles; few undifferentiated pedotubules.

Bt2 macroscopic; Very iron rich ped (redder than samples of overlying horizons) rim slightly darker than interior; few large voids and few thin planes; common dark specks.
microscopic: Matrix. Strongly undulic plasmic fabric porphyroskelic distribution pattern with abundant mostly silt sized quartz grains, many voids. Special features. Few, locally common, thin to medium

ferriargillans, with the outer edge of the argillans being somewhat lighter in colour, some of the bigger argillans are ruptured; few coarse discrete manganiferous glaebules.

Pedon 15 - Land evaluation (W. Veldkamp)

For this soil P-Fixation and workability are considered to be the main constraints. Actual data on P-fixation are not available, but because of a ratio of Fe_2O_3/clay of over 0.15 in the topsoil the assumption of P-fixation has been made.

P,S and maybe Mo and B applications are required. The potassium status is satisfactory at the moment, but regular K-applications are recommended to maintain a good K-supply,. Ripping, as is practiced at the farm, is beneficial, but the physical rooting condition is not the most limiting constraint.

Sunflower, sorghum and soybean are the most suitable crops in a low input system. Under high inputs the crop choice is much wider, including cotton beans and depending on the structure and consistence of the topsoil, groundnut and if the P-problem can be overcome, maize.

The farm has a rotation of irrigated (winter) wheat and soybean on an important part of its land. Furthermore maize, potatoes, onions are the main crops.

Ratings of the land qualities: pedon 15

POTENTIAL CONSTRAINTS	Low inputs	High inputs
high temperature	2	2
high humidity	1	1
frost	1	1
length growing period (70% prob.)	125	125 (days)
eff.min.rainfall (70% prob.)	1;350	1;350(rating,mm)
occurrence critical periods	1	1
occurrence drought	x	x
SOIL CONSTRAINTS		
phosphate fixation	2	1
potassium	1	-
Ca/Mg	1	-
boron	2	-
molybdenum	1	-
sulphur	1	-
rooting conditions (physical)	1	-
heavy topsoil	3	3
workability	2	1 (texture)

Explanation of ratings:
-: no constraint
x: special drought constraint
1: slight constraint
2: moderate constraint
3: severe constraint
4: very severe constraint

PEDON 15 - Land evaluation classes

CROP	-LOW INPUTS- class	most limit. const.	-HIGH INPUTS- class	most limit. const.	EFFECTIVE INPUTS
Maize	3	Np	2	Np	P
Sorghum	1	Np,S	1	Np	PS
Cassava	3	W	3	W	-
F/millet	2	Ht	2	Ht	-
B/millet	2	Ht	2	Ht	-
Wheat	3	T	3	T	-
Dryl. rice	5a	D	5a	D	-(with irrigation:class 1-H; effective inputs PS)
Paddy rice	5a	D	5a	D	-(with irrigation:class 1-Np; effective inputs PS).
Sunflower	1	B,Np,S	1	Np	B,P,S
Soyabean	1	K,Mo,Np,S	1	Np	K,MoP,S
Groundnut	2	W	1	Np	PKS,Mo,B, mechanized tillage
Ph/bean	2	Np	1	Np	PS,Mo
Cotton	2	Np	1	H,Np	P
V/tobacco	4a	Ht	4a	Ht	-

A: Acidity, B: Boron, Ca: Calcium, D: Drought, F: Frost, G: Degredation, Ge: Germination, Gs: Length growing season, H: Humidity, Ht: Heavy topsoil, K: Potassium, M: Mechanisation (anthills), Mg: Magnesium, Mo: Molybdenum, N: Nutrients, Np: P fixn., O: Oxygen, P: Puddling; permeability, Rp: Rootability, S: Sulphur, T: Temperature, W: Workability, Zn: Zinc

Some remarks about pedon 15

At the foot of the present pit a venous saprolite is found. It seems to be a typical igneous intrusion. Rock is not reached within 6 m depth. Only 6 mm small pebbles of gabbro coated with calcareous material were collected. In Table 1 the mineral composition of the sand fraction of less than 250 um is given. Up to 185 cm depth the data refer to another pit about 50 m away. The data concerning the saprolite and gabbro pebbles refer to the present pit.

In the A and B horizons the mineral suite is similar to the saprolite except that the more readily weatherable gabbro minerals have disappeared. Thus the higher concentration of quartz and plagioclase can be expected. An interesting feature is the very limited weathering of the minerals, which is suggestive of recent developments.

Clay mineralogical investigations demonstrated a suite with halloysite, illite, Kaolinite, smectite and vermiculite. The 2:1 minerals are probably interlayered with possible combinations of smectite-vermiculite, smectite-chlorite and smectite-illite. Other minerals detected are biotite, a feldspar, quartz and talc. Kaolinite seems more pronounced in the upper part of the profile, but somewhat disorganized. This may reflect the transformations due to an in situ development which notion is also supported by the grain mineralogy.

The organic matter content is relatively high and may well form a pool of nutrients like phosphorus, nitrogen and sulphur. The mineralogy has demonstrated considerable reserves of nutrients. Therefore the inherent fertility of this soil is high. Micro-nutrient deficiencies have not been reported.

The soil is "iron-rich" and does tend to retain phosphate. In developing phosphate adsorption isotherms, 120 ug p/g soil was required to obtain a satisfactory soil solution containing 0.2 ppm as phosphorus. Yet recovery with 0.01 M $CaCl_2$ with shaking periods of six hours until the phosphorus content was less than 5% of the first extract produced a high recovery of about 60%. This compares with about 40% for those oxisols/ ultisols of the high rainfall zone. For the York Farm profile it can be stated that when enough P is applied a large labile pool of P exist. The organic matter content may play a role in this respect.

Workability is a constraint on this soil. When the soil is wet mechanical cultivations are virtually impossible, so in high technology situations crops requiring several operations on the land between December and March may be at higher risk. Compaction problem related to mechanised operation are known to occur. Ripping is the usual solution.

The York Farm profile represents one of the best soils in Zambia. Development over basic rocks that includes dolomite,

limestone and gabbro the mineralogical and chemical data support the field observations of a soil system with high potential fertility. These soils are used for commercial arable farming and for horticulture. Continuous cropping is common. For high technology there is considerable scope. Phosphate fixation does not seem to be a major problem.

Table 1 Minerals identified in sand fraction less than 250 um.

Depth (cm)	Mineral	Approximate %
0 - 17	biotite	less than 5
	quartz	40
	plagioclase	25
	opaque	25
	tourmaline	less than 5
37 - 80	biotite	5
	epidote	5
	quartz	40
	plagioclase	25
	opaque	20
	tourmaline	5
115-185	biotite	10
	epidote	less than 5
	quartz	30
	plagioclase	35
	opaque	20
	tourmaline	less than 5
		old pit
		new pit
saprolite	biotite	less than 5
	quartz	10
	magnetite	20
	muscovite	15
	plagioclase	50
Gabbro petole		
	actinolite	nd
	biotite	nd
	hypersthene	nd
	magnetite	nd
	olivine	nd
	plagioclase	nd

DISCUSSIONS HELD AT THE PROFILES

Pedon 1

Chairman : Otto Spaargaren
Secretary : Michael Sishwashwa

Environment and land use

The environmental setting of the pedon was explained by members of the Soil Survey Unit. The pit is situated in an upper slope/crest position in a typical plateau environment. It was pointed out that Misamfu Research Station in fact forms part of a kind of tableland that is situated about 150 m higher than the main plateau covering most of Northern Province. The parent material is not exactly known, but should belong to the metamorphised acidic material that underlies the table land.

The traditional large circle chitemene system, involving the lopping of tree branches which are then heaped in a newly cleared field and burnt, was mentioned as the main traditional farming system in the area. Under this system fields are cultivated for about three years, although a new field has to be opened up every year for finger millet, which is the first crop in the rotation, and the main staple food.

Cassava is another important crop. Prof. Moorman mentioned that although the nutrinal value of the tubers is not very high, the leaves of the plant can also be eaten. Sweeter cassava varieties existed, but these could normally not be grown due to their susceptibility to disease stress, they had to be crossed with more bitter cassava varieties which have a higher HCN content. Upland rice was not believed to be a very suitable crop for Northern Province, as the mean annual rainfall is still too low to prevent this shallow rooting crop suffering from short drought spells.

Profile description

- The use of an AB horizon was questioned, as it was felt it could be incorporated in the A horizon
- The qualification very sticky was not believed to be correct in this type of soil
- An explanation had to be given how pores could be described in as much detail as done in the profile description
- It was stressed that profile descriptions should be a record of description, and should therefore include the field texture and not the particle size class as determined in the laboratory.
- The acidity of the horizons was nicely reflected in chemical parameters like exchangeable calcium and aluminium, and in physical characteristics like the rooting pattern. Particularly striking was the way in which roots at the

boundary of a very acid subsoil tended not to grow downwards but to continue growing in a horizontal direction.

Classification

The epipedon is not dark enough for a mollic or an umbric, and became thus an ochric. An argillic horizon was recognized, on account of the following criteria:

- enough clay increase with depth
- on increase of lime clay/clay ration
- sufficient depth
- presence of clay skins.

The top of the argillic horizon lies between 10 and 20 cm. Because of the presence of an argillic no oxic-B can exist at similar depths. Above the argillic horizon there is not sufficient thickness left over for an oxic horizon.

No other diagnostic properties could be established. Since the soil meets all the requirements for an ultisol, including a base saturation of less than 35% (by sum of cations) at 140 cm depth, it belongs to the order of the ultisols. The soil moisture regime places it in the suborder of the ustults, while the slight decrease in clay content with depth makes it a paleustult. Owing to the low CEC per 100 g clay the subgroup was determined to be the oxic paleustult, analogus with the subdivision into subgroups of the haplustults.

The Mufulira series was classified as a clayey, mixed, isohyperthermic member of the family of the oxic paleustults.

The classification under the FAO legend of the Soil Map of the World would be a dystric nitosol if the nonferric qualification on the ground of a CEC at less than 24 meq/100g clay was disregarded.

Agricultural Potential

According to Prof. Buol this type of soil could be made productive, if an initial lime application at about 1-2 tonne/ha for each meq. exchangeable Al would be applied, to be followed by maintenance liming every 3 years or so, and normal fertilizer application for one rainfed crop per year as recommended for the highly leached soils in general. A high level of management would be required for this kind of soil anyway.

Prof. Moorman disagreed, pointing out that the physical characteristics of these soils are very bad, making it virtually impossible to bring these soils under large scale intensive production that will be profitable. In particular the erodability will be a major problem of the soils.

DISCUSSIONS HELD AT THE PROFILES

Pedon 2

Chairman : Otto Spargaren
Secretary : Michael M. Sishwashwa

An introduction on the general information of the site was outlined briefly to supplement what is in the field tour guide. The general information of the soil was also briefly outlined. Then the vegetation was identified as a mixture of Brachestigia, Jubanadia and other isolated plant species.

In general it was agreed upon that the crops (Land Use) likely to grow in this soil are similar to those of Pedon 1 but that crops on soils of pedon 2 would perform better.

The profile description was then read out and discussed by the participants and it was agreed that the description was correct.

Classification

Firstly the diagnostic epipedon was established and it was agreed to be an Ochric epipedon due to:-

1. The colour was light with high values and chromos
2. It was too thin to be any other epipedon.
3. That there was low organic matter content.

Then the sub-surface diagnostic horizon was identified as Argillic with reasons that there was enough clay increase of more than 3% in the illuvial horizon than the eluvial horizon. But lack of much evidence of clay eluviation and the uncertainty of the presence of clay skins plus lack of vital data to prove the presence of an Argillic threw the discussion into a long controversial state. Through very precise examination clay skins were identified by Dr. Hari Eswaran and were seen by many participants in the lower part of the horizon. Thus finally it was agreed that an argillic horizon was present because it met the requirements 1,2 and 4a of the key to soil taxonomy page 7. Then a question was posed whether there was an oxic horizon on top of the argillic horizon? it was tested against the requirements of an oxic horizon and it met the requirements 1,2,3,4,5,6,7 of the oxic horizon according to the key page 13, except for the first one in which the thickness is supposed to be at least 30cm but here it is only 11cm thick thus disqualifies it to be an oxic horizon. Then the discussions continued to the order of the soil.

It was identified as an ultisol due to the presence of an argillic horizon with a low base saturation of less than 35%. It qualified to be ustult due to the ustic moisture regime.

It was named a paleustult because of the argillic horizon which has a clay distribution with depth such that the percentage of clay does not decrease from its maximum amount by more than 20% of that maximum within 1.5m of the soil surface. In this case the maximum clay content is 33% which is the last horizon and is slightly higher than all the overlying horizons thus it qualifies into a paleustults.

The final classification was Fine loamy, siliceous, isohyperthermic oxic paleustult. Tnese classifications were not opposed.

DISCUSSIONS HELD AT THE PROFILES

Pedon 3

Chairman : Thware Asumadu
Secretary : Zaona Zulu

Definition and recognition of the diagnostic horizons were done as following the Field Tour Guide.

The textures in horizons BA (16-37cm) and Bw1 (37-63 cm) were corrected to read sandy clay.

Vegetation and land form

Mr. Cuulu Kalima had described the vegetation as not being very much different from that of pedon 1 and 2 in the Guide which was dominated by Julbernadia paniculata, Brachystegia speciformis and peterocarpus angolensis. The soil was said to have been formed from quartzitic sandstone. The area generally sloped northwards towards a stream.

Pit description

After an initial correction of chemical data in the guide of this pedon, the Chairman asked those who wanted to take photographs of the pit to do so. Thereafter individuals were allowed to examine the profile for diagnostic soil properties.

Mr. Benson Sokotela read through the description and Mr. Lazarus Chileshe explained the micro-morphological data. Mr. Wen Ting-Tiang remarked that the structure of the 60-124cm horizon was more massive than of 124cm below. Professor Tarvenier was appointed advisor for the pit.

Classification

Dr. Salama identified the epipedon of as an Ochric based on colour. This was unamymously agreed upon. Before going on to the diagnostic sub-surface horizon, comments on observations were invited from the participants whether any member of the team had seen any clay skins or cutans in the profile. Dr. Hari Eswaran pointed out that there was intense biological activities throughout much of the pit surface and might have contributed to destruction of cutans. Criteria for an argillic horizon were examined using the key. Five participants voted for the presence of an argillic horizon and the rest voted against it. Professor Tavernier said these were not clay skins. Professor Buol felt there was an argillic horizon and that he saw clay skins at about 2 m below. Professor Moormann enlightened the group that there was not enough data to qualify this particular horizon as an argillic in terms of the Taxonomy. Professor Rudy Dudal added conclusively that it was not an argillic horizon. Dr. Eswaran suggested then that since there was disagreements as to whether

there was an argillic horizon or not, the profile should be classified under two assumptions as follows:-

(a) with an argillic horizon
(b) Without an argillic horizon, until further data was available for definite classification.

On assumption that there was an argillic horizon the profile was classified as follows:

Epipedon - Ochric epipedon
Diagnostic Subsurface horizon - Argillic
Order - Ustisol
Suborder - Ustults
Group - Rhodustults
Subgroup - Oxic Rhodic Paleustult
Family - Fine loamy, Siliceous, Isohyperthermic, Oxic Rhodic Paleustult;

Using particle size and mineralogy Assuming there was no Argillic, the profile was classified as follows:-

Epipedon - Ochric epipedon
Diagnostic Subsurface horizon - Oxic
Order - Ustisol
Sub order - Ustox
Group - Haplustox
Sub group - Ultic Haplustox
Family - Fine loamy, Silicious, Isohyperthermic, Ultic Haplustox

DISCUSSIONS HELD AT THE PROFILES

Pedon 4

Chairman : Ted Angen
Secretary : Leif Bustness

Enviroment

Miombo woodland. Jubelnardia, Brachystegia and Uapaca species elevation 1800m asl. Rainfall 1100 - 1200 mm per year. The Farmer came to the area in 1979-80. Main crop is wheat. Last year 600 acres crop rotation with maize 2000. head of cattle. Fertilizer 250-300 kg/ha superphosphate and Urea (unspecified amount) No liming. Yield 1985 2.1 tons wheat per ha. Management problems:low tillering of the wheat, high rainfall at the feeding time (leaching) and it causes also difficulties for weed control.

Profile description

Te description was presented according to Field Tour Guide by Mr. Masinja and the micromorphology was presented by Mr. L. Chileshe. Less than 1% of clayskins were found, therefore the clayskins which are found were not mentioned in the description.

It was said that it is preferable that any clay skins found, regardless amount, are mentioned in the micromophological description (Moorman). Clayskins, but of poor quality, were distinguished in the pit.

Remarks on horizon nomenclature: compared to pedons 2 and 3, A2 horizon in pedon 4 is similar to AB horizon in pedon 2 and BA horizon in pedon 3. The A2 varies between a Bt and BA horizon.

Remarks on structure.

Objections were raised to the stated prismatic structure in Bt2 horizon. The soil moisture control section had a calculated upper limit as follows:
upper limit 49cm 1/3 bar 2.5 cm
Lower limit 162 cm 1/5 bar 7.5 cm
The calculations provide a limit for where to take measurement.

Classification

Epipedon: Ochric. Depth: 0 - 28 cm.
Subsurface horizon: Argillic. The measuring point for determining clay increase could be at any depth and the increase should be 1.2 times over not more than 30 cm. Surface of argillic horizon: 28cm
Soil order : Ultisol
Sub order : Ustult
Great group: Paleustult

Sub Group : Oxic Rhodic or Rhod Oxic
Family : Fine kaolinitic isohyperthermic family of Rhodoxic thermic family of Rhodixic Paleustult.

Discussion (Conclusions)

This is an very doubtful ultisol. Clayskins are only found in the lower part (bottom) of the argillic horizon, therefore it is not an ultisol. It is a typic tropeptic Haplustox according to the opinion of the participants.

FAO Classification

According to FAO's classification system this soil has an argillic horizon between 25 and 60cm. It is a Nitosol. If it has not an argillic horizon it will become a Rhodic Ferralsol.

Land evaluation

- the soil has problems with Al-toxicity and acidity
- it has very poor nutrient content, especially low in K
- it is exhausted after 4-5 years without application of fertilizer. Wheat grows better at this farm than at Katito (Zam-Can's Farm) and the soil is considered to be similar. No explanation so far.

At Katito trials with lime and wheat:
0 tons per ha lime - Yeild 110 Kg/ha
2 tons per ha lime - Yeild 1150 kg/ha

DISCUSSIONS HELD AT THE PROFILES

Pedon 5

Chairman : Cuulu Kalima
Secretary : Nesofwa Mulenga

Profile description

(1) Structure: Strong fine medium and coarse subangular blocky throughout the profile except for the last horizon where it is strong to moderate.
(2) Colour: 2.5YR 4/8 dry and 2.5YR 3/6 moist throughout.
(3) Thin cutans throughout profile except in the first horizon. It was also mentioned that every horizon must be sampled for this is important for genetic interpretation. According to the micromorphological observations made by L. Chileshe at 94cm depth no cutans were seen.

(4) The analytical data for the following look suspicious hence repeat the analysis, - (a) Base saturation
(b) Extractable acidity

Classification

Epipedon - Ochric
Diagnostic sub surface horizon - Argillic

It was also noted that in the KEY there is a topographical error of OR in 4a. Instead it should read OF as per the original meaning of that sentence in the Soil Taxonomy. However S. Buol would opt for an oxic horizon, thus meeting condition 4C.

Not an ultisol because does not meet conditions 1a and 1b
Alfisol: Suborder - Ustalf
Great group: Rhodustalf
Sub group - Oxic isohyperthermic
Family: fine oxidic isohyperthermic oxic rhodostalf
FAO legend - Dystric Nitosol

ICOMOX ICOMALC:
- No clear argillic horizon
- Kandic but 40% clay
- Would be classified as Rhodic fine Kaolinitic isohyperthermic ultic haplustox.

Land use

P fixation is a major problem and optimal maize yields cannot be obtained. Good yields can be obtained for crops like sorghum, S/flower, S/beans, G/nuts and beans. Good yields should be expected after liming and zinc application. Chemical degradation should be checked. Heavy topsoil texture makes workability not easy.

DISCUSSIONS HELD AT THE PROFILES

Pedon 6

Chairman : Benson Sokotela
Secretary : Austin Mambo

Introducyion

Mr. P. Woode in his introductory remarks described the environment, problems of classification as experienced in the past, the geology and the management aspects of the soil.

The Environment

The profile pit No. 6 is situated on gently undulating upland, with slopes ranging from 2-5%. Steeper slopes occur westward away from the site.

The vegetation is miombo woodland and the predominant tree species were said to be Brachystegia, Julbernadia and few Uapaca

The Problems of classification in the past.

_____This pedon was said to have had caused classification problems due to the fact that the surveyors found clear cutans in the wet seasons, and in the dry season these were not being seen. The BSP range was said to range from 20 - 70%. As such the problem of differentiating the order of ultisols and Alfisols was experienced.

The Geology

The geology of the area is not well known, and as such the parent material is not properly known. It was however said to be most likely composed of metamorphosed sandstone and sedimentary material. Other materials such as basement complex are also said to be existing in the area.

Management Aspects

Maize and tobacco are the main crops on these soils. Under these crops acidity is a problem which quickly follows the use of nitrogenous fertilizers.

The upper soil compacts a bit under natural conditions. The compaction is speeded with farm machinery. This results in a layer of compact subsoil which impedes both drainage and root penetration. The result is that due to the rooting check the plant growth of whole plant/crop is checked, and due to checked or impeded drainage the erosion risk is increased. To reduce this wet ripping/subsoiling is done.

Profile description

Comments

Strong structure was said to be referring to the degree of ped development and as such should not be interpreted as consistence, dry.

It was also suggested to the authors of the profile to separate macro and micro structure as it was difficult to understand a massive structure which was said to be parting to strong very fine granules.

In the Bw1 horizon most of the people agreed that vertical and horizontal continuous cutans were seen. A few people on the other hand could not see the cutans.

The following corrections to the profile as it appears in the tour guide were made.

A horizon - the dry colour was changed to 10YR6/2 and the moist colour to 10YR 4/2 the texture was also changed to loamy sand.

AE horizon - the dry color was changed to 10YR 6/3 and the texture to loamy sand

EB horizon - the dry color was changed to 7.5YR 7/4 and the moist color to 7.5YR 6/4

Bw2 horizon - the dry color was changed to 7.5YR 6/8 and the moist color to 7.5YR 6/6

Bw3 horizon - the moist color was changed to 5YR 7/8

It was pointed out that these changes especially in color may be due to differences in the authors opinion.

Additional Remarks

Evidence of elluviation was reflected by the presence of bleached sand grains and bioactivity in the EA horizon from 11-34cm.

In the EB horizon from 34-61cm pedotubules were seen. Compaction is also reflected by an increase in the bulk density.

Classification

Three diagnostic horizons were observed as follows:-

(a) An Ochric epipedon from 0 - 11cm
(b) An Albic Subsurface horizon from 11 - 34cm
(c) An Argillic subsurface horizon from 34 down

No other diagnostic properties were discussed/identified.

Comments

It was suggested that identification and/or checking of diagnostic horizon should be done systematically from the top of the pedon (i.e. Soil Surface) down the whole profile to avoid confusion.

It was also pointed out that when an argillic horizon is said to be exclusive of the oxic it does not mean that they cannot occur in the same pedon. It simply means that the two cannot overlap.

After following the key it was finally concluded that the pedon classifies as a Siliceous, Isohyperthermic Oxic, Ultic Paleaustalf.

Management

Virginia tobacco has been grown according to the owner of the farm where the profile is sited lower yields were obtained which he thinks are probably due to lower temperatures. He however added that he has experienced that long periodes of cropping do not pay on these soils. As a solution he is doing a rotation which results in reasonable yields with no erosion. The rotation is maize with a nitrogenous fertilizer and soya beans without nitrogenous fertilizers, then fallow.

Minor elements zinc and boron are thought to be prevelant

Input rates:-

1 tonne lime/acre every 4 - 5 yrs
250 kg/acre D. compund for maize. (D compound is a 10.20.10 fertilizer.)

Yields on soyabeans are rather low. This farmer however feels a better variety may change the yields of soya. Average maize yield is about 21 x 90kg bags/acre.

Carrying capacity of cattle on fallow land is about 1 - 2 head/acre and about 2 - 3 head/acre on virgin land.

No real drought has ever been experienced by this farmer since 1966.

DISCUSSIONS HELD AT THE PROFILES

Pedon 2

Chairman : S. Salama
Secretary : B. M. Pederson

General remarks

This soil was said to be developed on residuum from limestone material and hence the general acidity problem in dambos in other areas in Copperbelt is not present in the dambos nearby. The original pit was dug some distance (approx. 150m) from the pit visited during the ST-Forum. This had to be taken into account when describing and classifying the pedon on the basis of the presented laboratory analysis.

The structure was said to be somewhat weaker in the previously sampled pit than what was observed in pit visited. For this reason the pit was described and some differences from the original pit noted.

Profile description

A (0-8cm) : 5 YR 3/4 (dry)
AB (8-28cm): 2,5YR 2/4 (moist); Weak to moderate, fine, subangular blocky structure; plastic and sticky.
Bw1 (28-60): 2,5YR 3/6 (Moist) Moderate, medium subangular blocky structure.
Bw2 (60-110): 2,5YR 3/6 (moist); Many continuous thick, broken and thick cutans
Bw3 (110-160)+: 2,5YR 4/8 dry, 2,5 YR 3/6 (moist); Many, continuous, thick cutans structure is prismatic, breaking to moderate, fine, medium and coarse subangular blocky.

Remarks - Subdivision of an established seemingly uniform horizon from 28cm and deeper was made from indication of a change in resistance to a knife scratched down through the profile surface. Members in the group disagreed in this and said the subdivision was making something simple more complicated than needed.

Classification

Epipedon: Ochric
Subsurface horizon: Argillic

The profile was said to have Oxic properties in the epipedon, although not qualifying for an oxic horizon.

Soil Order: Ultisol (35% B.S. % at 180cm)
Suborder: Humult (0,9% Org. C)
Great Group: Palehumult (Clay distribution OK, Total resistant minerals = 99%, Total weatherable minerals: 1%)
Subgroup: Ustoxic Palehumult, meeting requirements for both

orthoxic and Ustic palehumult. Ustoxic palehumult means the soil is having oxic properties and ustic moisture regime.
Family: (control section, 7-57cm, upper 50cm of Bt). Clayey, mixed, isohyperthermic family of ustoxic palehumult.

After pit inspection some participants also doubted the clay increase in this pit and recommended new analysis to be taken. Others said a first field - classification in the pit rather would put it into order Ultisol than Alfisol due to an expected higher BS% (Carbonatic parent material). It was also said that the pedon doesn't have a clear dark color indicating a humult. In addition it was mentioned that this soil after only a few years of cultivation would be subject to a decrease in organic matter due to increase decomposition.

With regard to the observed clay-skins in the profile it was commented that these are not exclusively an indication of Alfisol. Also Ultisol could in some cases have well developed clay skins.

Two main processes were explained as the main factor in the accumulation clay skins:

Alternative wetting and drying.
Dispersion of Fe and Al oxides by organic acids.

FAO classification - Dystric Nitosol
The pedon was said to be a central model of a Nitosol.
New 3rd level of FAO-Legend - Rhodic Dystric Nitosol

Comments

Some participants were not happy with the classification of the pedon being a listoxic palehumult: % Org.C is not too reliable and a better criteria was said to be kg Org.C which is not obligable if required % Org. C is enough.

Land Use and Management

Wheat: Seeding in May (direct drilling), No Liming, heavy fertilizing (300Kg Urea/ha, 200Kg mixed (mainly phosphate)), Zn-fertilizer has been successful. Yield: 4-6 tons per ha. Irrigation: 18 inches (45cm) in 10 applications. Good conditions for wheat, diseases are minimal and tillering sufficient mostly due to low temperatures in the first part of the growing season. Soyabeans are being grown during the wet season and is a good crop for rotation. In near future the wheat scheme will be connected to the main electricity network. Consequently the price of inputs can be reduced. So far the electricity needed for irrigation pumps has been very expensive produced by diesel generators. From this reason the profit from the production is likely to be better and break-even limit of approx. 4-5 tons/ha will be lowered.

DISCUSSIONS HELD AT THE PROFILES

Pedon 8

Chairman : Peter Woode
Secretary : Barry Dalal-Clayton

Environment and Background

This pedon represented another example of the so called "Sandveld Soil", developed over granitic gneiss (according to the Geological Map). The site was on a gently broad interfluve with only remnants of natural Miombo vegetation remaining. The chairman explained that the soils on the farm had been subjected to a great deal of mismanagement. Originally a maize-tobacco farm, it had more recently been monocropped for 8 years under maize, followed by 5 years during which the larger part of the farm had not been used. The monocropping and intensive use had resulted in the development of a hard pan and extensive soil erosion. Some ripping had been tried and this had a significant difference in crop performance. In addition sprinkler irrigation on a limited area had met with some success.

Profile Description

Due to shortage of time the chairman asked Prof Van Wambeke to provide a brief description of the profile. The need to take the colour of both ped faces and rubbed soil in the topsoil was stressed, particularly in the identification of mollic epipedous. Prof. Van Wambeke highlighted the essential features which included the following: a) small reddish concretions and specks increasing with depth and becoming important in the lower profile. b) massive structure in the upper subsoil, becoming subangular blocky in the middle part of the profile. c) The consistency showed a similar trend to structure with maximum hardness (dry) around 50cm depth. d) Clay skins were observed in the subsoil (depth unspecified). The need to apply horizon designations in the field and to describe pedons as fully as possible was stressed, since return visits are expensive and often not possible.

Horizon identification

An ochric epipedon was identified since the A horizon was too thin to be mollic or umbric.

At this point Prof. Tavernier advised that the next essential exercise was to examine the soil immediately below any epipedon before looking for lower subsurface horizons to determine the presence of eluvial horizons such as albic. In this case an eluvial horizon was present, but was not albic since the chroma was too high.

An argillic horizon was concluded to be present, on the

basis of meeting the required clay increase and the clear presence of clay skins. The top of the argillic was roughly placed at 27cm depth. Prof. Lenvain suggested it to be at 22cm when predicted graphically whilst Prof. Moorman indicated that his computer program placed it at 27cm with a probability of over 90%.

No abrupt textural change was present but the clay increase was sufficient to meet the requirements of a kandic horizon.

Classification

Working through the key the profile failed the ultisols on account of its BSP exceeding 35% throughout the subsoil. It failed the mollisols on account of lacking a mollic epipedon. It was concluded that this profile met the requirements of the Alfisols - having a clear argillic horizon with a BSP in excess of 35%.

The absence of an aquic moisture regime and the absence of a frigid or cryic temperature regime placed the profile within the Ustalf suborder.

The absence of a duripan, plinthite or natric horizon led to an examination of the requirements of the paleustalf great group. A decrease in clay percentage in excess of 20% pf the maximum in the argillic horizon (based on the projected percentage in the centre of the Bt3 horizon) resulted in this profile failing the paleustalf great group.

The hue was not redder than 5 yr throughout the argillic horizon and thus failed the Rhodustalf great group.

Thus this profile was placed in the Haplustalf great group.

An examination of the characteristics of a Typic Haplustalf revealed that this profile failed the typic concept on the following prescribed counts.

d) The CEC in the major part of the argillic horizon was <24 meq per 100g clay.
f) A lack of a calcic horizon or soft powdery lime within 1.25m of the surface.
g) A BSP of >75% throughout the argillic horizon.

Thus the profile was placed in the oxic haplustalf subgroup.

The final classification was Fine, Kaolinitic, Isohyperthermic, Oxic Haplustalf.

FAO classification - Ferric Luvisol

Ferric properties included the presence of red specks and numerous red concretions, and the low CEC indicating a low

activity clay.

Prof. Dudal explained that these soils were very extensive and very poor soils which are erosive and tend to seal and become very hard when dry, which is a major impediment when working such soils. After 3 weeks or so of rain oxen have difficulty getting on to such soils and tend to cause severe puddling.

Genesis

Prof. Dudal suggested that such soils occured in areas which have previously had a higher ground water table and that the concretions were probably fossil from such times.

Dr. Eswaran suggested that the red specks could be the product of rock fragments weathered in situ. Prof. Tavernier pointed out the presence of bleached zones surrounding several small concretions which indicated the movement of iron into the concretions.

Commenting on the potential of these soils Dr. Veldkamp observed that these soils have a very poor physical condition.

DISCUSSIONS HELD AT THE PROFILES

Pedon 9

Chairman : Brian Mhango
Secretary : Rhabson Mwenda

Epipedon: Mollic

Subsurface Diagnostic horizon: Argillic

Order: Mollisolls

Suborder: Ustolls

Great Group: Paleustolls

Sub group: Udic Paleustolls - this subgroup was arrived at due to the absence of soft powdery lime.

Family: - fine, mixed, isohyperthermic, family of udic Paleustolls.

FAO classification: Luvic Phaozem

Management; It becomes difficult to go into the field when wet as it becomes very slippery and sticky against the implements.

DISCUSSIONS HELD AT THE PROFILES

Pedon 10

Chairman : Boago Moganane
Secretary : Rusmus Masinja

Introduction

Before the Chairman introduced the pedon to the participants, new attempts were made by the participants to determine colour and texture to compare to the ones by the Authors. Most of the colours were similar to those by the authors but some differences were found in structure.

The Chairman introduced the pedon to the participants. Mr. Cuulu Kalima was requested to give a general talk on vegetation, which he said it was mainly Munga woodland (Acacia spp.), he also gave the prevailing climatic conditions and the genesis. Mr. C. Kalima as the Soil Surveyor of the area under discussion went on to say, the soil moisture regime was Ustic and Soil Temperature regime as Isohyperthermic. On genesis, the soil is believed to have developed from Lacustrine sedimentary material. Other views on genesis were expressed, as from Mr. Barry Dalal-Clayton, who said that, he was of the opinion that, the pedon was an old terrace, Underlain by Karroo rocks, hence the parent material Colluvium and alluvium. He went on to say, Kafue flat was an old fault line, so with time, it was filled up with material from the surrounding higher lands.

Classification

Diagnostic epipedon:	Ochric
Diagnostic subsurface horizons:	Cambic
Order:	Vertisols
Suborder:	Ustert
Great group:	Chromustert
Subgroup:	Typic Chromustert
Family:	Fine, Mixed, Isohyperthermic of Typic Chromustert
Series:	Kafue series is a member of the fine, mixed, isohyperthermic of the Typic Chromustert
FAO:	Chromic Vertisol, Sodic and saline phase.

The classification according to FAO was done by Dr.R. Dudal

Discussion

Dr. Hari Eswaran gave a talk concerning the approach, when one is describing a vertisol pedon. He demonstrated to the participants how one can do it in the field. He said, when

describing Vertisols, don't only look at one feature, but you should look at many features which are visible in the field, those of which are common in a Vertisol pedon such as:-

(a) There will be a high frequency of Gilgaias the main characteristic of the landscape, he however continued to say, in cultivated areas Gilgai may not be seen, for they get destroyed during cultivation, though they may reappear if the field is rested.

(b) Large cracks are well expressed on surfaces of uncultivated areas and these should be at least 1cm wide and 50cm deep. In cultivated areas, it can not be easily seen on the surface, unless a pit is dug, for these cracks only start from below the Ap horizon.

(c) Slickensides, which are always visible in the pit as always titled not horizontal.

(d) Slickensides are supposed to intersect, this you have to see before you call it a vertisol

(e) Slickensides arrangement is ball shape. The amplitude of the ball structure is important for genesis.

(f) Check for wedge shaped structural aggregates, these are mainly due to stress, usually on the upper part of the slickenside, one can usually observe some cutans on these wedge shaped structural aggregates. Within this region, there will be a wide distribution of lime concretions (Back-shot concretions).

Dr. Eswaran also talked of clay content to be higher in the hollow of the gilgai than in the ridges and that salinity is higher in ridges than in hollows. As a result of churning mechanism of these soils, Dr. Rudy Dudal said, is usually a presence of rounded $CaCO_3$ concretions on top and sharp edges $CaCa_3$ below. He (Dr. Dudal) said, this may be a guide in the field if one is not sure as to whether the soil churns itself.

Management

In this pedon, it was noticed that, the upper part had negligeable salinity and salinity was increasing with depth. This hence resulted into pH and conductivity increasing with depth. Dr. Rudy Dudal, however, said these soils are said to be self defence, because salinity can only be limited to 50cm due their churning mechanism. However, the problem of workability was prevalent, for these soils required high capital input. Dr. Dudal at this point enlightened the participants that there were some other kinds of vertisols with a loose surface and these were easy to work, however this particular one (pedon 10), he said, was the difficult one. Regardless of all these problems, he said they were good soils. Dr. Frank Moorman talked of the general

lack of Zinc in these soils, he said this can be overcome by proper application of Zinc. Proper drainage should be done to avoid salinity cases.

Land use

On land use, Dr. Frank Moorman said these soils can be put to cotton and sugar cane growing. They can also be put to rice growing provided there was enough water for flooding. Vegetable and citrus tree growing can be practiced.

DISCUSSIONS HELD AT THE PROFILES

Pedon 11

Chairman : Vernon Chinene
Secretary : Katherine Veibeek

Environment

Vegetation: Munga woodland (Munga thorn) with domination of Combretum, Parinai, Ptericorpus, Acacia specias. Occurs normally on base rich, clayey soils whereas miombo woodland which we saw at some of the previous profiles occurs on poorer sandier soils.

Climate: Since we moved to the South of the country the rainfall is lower, about 800mm.

The Southern province is traditionally the bread basket of Zambia but in the last 3 to 4 years here also drought has given
many problems.

Parent material: Calcareous schist

The Research station where this profile is situated studies cotton, surface, soya beans and grain legumes mainly

Profile description

Some differences were observed between the colours in the original description and those described during the excursion.

Cracks are narrow, very deep, spaced generally less than 30 cm apart.

Prof. Tavernies subdivided the profile according to structure:

A 0 - 8 nearly massive to weak fine subangular blocky
E 8 - 20 massive structure with slightly hard consistency
Bt 20-186 moderate medium prismatic breaking into medium subangular blocky

Clay cutans start as patchy thin in the top of the Bt, increase with depth and become thick continuous. They have a distinct colour contrast with the inside of the peds.

Classification

Ustic moisture regime
Hyperthermic temperature regime
Epipedon: Ochric (Mollic is exluded due to colour from 20 cm

Subsurface horizons: argillic

First the allic horizon was checked and was excluded because the chroma was to high. Here a remark was made whether we first have to check for the albic or follow the book. The horizon list is no key so you can follow the list or follow the horiron designation in the profile.

The top of the argillic horizon is put at 10cm depth. the top of the argillic horizon is often very difficult to establish on the criterion of clay increase alone. The EA horizon shows a downward movement of clay (eluvial process) even if due to plotting the argillic starts in that horizon. So some people thought that the top of the argillic horizon should be defined better.

The top of the argillic horizon occurs below an eluvial horizon. So here it would start at 21cm depth.

Consider clay increase BUT together with the occurence of cutans (cutans are not present in the EA horizon)

Consider the clay increase after mixing the top of the profile up to 18cm depth.

Soil order: Alfisol (Ultisols do no key out since B.S is 35% in depth).
Suborder: Ustalf due to ustic N>R
Great group: Paleustalf (The clay content does not decrease with more than 20% from the maximum clay content on and has hues redder than 10YR).
Subgroup: Oxic Paleustalf
Criteria of the typic subgroup are not fulfilled
Remarks on criteria: A: is ok for most of Zambia.
F: vertic properties are used on subgroup level not on the order level in the vertisols
K: for lamellae of clay illuviation in sand profiles.
Family level: Control section is upper 50cm of the argillic
Particle size class: weighted average of clay % from 10-60cm 28% - fine loamy
Mineralogy: mixed

FAO Classification: Eutric Nitosol
Profile with high B.S. argillic horizon, stretched bulge, of clay content.
The Oxic Paleustalf correspond completely with the Eustric Nitosol except for the one with the albic horizon. The allic horizon is not neglected on subgroup level in USDA.

If cracks were seen as described this profile would be a Vertic Luvisol which according to Prof. Dudal would be

preferable. The Eutric Nitosol is regarded as a profile with low bulk density, better workability on deep good structure which is not the case here.

ICOMLAC Committee: No LAC soil

Management

These soils are strongly subjected to erosion if located on slopes. Capping (sealing) of the top occurs under extensive agriculture. (Bad germination of seeds). Chemically good soils but under extensive agriculture minor element deficiencies might occur. Fast acidification due to N fertilizers e.g. $(NH_4)_2SO_4$. Good crops are sorghum, cow peas, grain legumes such as beans, peas. Liming will be necessary after some years especially for grain legumes. These soils have a good water retention deficiency.

DISCUSSIONS HELD AT THE PROFILES

Pedon 12

Chairman : Thuli Mafoko
Secretary : K. Asumadu

Environment

Rainfall in this area is the lowest in Zambia (about 800mm per annum) and this has an ustic moisture regime. Soils are considered to have formed from eolian sands in the Kalahari sands. Generally, the sands occur in depressions up to a depth of 5m. Below this depth, the Kalahari sands generally overlie clayey soils. Where basalts occur as the parent rock, heavy clays (vertisols) are found.

The drainage of pedon 12 was described as excessive due to the coarse texture of the sands, which from the highest percentage of the particle size components. Run off was also described as slow due to the high permeability of the sands.

Pedon 12 was located in vegetation type described as Miombo mixed woodland. Typical land use consists of cultivation of maize, sunflower and cotton on small scale holdings. Some medium scale farmers also operate in the area. Vegetables are generally grown in the valleys under irrigation. The groundwater on the sands is generally very deep.

Profile Description

Professor R. Dudal was given the responsibility of describing pedon 12. He started by emphasising the importance of Profile description in classification and suggested a minimum amount of equipment needed for a successful profile description as follows:-

(a) Knife and hammer (for studying structure)
(b) Munsell (or Japanese) colour chart.
(c) HCl for testing the presence or absence of $CaCO_3$
(d) Lens for viewing clay skins, pores, grain surfaces etc.
(e) Key for field taxonomical classification. This is important because the Pedologist can then anticipate the information that would be required for the final classification and therefore sample the profile accordingly.
(f) Field pH kit,
(g) Spade for cleaning the pit face,
(h) Water bottle for texture determination and also more colour reading
(i) FAO-UNESCO legend for correlation purposes
(j) Note book and a pen
(k) towel to clean away dirt and thus determine textures without contamination. Other pieces of equipment suggested are a camera, a tape, plastic bags for sampling and means of transport.

Professor Dudal suggested that colours should not be read in direct sunlight, colours are best read either in shade or in indirect sunlight. He also emphasised the need to use masks provided in the colour books. The black mask must be used for the dark colours and the white one for light colours. He also advised that profile description should not be done in hurry enough time must be denoted to this exercise. Description should only be done when the pedologist is mentally alert and physically up to it.

The following general description was provided by Professor Dudal.

O horizon - Has high organic matter comprising both litter and mineral material, Wavy boundary, due to mixing of soil material by termites, colours dry 10YR 3/3, moist 10YR 2/2.

A horizon - Loamy sand, massive breaking to single grains, colours, dry 10YR 4/3 moist 10YR 3/3 wavy boundary.

E horizon - Less organic matter lighter colours, massive and coherent sand grains don't run on profile surface. Wavy boundary colours dry 7.5YR 4/3 moist 7.5YR 4/6.

BW1 horizon - More coherent and massive colours: dry 5YR 5/6, moist 5YR 4/6.

BW2 horizon - Massive breaking to weak coarse subangular blocky, clay fringes present but no clay cutans seen, some sand grains are embedded in clay metric. Colours dry 2.5YR 4/6, moist 2.5YR 3/6.

Classification

The presence of a mollic epipedon was suggested but this was rejected because the observed structure of pedon 12 did not meet the strong structure requirement of a mollic epipedon as defined in the key. It did not also meet the depth requirement of a mollic epipedon. An Ochric epipedon was considered to be present.

The presence of an argillic horizon was confirmed based on the following criteria,

(a) there was a clay increase in the argillic horizon and this occurred within 30cm.

(b) the argillic horizon was at least 1/10th as thick as the sum of the thickness of all overlying horizons

(c) Generally, the profile was structureless, thus the presence of clay skins on ped surfaces was not required however, the argillic horizon was observed to contain oriented clay which

bridged some sand grains and some pores.

The soil was considered an alfisol due to its high base saturation (50%)

The moisture regime of Pedon 12 was Ustic. Thus the sub-order was on Ustalf

Pedon 12 satisfied the clay distribution and colour requirements of Paleustalfs and was considered a paleustalf. Following the criteria outlined for making a distinction between typic paleustulfs and other sub-groups, it was agreed that, the great subgroup was an oxic psammentic paleustalf.

The upper 50cm of the Bt was used as the control section for family of particle size class determination pedon 12 turned out to be sandy. The mineralogy was sileceous because it contained more than 93% quartz. The final classification for Pedon 12 was sandy sileceous hyperthermic oxic psammentic paleustalf.

Because there was a disagreement within the participants and resource personnel over the presence or absence of an argillic horizon, it was decided that the profile would also be classified on the assumption that there was no argillic horizon present. The group was unanimous in its verdict that there was no oxic diagnostic subsurface horizon. The order was considered an entisol and the sub-order, psamment. The sub-group was Typic Ustic-psamment. The final classification assuming the absence of an argillic horizon, was siliceous hyperthermic Typic Ustipsamment.

FAO Classification

Professor R. Dudal Classified Pedon 12 as a Ferralic-arenosol because, it contained more than 60% sands 15% clay, had a low CEC (NH_4OAc method) and had no other diagnostic sub-surface horizons.

Management

The major constraints to the cultivation of plants on these soils are the low water holding capacity and also the erratic nature of the rainfall. Low fertility was also considered a constraint. Plants with high drought resistant properties may be suitable.

DISCUSSIONS HELD AT THE PROFILES

Pedon 13

Chairman : Sibongo Lubinda
Secretary : Vincent Mbita

Environment

Very gentl, undulating interfluve. Soil temperature regime - hyperthemic. Soil moisture regime- Ustic. Vegetation cleared paddock grass species are dominated by Hyperthemia. Drainage: well. Parent material: Residium from schist and phyllite material. Elevation: 1075m msl

Profile Description

- Structure: 0-19 massive
  19-31cm - massive and strongly coherent
  31-198cm - very weak, medium to coarse subangular blocky

- Consistence: 0-19cm slightly hard to soft
  19-31cm hard
  31-198cm very weak, medium to coarse subangular blocky

- Field texture: 0-19 cm sand
  19-31 loamy sand
  31-198 sandy clay loam

Special features

(a) Clay cutans: thin patchy clay cutans were found from 4th horizon, becoming abundant with depth.

(b) Rock fragments: small, white patchy rock fragments were detected in 3rd horizon (72-125cm) and deeper. Rock fragments were found to be remnants of weathered rock. Also some quartzitic and siltstone rock fragments of gravel and some sizes were present at the bottom of the profile 185-198cm.

(c) Mottles: Common, medium and faint yellow mottles (10YR 6/6) were observed in the 4th 25th horizons, 125-198cm.

(d) Boundary: Soil boundary were difficult to see in the control section. But the boundary between the 1st and 2nd horizon was clearly seen i.e. clear and wavy.

Classification

- Diagnostic surface horizon: Ochric

- Diagnostic subsurface horizon: Argillic horizon because it met the clay increase requirement as well as clay clay bridges plus clay cutans.

- Orders: Alfisol - it is not Ultisol because the base saturation by sum of cations is more than 35%

- Suborder: Ustalf

- Great group: Paleustalf

- Sub group: Oric Paleustalf

- Family fine loamy. mixed, hyperthermic Oxic Paleustalf

Proposed classification: Typic Kandiustalf

FAO classification - Eustic Nitosol

It is not Luvisol because of low CEC. The proposed (texture) classification is Ferric or Chromic Lixisol. Lixisols are soils with high base saturation and low CEC.

Management

- Alfisol: has high base saturation i.e. 35% by sum of cations
- Ustalf: It has ustic moisture regime that means it is composed of dry and wet seasons. In this case 6 months dry and 6 months wet approx.
- Paleustalf: rather argillic horizon that is water storage is relatively better than in sandy soils.
- Oxic Paleustalf: It reflects 24 meq. CEC/100g clay i.e. rather highly weathered profile.

Genesis

Probably transported (over minor distances) material with gravel containing some weatherable minerals.

DISCUSSIONS HELD AT THE PROFILES

Pedon 15

Chairman : Jim Cheatle
Secretary : Helge Stray

The group was divided into 5 teams. Each team classified the soil without using particle size data. The result of the classification was: Fine mixed hyperthermic udic Paleustoll. Only one of the teams disagreed in this classification suggesting alfisol instead of mollisol (color requirement not fulfilled for mollic epipedon in their opinion). Prof. Tavernier gave a description of the soils genesis. It was concluded that this soil was in an intermediate state of weathering and soil matter has only been transported over a minimum distance.

FAO Classification according to Prof. Dudal was: LUVIC PHAEOZEM

The main constraint to management is workability during wet season due to high content of 2:1 lattice days. This soil is considered to be one of the best in Zambia for agriculture under sustained production.

The basic parent material and the fact that the soil is in an intermediate state of weathering is reflected in a high base saturation, high CEC and relatively high pH.

APPENDIX 1

PROGRAM JULY - AUGUST 1985

Sunday 14 Participants arrive and register

Monday 15

Opening Ceremony

Technical Session I (Chairman Nicholas Mumba)

10.45 Role of Soil Surveys in Agricultural Development Programs.
Rudy Dudal, University of Leuven, Belgium

11.30 Soil Taxonomy: A technical language of soil Science (a film)

12.00 Purpose of the Forum Hari Eswaran

12.30 Lunch

Technical Session II (Chairman Nicholas Mumba)

14.00 Principles and logic of Soil Taxonomy Stanley Buol, North Carolina State, University, USA

15.00 Structure of Soil Taxonomy and nomenclature Rene Tavernier, University of Ghent, Belgium

16.00 Break

16.30 Diagnostic surface horizons, Hari Eswaran

17.30 Diagnostic subsurface horizons, cambic, argillic, kandic. Frank Moorman, University of Utrecht, The Netherlands.

18.30 Adjourn

Opening cocktail party

18.30 Venue: Commonwealth Programme Africa Centre

20.00 Closing

Tuesday 16 Technical Session III

(chairman: Lazarous Chileshe, Morning
Maxon Lowole afternoon)

08.00 Diagnostic subsurface horizons: oxic. spodic, albic. Stanley Buol

09.00 Diagnostic Subsurface horizons:
calcic, petrocalcic, gypsic, petrogypsic, salic
Rudy Dudal

10.00 Break

10.30 Other diagnostic features
Hari Eswaran

11.30 Soil moisture and temperature regimes
Rene Tavernier

12.30 Lunch

14.00 Histosols
Rudy Dudal

15.00 Spodosols
Rene Tavernier

16.00 Break

16.30 Alfisols
Frank Moorman

17.30 Ultisols
Goro Uehara

18.30 Adjourn

Wednesday 17 Technical Session IV

(chairmen: Robert Magai, Morning, Alois Hungwe afternoon).

08.00 Oxisols
Hari Eswaran

09.00 Inceptisols

10.00 Break

10.30 Mollisols
Stanley Buol

11.30 Vertisols
Rudy Dudal

12.30 Lunch

14.00 Entisols
Frank Moorman

15.00 Aridisols

16.00 Break

16.30 Soil Families
Hari Eswaran

17.30 How to classify - S.W. Buol (2 paper)

18.30 Adjourn

Thursday 18 Technical Session V

(Chairman Arie Remmelzwaal)

08.00 Chemical analyses for Soil Taxonomy
Jim Cheatle, Soil Survey Unit Zambia

09.00 Charge Characteristics of soils in the tropics Goro Uehara, University of Hawai, USA.

10.00 Break

10.30 Mineralogy and Micromorphology of soils in the tropics
Hari Eswaran

12.00 Lunch

Technical Session VI

(Chairman: Cees Van Beek)

13.30 Geology and geomorphology of Zambia
Lazarous Chileshe and Wen Ting-tiang, Soil Survey Unit, Zambia

14.00 Agroclimate of Zambia
Maurice Muchinda (Meteorological Dept.) and Otto Spaargaren (Soil Survey Unit), Zambia

14.30 Vegetation of Zambia
Francis Shalwiindi, Ecology Section MAWD, Zambia

15.00 Break

15.30 Soils of Zambia
Robert Magai, Soil Survey Unit, Zambia

16.00 Land Use in Zambia, Josephy Mutelo, Land Use Branch MAWD, Zambia

16.30 Land Evaluation in Zambia
Cuulu Kalima & Wietze Veldkamp, Soil Survey Unit, Zambia

17.00 Adjourn

Friday 19 Field trip I
07.00 Departure from Commonwealth Youth Programme Africa Centre to Kasama. Lunch at Kundalila Falls or near Chitambo Hospital. Accomodation in Kasama the Farm Training Institute.

Saturday 20 Fieldtrip II
Misamfu Research Station

Pedon No. 1.	Chairman	Otto Spaargaren
	Secretary	Micheal Sishwashwa
2.	Chairman	Hari Eswaran
	Secretary	Wen Ting-tiang
3.	Chairman	Ralph Kabwaza
	Secretary	Enock Ntokotna

Introduction on the Soil Productivity Research Project, by Alfred Mapiki, SPRP.

Sunday 21 Field trip III
Kasama to Mbala

Pedon No. 4.	Chairman	Ted Angen
	Secretary	Leiv Bustness

Afternoon: Touristic
Return to Kasama

Monday 22 Field trip IV
Kasama to Mpika

Pedon No. 5.	Chairman	Cuulu Kalima
	Secretary	Nsofwa Mulenga

Afternoon Integrated Rural Development Project Mpika.
Overnight stay at the Agricultural Collage Mpika.

Tuesday 23. Field trip V
Mpika to Kabwe

Pedon No. 6	Chairman	Daniel Banda
	Secretary	Austin Mambo

Accommodation in Mulungushi Motel and Elephants Head Motel, Kabwe.

Wednesday 24
Field trip VI

Pedon No 7.	Chairman	Samir Salama
	Secretary	Baord Pedersen

Pedon No. 8 Chairman Peter Woode
Secretary Barry Dalal-Clayton
Accommodation same as 23/7

Thursday 25

Field trip VII
Kabwe to Kafue
Pedon No. 9 Chairman Brian Mhango
Secretary Rabson Mwenda
Pedon No. 10 Chairman Boago Moganane
Secretary Rusmus Masinja

Overnight stay at River Motel Kafue.

Friday 26 Field trip VIII
Kafue to Livingstone
Pedon No. 11, Chairman Kingstone Nyamapfene
Secretary K. Asumadu

Accommodation at Rainbow Lodge, Livingstone

Saturday 27
Field trip iX
Pedon No. 12 Chairman Thuli Mafoko
Secretary Katherine Verbeek
Afternoon: touristic
Accommodation same as 26/7

Sunday 28 Field trip X
Lingingstone to Lusaka
Pedon No. 13 Chairman Sibongo Lubinda
Secretary Vincent Mbita

Monday 29 Technical Session VII
(Chairman Obed Lungu)

08.00 - Principles of Agrotechnology Transfer
Goro Uehara
09.00 - Application of systems analyses for agricultural research and transfer
Goro Uehara

Tuesday, July 30 Technical Session VII
(Chairman - Jef Maes)

08.00 - Soil survey interpretation
A. Van Wambeke
09.00 - Land evaluation Rudy Dudal
10.00 - Break
10.15 - Field trip XII
Visit to York Farm, Makeni
Pedon No. 15 Chairman Jim Cheatle
Secretary Helge Stray

13.00 - Lunch (at CYPAC)

Technical Session IX
(Chairman - Wietze Veldkamp)

14.00 - Evaluation of soil physical properties
Jaak Lenvain
14.45 - Fertility evaluation of soils
Obed Lungu
15.30 - Break
16.00 - Effect of liming on oxisols and ultisols Bal Ram Sing
17.30 - Adjourn
19.00 - Pre-dinner Cocktail
19.30 Dinner
Venue: Intercontinental Hotel

Wednesday, July 31

Technical Session X
(Chairman - Bill Aulakh)

08.00 Agronomy of maize
I. Tembop and D. Mbewe, UNZA
08.45 Agronomy of Sunflower
M. Chisi, Mt. Makulu Central Research St.
09.30 Break
10.00 Agronomy of Soy-beans
J. Tembo
10.45 Agronomy of Wheat
D. Lungu, UNZA
12.15 Lunch

Technical Session XI
(Chairman - Nicholas Mumba)

13.30 NORAD'S Technical Assistance Programme
Irene Hoel
14.00 USAID'S Technical Assistance Programme
Jim Ragin
14.30 SADC'S Technical Assistance Programme
Henry Mearice
15.00 Break
15.30 Forum Evaluation:
K. Asumadu (Zimbabwe)
R. Masinja (Zambia)
R. Dudal (Belgium)

16.30 Forum Recommendation and closing ceremony

APPENDIX 2

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APPE' IX 3

SOME INFORMATION ABOUT SOIL PRODUCTIVITY RESEARCH PROGRAMME

Karl H. Solbery

Introduction

The Soil Productivity Research Programme (SPRP) is a NORAD funded research programme with objectives to provide alternative farming methods to the small holders in the high rainfall areas of Zambia. The prevalent farming method is shifting cultivation (Chitemene).

The programme was initiated on basis of agreement between Government of Zambia (GRZ), the Norwegian Agency for International Development (NORAD) and the Agricultural University of Norway (AUN).

The SPRP is conducted/monitored by the AUN on behalf of NORAD, involving administrative and professional backstooping. On the other side, the research programme is an entirely integrated part of the agricultural research organization in Zambia, with a steering committee (Project Unit) at Mount Makulu Central Research Station and an Advisory Committee at the ministry level, chaired by the Assistant Director of Agricultural Research.

The work is centered at Misamfu Regional Research Station, Kasama, and covers the Northern Province in Zambia, approximately 157,000 km² of which 90,000 km² are arable.

The first phase of SPRP was set out in 1981. The emphasis of this preparatory phase was to provide better understanding of soil conditions, crop production and farm management systems and their interactions. Information sources were Department of Agricultural Research, Land Use and Extension branches, Parastatal agencies, local farmers and relevant literature. In addition, the SPRP's soils, agronomy and agricultural economy sections carried out field investigations in different parts of the high rainfall areas. In February 1983 the phase I was wound up with a seminar in Lusaka under the heading: Soil Productivity in The High Rainfall areas of Zambia.

During the phase I a series of Occasional Papers were issued. A list of the papers is included in this information paper. The whole research programme is supposed being composed of another three different phases, with a total time aspect of 15 - 20 years.

Phase II started with research work in July 1983, after termination of phase I. The overall strategies of phase II to phase IV are outlined below, according to the SPRP document.

Phase II. - Research on soil management, crop management, and farm management for a range of farming systems presently in use or of potential use for the high rainfall areas. Further investigations of limitations in the soil-plant system. Training of Zambian professional staff and build-up of Zambian expertise.

Phase III. - Research and build-up of extension concerning soil management, crop management and farm management for farming systems selected and planned from research results obtained during phase II. Further build-up of Zambian expertise.

Phase IV: - Gradual phasing-out of NORAD-AUN assistance Supporting services with regard to analytical work, fellowships and consultancies to be maintained.

Research work

The research task of SPRP offers a very wide range of, and a series of challenging, activities, from "fundamental" research with acid soil chemistry to more practical oriented research on farming systems.

Outlining the research strategy, in a research programme like SPRP, is very important or being a crucial task in order to perform efficient and target-group directed work. The target group is defined and research results that would help overcoming certain constraints preventing them from advancing into permanent farming, are wanted as soon as possible.

The SPRP Advisory Committee decided in February 1985 to have an international consultancy team to SPRP with objectives to assist in formulating a streamlined research programme directed to the target group's constraints and problems.

In March 1985 a team from the International Council for Research in Agroforestry (ICRAF) visited SPRP and carried out a D & D exercise, with objectives to work out an appropriate research programme in agroforestry. Their report is expected very soon.

The SPRP consists of three research disciplines; Crop science, Soil Science and Agroforestry. The Soil Microbiology is another discipline that will be added to the others in August/September 1985. Each discipline is conducted by an expatriate research officer.

In the 1984/85 season altogether 29 field trials were established and implemented. The total number of treatments counts 220. Below is shown a short summary of the trials carried out in 1984/85.

Crop Science

- 3 Chitemene trials
- Crop rotation trials
- Green manure trial
- Intercropping trials
- Miscellaneous pilot trials with different crop species for testing and screening weeding flat land contra ridging

Soil Science

- Pot trial with soils from old and new Chitemene
- Frame trial - compost, calcium carbonate, magnesium sulphate to beans on a very acid soil
- 2 lime comparison trials
- Organic matter trial
- P-placement trial
- 6 Fused Magnesium Phosphate trials
- 2 Rock Phosphate trials
- 1 long term lime trial
- Miscellaneous pilot trials

Agroforestry

- 1 Alley Cropping trial
- 1 Pigeon peas variety trial
- 1 *Leucaena* variety trial
- 1 trial with different tree species (for observation and screening)

As the results from the 1984/85 trials are not yet computed and written up, we are unable in this paper to present any results.

Training of Zambian counterpart staff

A major task in the programme is to build up professional competence within Zambia on farming systems by training Zambian graduates. Strong emphasis should therefore be given to development of a training programme in collaboration with Zambian authorities. The training should be given at two levels: 1) on the job training and 2) by specialization at degree and diploma levels.

According to this, the SPRP Advisory Committee appointed an ad-hoc group (January 1984) to work out a training programme. A report was submitted in February 1985 and it was treated by the Advisory Committee its annual meeting.

The working group suggests that before the MSc. course is offered by UNZA (earliest 1986/87) the candidates should be offered MSc. studies in Zimbabwe.

Conclusions/recommendations

The Working Group recommends that SPRP should recruit six candidates to fill the four positions and all the six should be suitably trained. The excess member is in consideration of eventual resignation or unforeseen circumstances.

The first three candidates should be sent abroad for a diploma course from where they should proceed to MSc. in Zimbabwe. If a suitable candidate for agroforestry is identified, he/she should be sent to Oxford University for MSc in Agroforestry.

Considerable effort should be put into running the first formal course for laboratory staff when the University of Zambia is closed.

At an appropriate time, NORAD should provide personnel and financial assistance to the MSc programme at UNZA in soil studies.

Student participation in SPRP

SPRP has taken the advantage of having MSc students to carry out research work which is suitable for thesis work, simultaneously as this is a part of the research programme. A substantial amount of work is in this way efficiently carried out. Their contribution to the research work - in addition to the work being carried out by the permanent staff - is considerable, and it increases the total out-put markedly. Up to now, 11 Norwegian MSc students have been with SPRP. In 1985, for the first time, two Norwegian PhD students are carrying out special projects with SPRP.

After having established the MSc. in Soil and Crop Science at the Agricultural School of Science, UNZA, the major part of the students in SPRP will come from UNZA.

A cooperation with the Department of Biology, UNZA, is already initiated, leading to a Zambian MSc student in agroforestry.

Occasional papers
(Published by the International Development Programs, IDP, Agricultural University of Norway)

No. 1. Ruth Haug: Agricultural crops and cultivation methods in the Northern Province of Zambia

No. 2. Trond Vedel: Social-economic and ecological constraints on increased productivity among large circle Chitemene cultivators in Zambia

No. 3. Paul Vedel and Ragnar Oygard: Peasant household resource allocation

No. 4. Kristi Anne Stolen: Peasant and agricultural change in Northern Zambia

No. 5. Stein Jerge Holden: A survey of the vegetable production and marketing on the central plateau in Northern Province, Zambia

No. 6. Henning Svads (ed.): Proceedings of the seminar on soil productivity in high rainfall areas of Zambia, Lusaka 8. - 10. February 1983.

Occasional Paper No. 1, 2, 3 and 5 are polished and slightly modified versions of the student's MSc thesis work in SPRP in phase I. More Occasional Papers are expected published in 1985.

CHARACTERISTICS OF SERENJE, MPIKA, CHINSALI IRDP PROJECT AREA

Altitude;	1100 - 1500, Luangwa valley 900m	
Rainfall	November to beginning of April. 1100mm along the more populated watershed. Rises to 1200 mm in the hills and towards the Bangweulu swamps, and falls to 700 mm in the valley. Coefficient of variability about 25%.	
Geology		
Luangwa valley	Karoo rocks - deposited during formation of Luangwa the rift, conglomerates and rapidly deposited sediments.	
	Basement complex	highly metamorphosed gneisses and granites with some minor basic/intermediate intrusions
Hills	Muva-system	slightly/moderately metamorphosed sedimentary rocks which have intensely folded, shales mudstones, siltstones, pelites, sandstones, quartzites
Plateau	Katanga system	unmetamorphosed flat-lying sediments, basal conglomerates below sandstones, mudstones and sillstones.
	Granite intrusions	- mostly in highland near escarpment
	Basic/intermediate	- mostly in Muva and basement complex - Many small gabbro/ dolsrite intrusions. Important where large such as in the Katanga systems from Chikwanda to Mufubushi.

Approximate extent of soil and land types in IRDP area

Land/Soil type	% of total area	% of arable
Plateau		
Dambo	7	
Imperfectly drained soils (dambo fringe)	4	
Shallow land (<30cm)	4	
Clay soil well structured	1	33
Silty leached sandveldt soils	12	31
Sandy leached sandveldt soils	21	54
Deep sandy soils	5	13
Total plateau	54	
Other land types		
Highland	11	
Valley (Luangwa)	19	
Floodplains	6	
Swamps	4	
Total other	46	

Characteristics of Major Arable Soil Types Serenje, Mpika and Chinsali

Characteristic	Silty loam-Clay loam to soil1	Loamy sand to sandy loam top soil[1]
% of Arable area	33%	66%
Structure	Very stable	Stable
Consistence dry	Hard	Slightly hard
AWC (%)	10%	9%
CEC(NH_4OAC, pH7)	10-35me/100g soil	10(low to v.low)
BS% (Top soil)	(medium) 35-50%	40-60%
pH(0.01M$CaCl_2$,1:5)	4.5 - 5.5 Constant or decreasing with depth	adequate in virgin soil often increased with depth
Lime req.	Where fertilizer applied	
avail .P(Bray1)	1-5 ppm (Acutely deficient-deficient)	
Exch K	0.1-0.4meq/100g (marginal-adequate)	
Other	S deficient, B deficient, some evidence of induced Zn deficiency.	

Note 1. Problem of textural definition. In Silty loam/clay loamy there is lot of micro-aggregation and cementation by sesquioxides. Therefore using chemical dispersants for mechanical analysis gives a misleading picture of field texture, increasing clay content by up to 40%. These definitions are thus field textures.

2. pH adequate until fertilized, but then requires lime to maintain.

3. Need for Sulphur in fertilizer and boron for some crops

4. Apparently the more fertile heavier soils have physical limitation in that can't cultivate before cultivation rains.

Proportion of farmers in 3 sample points in different farmer categories from 1978-84

Category	Bag sales	--% of sample farmers in years-- 1978	1980	1982	1984
Subsistence	0	60	45	30	25
Emergent	1-30	29	44	50	48
Small-scale Commercial	31+	11	11	20	28

Mean crop areas per farmer at 3 IRDP Sample points, 1982/83

Crop	Chinsali (Mubanga) (ha)	Mpika (Mpumba) (ha)	Serenje (Chibale) (ha)
Hybrid maize	1.11	0.70	1.80
Local maize	0.10	0.32	0.51
F. Millet	0.50	0.26	0.70
Beans	0.04	0.22	0.26
Cassava	1.05	0.19	0.14
Groundnuts	0.04	0.02	0.05
Others	0.41	0.25	

1. Includes intercropped

2. Includes intoyo, Sweet potatoes, sorghum and intercropped maize.

SOIL ENVIRONMENTAL FACTORS THAT INFLUENCE PLANT DISEASE DEVELOPMENT

S.S. Susikwana

Introduction

Although all perenial and many annual plants as well as their pathogens are present in the field throughout the year almost all diseases occur only, or develop best during the warmer part of the year. It is also common knowledge that most diseases appear and develop best during wet, warm days especially after rains, or that plants heavily fertilized with nitrogen usually are much more severely attacked by some pathogens than are less fertilized plants. These general examples clearly indicate that environmental conditions prevailing in both air and soil, after contact of a pathogen with its host, may greatly affect the development of the disease, and frequently they determine whether a disease will occur or not. The environmental factors that most seriously affect the initiation and development of infectious plant diseases are temperature, moisture, light, soil nutrients and soil reaction (pH). Their effects on disease may be brought about through their influence on the growth and/or susceptibility of the host or on the multiplication and activity of the pathogen and or finally, on the interaction of host and pathogen and its effect on the severity of symptom development.

It is obvious then that for a disease to occur and to develop optimally, a combination of three factors must be present; susceptible host, infective pathogen, and favorable environment. However, although plant susceptibility and pathogen infectivity remain essentially unchanged in the same plant for at least several days, the environmental conditions may change more or less suddenly and in various degrees. A change in any environmental factors may favour the host or the pathogen or both, or it may be more favorable to the one than to the other, and the expression of disease will be affected accordingly. Plant diseases generally occur over a wide range of the various environmental conditions. Nevertheless, the extent and frequency of their occurrence as well as the severity of the disease on individual plants, are influenced by the degree of deviation of each environmental condition from the point at which disease development is optimal.

Temperature

The soil temperature can affect disease development by affecting the host (e.g. tomato), the pathogen (e.g. Fusarium sp.) or the host pathogen interaction (tomato x Fusarium). The pathogens subsist in the soil, enter the respective host plant through the root system, and bring about their pathogenic influence on the host through their growth activity in vascular tissues. T.G. Dickson studied seedling blight of maize and wheat cause by Gibberella zeae and found that the disease is most

severe on maize at temperatures below 13deg. C, while on wheat it is most severe at soil temperatures above 13deg.C. Since the growth of wheat is favoured by cool temperatures, and growth of maize by warm temperatures, the disease is most severe at temperatures unfavorable for growth of the host. Thus soil temperature in this case appears to affect disease development by affecting the host's susceptibility.

In the case of Verticillium wilt of cotton (Verticillium albo-atrum), disease development is most severe at soil temperatures most favorable for growth of the pathogen, temperatures of 20 - 30 deg. C. The fungus will not grow at temperatures above 30deg.c and hence there is no infection at temperatures of 33 - 35deg. C.

The root rot disease of tobacco caused by Thielaviopsis bassicola illustrates the example of how temperature affects the host-pathogen interaction. Tobacco grows best at soil temperatures of about 28 - 29deg.C, while T. Basicola grows best at 22 - 28deg.C. The optimum temperature for disease development is 17 - 23deg.C, while no disease develops at 29 - 30degC. The reason for this is that at the optimum temperature for the host, it is able to develop cork cambium and pericycle in the root to ward off the invading pathogen. However at lower temperatures the host is unable to develop these protective layers and even though the temperature is not the best for growth of the pathogen, it can still grow enough to cause a severe disease.

In most of the diseases considered above, the host is susceptible to the pathogen over a relatively low period. The enhancement or suppression of the disease follows more or less the season variation in soil temperature. There are numerous diseases, however, in which the period of susceptibility of the host is a relatively short one.

Soil Moisture

Moisture disturbances in the soil are probably responsible for more plants growing poorly and being unproductive. The subnormal amounts of water available to plants may result in reduced growth, diseased appearance, or even death of the plant. Lack of moisture may also be localized to certain types of soil, slopes or this soil layers underlaid by rock or sand and may result in patches of diseased-looking plants.

Moisture, like temperature, influences the initiation and development of infectious plant diseases in many interrelated ways. The most important influence of moisture seems to be on the germination of fungal spores and on the penetration of the host by the germ tube. Moisture also activates the bacterial, fungal, and nematode pathogens, which may then infect the plant. Moisture, such as the splashing rain and running water also plays an important role on the distribution and speed of many of these pathogens on the same plant or from one plant to another.

Moisture also affects disease by increasing the succulence of host plants thus considerably increasing their susceptibility to certain pathogens.

The vascular fusarial diseases, which are markedly influenced by soil temperature are not greatly affected by soil moisture. Some diseases, however, are very responsive to soil moisture. The rate and severity of disease development of root rot of garden pea caused by Aphanomyces sp. increase with the soil moisture level up to or close to saturation. Another disease which is influenced greatly by soil moisture is common scab of potato caused by Streptomyces sp. Here the pathogen is influenced in the opposite direction, the severity of disease increasing with decrease in the soil moisture level. The initial infection of cruficer rots by the clubroot pathogen is favoured by relatively high soil moisture. After infection takes place the influence of soil moisture is little or nil. White rot of onion is suppressed by high soil moisture and enhanced by low soil moisture.

In many diseases affecting underground parts of plants such as roots, tubers, and young seedlings - for example in the Pythium damping-off of seedlings and seed decays - the severity of the disease is proportional to the soil moisture and is greatest near the saturation point. The increased moisture seems to affect primarily the pathogen which multiplies, and moves best (zoospores in the case of Pythium) in wet soils, but it may also decrease the ability of the host to defend itself through reduced availability of oxygen in waterlogged soil and by lowering the temperature of such soils. Many other soil fungi, some bacteria, and most nematodes usually cause their most severe symptoms on plants when moisture is moderate to high but considerably below saturation, while yet others such as Streptomyces acabies (as already cited above) are most severe in rather dry soils.

Soil Reaction (pH)

The hydrogen-ion concentration of the soil solution has an effect upon the natural' macro-and microflora, and it may be expected to influence soil-borne plant pathogens as well. It is surprising that so few cases exists in which the influence is a striking one. Fusarium spp which are tolerant of a wide range of soil pH in culture are not conspicuously limited by soil pH.

However, the clubroot of crufifers, caused by Plasmodiophora brassicae, is most prevalent and severe at about pH 5.7, while its development drops sharply between 5.7 and 6.2, and is completely checked at pH 7.8. On the other hand, the common scab of potato caused by S. scabies can be severe at a pH range from 5.2 - 8.0 or above, but its development drops sharply at pHs below 5.2. It is obvious that such diseases are most serious in areas whose soil pH favours the particular pathogen and that they can be controlled, by increasing or decreasing the soil pH, respectively by adding appropriate materials such as lime and

ammonium sulphate. In these and in many other diseases, the effect of soil acidity (pH) seems to be principally on the pathogen, although in some, a weakening of the host through altered nutrition induced by the soil acidity may affect the incidence and severity of the disease.

Soil Fertility.

Nutrition affects the development and differentiation of plants, the rapidity of growth, the physiological processes of the plant cells, and thereby their state of readiness to defend themselves against pathogenic attack. Abundance of certain nutrients, for example nitrogen, may result in the production of young succulent growth and may prolong the vegetative period and delay maturity of the plant, making it more susceptible to pathogens that prefer to attack such tissues and for longer periods. Conversely, lack of nitrogen would make plants weaker, slower growing, and faster aging and would make them susceptible to pathogens that are best able to attack weak, slow growing plants. Thus high nitrogen fertilization increases the susceptibility of pear to fire blight (Erwinia amylovora), of tobacco to wildfire (Pseudomonas tabaci), of wheat to rust (Puccinia spp) and to powdery mildew (Erysiphe graminis), of various plants to Verticillium wilt (Verticillium spp). Reduced nitrogen may also increase the succeptibility of some plants to certain diseases, eg of tomato to Fusarium wilt, of many solanaceous plants to the Pseudomona solanacearum wilt, of sugarbeets to Selerotium rolfsii, of most seedlings to Pythium damping - off.

In general, high levels of potassium seem to reduce infection, e.g. of cereals to rusts and to powdery mildews, of tobacco to Pseudomonas tabaci, although they increase infection of tomato by Fusarium sp, and of citrus by Phytophthora sp. High levels of calcium also increase disease resistance, eg. of tomato to Fusarium wilt, of pears to Rhizoctonia root rot. The effect of phosphorus seems to be more variable since high levels were shown to increase the resistance of many plants to certain pathogens, eg. of tobacco to Pseudomona tobacco, of tomato to Fusarium sp, but also to decrease the resistance of almost as many plants to pathogens, eg. of tobacco and beans to tobacco mosaic virus of citru to Thielaviopsis sp.

It appears that, in general, plants receiving a balanced nutrition in which all required elements are supplied in appropriate amounts are more capable of protecting themselves from new infections and of limiting existing infections than when one or more nutrients are supplied in excessive or deficient amounts. Even a balanced nutrition, however, may affect the development of a diseases when the concentration of all the nutrients is increased or decreased beyond a certain range, as in the case of increased susceptibility of bean to powdery mildew (Erysiphe graminis) after application of excessively high concentrations of balanced nutrients to bean plants.

REMOTE SENSING OF NATURAL RESOURCES IN EASTERN AND SOUTHERN AFRICA SOIL SURVEY AND MAPPING

S.N. Kalyango and Wen Ting Tiang

Introduction

Increasing population pressure and the need to become more self-reliant in food production, industrial crops, timber and fuelwood all create a growing demand for more land. In Africa there are still vast tracts of land where little development has taken place and where potentially suitable soils can be brought into economic production. Sufficient data on the natural resources of such tracts of land are seldom available. Information on the soils, in particular, is often lacking. Nevertheless, soils constitute one of the most important components of land resources. Without good information on soils sound planning for the development and management of a given area is not possible. Conventional methods of soil mapping and assessment rely heavily on intensive aerial photo interpretation coupled with thorough field work. Such conventional methods are too slow and costly to provide the information required for rapid decision making.

The ability of resource satellites to provide a synoptic view of large areas and to record information in a multispectral form with a relatively high resolution facilitates the rapid study of extensive tracts of land. One such satellite system, Landsat, has the ability, under normal conditions, to record vegetation in the visible and near infra-red portions of the spectrum. Over a period of time changes in vegetation may be detected. These changes may be the result of physiological stress in the plants or the result of change in vegetation type, growth, succession, replacement or removal. These vegetation characteristics are recorded on the image and provide contextual clues about soil associations.

Vegetation contrasts affected by soil-plant moisture relationship are generally most apparent in the dry season image when the contrast between ground cover types is greatest. For this reason dry-season images were selected for analysis and also for use as a base map in the Zambian Soil Survey example described in this leaflet.

Zambia soil survey

The example presented here has been taken from a soil survey and mapping project in Zambia. The main objectives were to provide a soil resource inventory of the area, to produce a soil map at a scale of 1:500,000, to assess the area's agricultural potential, and to select areas for future detailed investigation as a prerequisite for a proposed agricultural development project.

The survey area covered three districts (Solwezi, Mwinilunga and Kasempa) totalling approximately 81,500 km². Twelve months were required to accomplish this project with 14 weeks (approximately 17 man months) in the field and 38 weeks (19 man months) in the office carrying out interpretation, synthesizing field data and mapping. Using conventional methods the same staff would take at least three years to complete the same work.

Population density in these districts is less than 10/km² and accessibility is generally poor. The underlying rocks are predominantly pre-Cambrian basement complex (gneisses and mica-schists with granitic intrusions) and the Kundulungu Series of the Katanga System (meta-siltstone, meta-argillites and quartzites as well as some dolomitic limestones). The mean annual rainfall, which increases from 900 mm in the south to over 1400 mm along the Zairian border in the north, puts almost the whole of the project area under the so-called 'high rainfall' area of Zambia. The distribution is uni-modal extending from November to April. The dominant vegetative cover of the area is miombo woodland with Brachystegia and Julbernadia forming the co-dominant species.

Procedure

Four full Landsat scenes and five subscenes were required to cover the whole study area. A complete aerial coverage of the same area would require approximately 1,500 photos of 9" x 9" format at a scale of 1:60,000.

A provisional interpretation of soil associations was produced by delineating on a transparent overlay those regions with homogeneous patterns. The regions were defined using hue, value and textural characteristics of the image and landscape, including drainage systems and density. This provisional map was subjected to field verification by spot sampling at a series of preselected sites along accessible routes. These sites were representative of homogeneous spectral patterns on the image. The actual definition of the soil association units cannot be achieved from Landsat imagery alone, however. Additional information is required from surveys and fieldwork.

Care was taken to ensure that all the major soil associations were included in the field verification. For each sample site, the soil was described, characterized and classified according to a simple field legend. Other information which was recorded included vegetation type and canopy density, geology (where it could be observed), relief, hydrology, land-surface features (gravel, outcrops, termite mounds) and human activities. The field information was synthesized with the provisional Landsat based soil association map to identify a number of major soil types. In turn, these major soils were sampled for laboratory analysis and the representative soil profile pits described in detail. A detailed legend of the soil taxonomic units was then drawn up. This legend was used to revise the

provisional map and define the soil association units. The map and legend were finalized after the results of laboratory analysis became available.

One of the advantages of Landsat multispectral imagery is that information collected in one area can be extrapolated to other areas of similar features. Therefore, maps of areas that were not sampled could still be made by extrapolation from similar areas where sampling was done. However, in cases like flood plains and burn scars it was difficult to recognize individual soil associations on the Landsat image and these soils were mapped as undifferentiated. In other cases it was difficult to identify the individual associations from Landsat data, and so in transitional zones or areas of intensive human activities (land clearing) soil units were mapped with a much more intense field sampling.

The final soil association legend consisted of a maximum of five soils for each association unit with one dominant soil (making up to at least 30% of the association by proportion), one co-dominant soil (at least 25%), and up to three major inclusions. The associations were identified on the map by a code consisting of two letter which represented the physiographic unit, a two-figure number which indicated the dominant soil and, in most cases, a one-figure number which was used to separate those associations in which the same soil unit was dominant. The soil units were classified according to the FAO/UNESCO Soil Map of the World legend, and correlated to the soil taxonomy of the USDA. It also provided information on the basic characteristics of each soil.

The siols

The main soil in the illustration is an orthic ferralsol (soil 11, fine, clay and sandy surface), a highly leached yellowish-red clay soil which is very common in the eastern half of the survey area and has developed over meta-siltstone. It has a pH of 4.0 to 4.2, a very low cation exchange capacity (less than 15 me/100 g clay) and base saturation (less than 20%). This soil dominates several associations, most of which contain some red soil (soil 10) as well. These soils, despite being more leached than the yellowish-red soils, seem to be preferred by the local farmers. They probably have a lower amount of soluble aluminium. These two soils (11 and 10) could not be separated on the image.

Other red soils, indicated by codes starting with 17 (acric ferralsol), were easily identifiable on the image. They have developed over limestone and occur mostly in depressed areas with little or no surface drainage. Associations which contain soil 11d as dominant ('d' stands for moderately deep to moderately shallow phase) can be recognized easily by the greenish-grey overtones.

The hilly areas, marked with Hh, can often be recognized (reddish orange grains) on the false-colour composite. They were easily identifiable on the black and white band 7 image. The associations in this landscape are dominated either by orthic ferralsol (soil 12, fine, loam surface, reddish-brown) or lithic dystric regosols (31/1). The co-dominant soil varies (12, 11d, 31 or 13). Vofr Hb stands for broken country. Mapping units associated with this physiographic unit are not easily distinguished from hilly areas on the image but can be discriminated using B/W single-band 7 and stereoscopic pairs of aerial photos. Nevertheless, on this image they can be recognized by their greenish blue tones mottled with red hues and very light specks (Hb 12/3), or black drainage veins with a halo (Bh 12/1). The dominant soil is generally orthic ferralsol with 11d or orthic ferralsol 13 (variable surface texture, deep to moderately deep with more than 20% gravel within 60 cm).

Land capability map

All the soils in the survey area were rated according to their agricultural potential for low-input sustained dryland farming with annual crops, taking into account a number of parameters such as profile development, textural class, soil depth, drainage status, CEC, pH, base saturation, etc. A division of five groups of soils was made: soils with a high potential, moderately high potential, moderately low potential, low potential and soils unsuited for the farming system under consideration. On this basis five land capability classes were established-each containing a certain percentage of soils with a defined agricultural potential

Comparison between the capability map extract and the corresponding Landsat subscene shows that in this case the better soils generally correlated with arable areas which appear uniformly red in tone and texture on the standard false-colour composite. However, an exception may occur where a red tone separation gives rise to soils of relatively lower potential. Such an example illustrates both the advantages and limitations of Landsat imagery data in soil resource assessment.

In general, moderately low potential soils (e.g. Pu 11d/1) were associated with light pink tones mixed with greenish-blue mottles on the image. Those spectral patterns which appear yellow-orange (PP31) and light red with grain texture (hilly areas Hh 31/1) correlated well with low potential soils.

The poorly drained soils (Df40) lie along big rivers or in flooded areas and are unsuitable for dryland farming. On one hand, it was possible to identify broadly those areas which had a good agricultural potential and thus increase the sampling efficiency and mapping accuracy. On the other hand, those separations which appeared spectrally similar on the image but significantly different in land capability received more detailed field inspection on a selective basis as a cross-check again

possible assessment errors.

Remote sensing technology has become an ideal tool for assessment of soil resources (productivity, extent and manageability) among other natural land resources. Countries where soil resource data are not available for regional development decisions can easily and cheaply generate sufficient information by using remotely sensed data. Existing exploratory or reconnaissance soil maps can also be up-dated rapidly with this technology.

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Approximate extent of soil and land types in IRDP area

Land/Soil type	% of total area	% of arable
Plateau		
Dambo	7	
Imperfectly drained soils (dambo fringe)	4	
Shallow land (<30cm)	4	
Clay soil well structured	1	33
Silty leached sandveldt soils	12	31
Sandy leached sandveldt soils	21	54
Deep sandy soils	5	13
Total plateau	54	
Other land types		
Highland	11	
Valley (Luangwa)	19	
Floodplains	6	
Swamps	4	
Total other	46	

THE KANDIC HORIZON AS A DIAGNOSTIC SUBSURFACE HORIZON

F.R. Moormann and S.W. Buol

Introduction

Perhaps the most severe classification problem for soils in which low activity clay dominate is the placement in Soil Taxonomy (1975) of pedons with a subsurface horizon that fulfills the textural requirements for an argillic horizon (soil Taxonomy, page 19-27), but the main accessory, property, i.e. clay skins in at least part of the argillic horizon are so weakly expressed that consistent quantification by either field or laboratory proccedures is doubtfull.

This problem has permeated the discussions of ICOMLAC, as witnessed by most of the committee's circular letters, as well as by the summaries of discussions of the first and second International Soil Classification Workshops. As a consequence of discussions in Malaysia and Thailand, a working hypothesis was introduced whereby a finer textured subsurface horizon (F.T.S.H.) with precisely defined limits is to be used as a diagnostic property for the purpose of distinction between low activity clay (LAC) Alfisols and Ultisols on the one hand, and Oxisols and LAC Inceptisols on the other. Subsequently the concept of the F.T.S.H. has been tested while refining the definition and proposing "kandic horizon" as it's name.

It should be noted that the problem of recognizing an argillic horizon based on the presence of clay skins, is not limited to the LAC taxa falling under the mandate of ICOMLAC and ICOMOX. Indeed, this problem is recurrent in the literature, as may be seen from a recent review and study by Mckeague et al (1981). Nevertheless, the difficulties of using the argillic horizon concept in classification are clearly multiplied in many of the LAC pedons that are in close spatial association with pedons that have oxic horizons. Difficulties are therefore particularly common in udic to perudic, isothermic or warmer iso-soil temperature regions.

Genesis

A kandic horizon is a subsurface horizon with a significantly finer texture than the overlaying horizon or horizons. The higher clay content of the kandic horizon cannot, by current macro-and micro morphological diagnosis, be traced to the subsurface accumulation by illuviation of layer-lattice clays. By convention, the clay fraction of a kandic horizon is composed predominantly of 1 : 1 lattice layer silicates mainly kaolinite, with varying amounts of oxy-hydroxides of Fe and Al.

The textural differentiation in pedons with a kandic horizon may be the outcome of one or more processes acting simultaneously or sequentially, affecting the surface horizons, the subsurface

horizons or both, of the mineral soil. These processes are not all clearly understood and agreed upon. These that are considered most important can be summariezed as follows:

i. Clay eluviation and illuviation

In soils with a kaolinitic and/or oxidic mineralogy of the clay fraction, evidences of illuviation of clay-sized particles are frequently absent. Specifically, clay skins which are considered concomittant to the illuviation process can be completely absent. Often they are present only at depths below or in quantities less than the limits considered diagnostic for an argillic horizon (pp. 25 and 38, Soil Taxonomy, 1975).

The absence of diagnostic clay skins may be due to a lack of orientation of the clay-sized particles during the eluviation-illuviation process. This is particularly so where a considerable portion of the clay fraction consists of Fe oxy-hydroxydes. More often, however, clay skins that may have formed as part of the early genesis of the kandic horizon may have disappeared under the environmental conditions in which kandic horizons are found. Biological activity of roots abundant in udic regimes may be one cause, but the main cause appears to be the activity of the soil fauna. Thorough mixing of the soils mass by termites and ants and, to a lesser extent, by earth worms, will cause the partial or total disappearance of clay skins over time and to a considereable depth, e.g. more than 150 cm in soils on permeable, well drained formations.

A considerable proportion of soils with a kandic horizon of which an illuvial origin is probable, is found on old surfaces, where the illuviation process may no longer be operative, or at least acting so slowly that mixing by soil organisms or deformation by dessication pressures easily overtakes the formation of clay skins. Characteristic for such conditions is the short-distance spatial variability in the occurrance of illuvial clay skins. As a result, they may be found in some pedons but not in other nearby pedons which otherwise have the same profile morphology. Even within the same horizon of a single pedon, some peds may have clay skins while others do not.

ii. Clay destruction in the epipedon.

The weathering of lattice-layered silicates is a process which may lead to the relative loss of clay-sized particles from the pedon. This loss is more from the upper horizon(s) where weathering processes are most intense. Under superficially hydromorphic conditions, this process can be relatively fast. Slow clay destruction with subsequent elimination of bases and some silica (ferrallitization) is a process particularly enhanced by high surface soil temperatures in well drained soils. Because this process afects superficial horizons to a greater degree than horizons deeper in the pedon, a vertical textural differentiation will occur in time. The relatively coarser residual material at

the surface can, due to biological action, be mixed with the underlying material, thus giving rise at a gradual increase in clay content from the surface down. Whereas this process is slow, it's effects will be mainly noted on old to very old stable surfaces. The process of elimination of clay-minerals from the surface, without concomitant accumulation in the B horizon, is known as "appauvrissement" in the French literature.

iii. Selective erosion

Rain drop plash and subsequent surface-erosion cause colloidal humus and the finest soil particles to be moved further downslope than the coarser fractions. Eventually, part of the fine fraction may be eliminated from sloping polypedons, leaving a coarser surface material. Mixing as by ploughing or biological activity may cause the whole surface horizon to become relatively coarser textured. The speed of this process depends on many factors, but in climates with highly erosive rains, on soils with incomplete or absent plant cover it may be very rapid. Coarser surface soil textures can frequently be measured in run-off plots within a few years. The superficial oblique movement of clay downslope seems to be widespread and selective erosion probably is a major process leading to textural differentiation in older cultivated lands, even if cultivation is intermittent as under shifting cultivation.

The process certainly is not exclusive to LAC soils. However, areas dominated by LAC soils frequently coincide with areas that have erosive rains so that textural differentiation due to selective erosion is a common occurrance. In warm ustic moisture regimes with high intensity rainstorms at the onset of the rain season, selective erosion on soils without a protestive plant cover is widespread.

iv. Sedimentation of coarser textured surface materials.

In stratified parent materials, coarser materials may overlay finer textured strata. Most commonly such a textural suite may be found in flood plains or on lower concave aspects of slopes. The young sedimentary nature of the coarser textured surface material is often identified by clear micro stratification and the finer textured subsurface layers should not be equated with a kandic horizon. However, in other landscape positions, lithological discontinuities occur, which may consist of a coarser material without micro stratification overlying a finer textured stratum. If the finer textured stratum fulfills the requirements of the kandic horizon, defined below, there is no known way to exclude it from the definition of this horizon. In fact, lithological discontinuities are now known to occur in many of the soils of the intertropical zone and in many cases the superficial material is coarser textured than the underlying stratum. In sloping land, for instance, surface soil material which lost part of its clay due to one of the processes described under i. iii., may move downslope so that the

coaser textured surface layers in a given pedon may not have formed in situ. The definition in the French classification (Aubert and Segalen, 1966) of the "remainiement" (reworking) process recognizes this as one of several explanations for a lower clay content in the surface layers.

Biological activity

Reworking of soils by earthworms, termites and ants is often cited as a cause for the development of coarser textured surface soils. Detailed studies in this respect do not corroborate this contention and the materials brought to the surface by these organisms is finer textured because of a relatively lower content of the coarser sand fractions and of a higher clay and fine silt content. In termite hills, for instance, the clay content is generally higher than that of the surrounding surface soils because the material is largely derived from the finer textured subsoil.

In summary, it can be stated that the kandic horizon is almost always polygenetic and at least due in part to its old age it is not possible to quantatively determine the share of each of the processes contributing to its formation.

Significance to soil Classification

The kandic horizon plays, by definition, only a role in the classification of soils in which the clay fraction is formed predominantly by low activity clays. In these LAC taxa, the use of the argillic horizon to distinguish Alfisols and Ultisols from Oxisols and Inceptisols, looses much of its meaning, because the main accessory properties of this horizon are either partially or completely absent or they are so weakly or iregularly detectable that they cannot serve as appropriate quantitative differentiae.

Yet, among these LAC soils, many are found that have lost clay from their superficial horizons, leading to a vertical textural differentiation which cannot be distinguished from others in which an argillic horizon has been recognized. Textural differentiation in LAC soils is, by itself, believed to be sufficiently important for the understanding of soil development and interpreting their management properties that it should be recognized at a high level of the classification. In clayey textured soils, the textural differentiation looses much of its genetic and practical importance. Hence, by convention, the kandic horizon is not used as a diagnostic horizon where the clay content is 40% or more in the upper horizons of the solum. Genetically, the presence of kandic horizons indicates a high degree of weathering of the mineral soil material. This is mostly related to the common occurrance of soils with a kandic horizon on old surfaces where weathering has taken place under warm climatic conditions with moderate to high precipitation during the rainy season(s). However, not all soils with a kandic horizon are old in the present landscapes: part of them have

formed in pre-weathered sediments of various age.

The high degree of weathering observed in the kandic horizon pertains to the clay fraction in which 1 : 1 lattice layer clays and/or oxy-hydroxydes of iron dominate, with or without gibbsite. The composition of the coarser fractions, more in particular the 20-200 micron fraction does not necessarily always reflect this stage of weathering. Whereas the content of silt and sand sized weatherable minerals in the kandic horizon is often low, this is not always the case, most notably in kandic horizons of soils developed on weathering products of crystalline rocks in landscapes which during the late pleistocene period have undergone rejuvenation due to erosion.

In summary, the main significance of the kandic horizon is taxonomic, i.e. to distinguish in the field between soils with a distinct clay increase with depth (Alfisols and Ultisols) and soils with no or only a weak clay increase (Oxisols and LAC Inceptisols). However, certain genetic scenarios are indicated by its identification.

Identification

The kandic horizon, by definition is a subsurface horizon, underlying one or more coarser textured horizons. The overlying horizons may normally be equated with an epipedon although occasionally the upper part of the kandic horizon may be the lowest part of an attenuated mollic, umbric or ochric epipedon. If a diagnostic clay increase falls within such an epipedon it is the increase that is determinant, and not the other characteristics. The coarser overlying horizons should be of sufficient magnitude that they can be recognized as such, when mixing the superficial soil layers to a depth of 18 cm, as in ploughing. In some soils under natural vegetation this requirements may be waived, provided the increase of clay content conforms to that of an abrupt textural change (Soil Taxonomy, P. 47) and takes place at a depth of not less than 5 cm.

The upper boundary of the kandic horizon normally is clear and gradual. A computer analysis of 45 low activity clay soils with an increase of the clay content as required for a kandic horizon indicated that in 15 profiles the required clay increase took place within 3.5-6.5 cm (clear boundary) while in 30 the increase occurred within 6.5 - 12 cm (gradual boundary).

The distinctness of the clay increase in isotropic parent materials is therefore a reasonable field characteristic to separate the kandic from the oxic or cambic horizon, where the clay increase is commonly absent or diffuse. In an isotropic parent material, the transition to the kandic horizon is mostly clear or abrupt, and is frequently marked by the presence of a stone-line or a gravelly layer. The material overlying this gravelly layer may have been deposited or it may have been brought to the surface by biological activity (termites, ants,

earthworms); it should however fulfil the requirement that is contains less clay than the underlying kandic horizon.

The probability that the differentiation between overlying coarser material and a finer textured subsoil is an exclusive lithological phenomenon increases with the depth at which the transition to the kandic horizon takes place. Moreover, the influence of the kandic horizon on management properties of the soil also decreases with the depth of this transition. For this reason, the top of the kandic horizon should be found at a reasonable depth which, by convention is defined as follows:

- If the clay content of the overlying, coarser textured horizons(s) is 20% or more, the upper boundary of the kandic horizon should occur at less than 100 cm from the surface.

- If the clay content of the overlying, coarser textured horizon(s) is less than 20 percent, and the particle size class (of part or of all of the upper 100 cm) is finer than sandy skeletal, the upper boundary of the kandic horizon should occur between 100 and 200 cm from the surface in the major part of the pedon.

The top or upper boundary of the kandic horizon is the depth at which the percentage of clay exceeds that of the overlying horizon by the appropriate amount after fitting a smooth curve.

Other field characteristics of kandic horizons are not normally diagnostic, since these horizons may have properties of the argillic-, the cambic- or the oxic horizons. Some resemble argillic horizons as regards a well developed subangular blocky structure, or the presence of bleached grains of sand and silt in the overlying coarser textured horizon(s). The ratio of fine clay (particles smaller than 0.2um) to total clay may be larger in the kandic horizon than in the overlying coarser horizon(s) but very few data are available.

Other kandic horizons have one or more properties of the oxic horizon and they would be called an oxic horizon but for the distinct clay increase. For the same reason, in pedons dominated by low activity clays we may find horizons which would have been called a cambic horizon but for the clay increase. The kandic horizon is parallel or nearly so to the surface of the polypedon. If this is not the case a recent deposit of the coarser surface material should be expected.

Summary of properties

The kandic horizon is a subsurface horizon in which at 50 cm below the top of the horizon or immediately above a lithic, paralithic or petroferric contact, whichever is shallower, the fine earth fraction has an apparent CEC/NH_4OAC at pH7 of 24 meq or less per 100 g clay or an apparent ECEC of 16 meq or less per 100 g clay. It has the following properties that can be used for

identification:

1. The presence of one or more coarser textured horizons overlying the kandic horizon is required. The minimum depth of the overlying horizons is 18 cm, after mixing as in ploughing, or 5 cm if the transition to the kandic horizon is abrupt.

2. The kandic horizon contains more total clay than the overlying horizon as follows. The increase in clay content is reached within a vertical distance of 12 cm or less.

a. If the horizon, overlying the kandic horizon has less than 20% total clay in the fine-earth fraction, the kandic horizon must contain at least 4 percent more clay.

b. If the horizon, overlying the kandic horizon has more than 20% total clay in the fine-earth fraction, the ratio of clay in the kandic horizon to that in the overlying horizon must be 1.2 or more, or the kandic horizon must contain at least 8 percent more clay.

3. A kandic horizon should be at least 30 cm thick as measured from its top in the absence of a lithic, paralithic or petroferric contact, or at least 15 cm thick if such a contact is present. Excluded from the definition of a kandic horizon are finer textured lamellae, irrespective of their cumulative thickness.

4. The layers or horizons, overlying a kandic horizon should not show fine stratification, nor should they have an organic carbon content that decreases irregularly with increasing depth.

5. A kandic horizon may have clay skins but they should not be thick and continuous in all parts, and the cross section should not have more than 5 percent oriented clay, to a depth of 125 cm below the surface of the soil or 75 cm below the top of the kandic horizon whichever is deeper.

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Role of Soil Taxonomy in Woodland Interpretations

S.W. Buol

Soil classification and soil mapping are separate and distinct desciplines. Together they form two legs of any soil survey triumvirate. The third leg of soil survey is an interpretation program which by necessity can be no better than the classification and mapping upon which the interpretation are based. Since all interpretations involve an understanding of the state-of the-art in the use of soils for the stated purpose of the interpretation it is possible to create poor interpretations from good soil mapping and classification.

There are an infinite number of ways to classify soils. Everyone, at one time or another, has probably classified soil. Black, red, sticky, rocky, wet and "no good" are all terms that convey some information providing the people communicating have similar past experience. However, what is black in North Carolina may be only dark in Minnesota and what is sticky in Florida wouldn't even rate a comment in Mississippi mud. There is also the necessity to describe where in the profile such terms apply; topsoil, subsoil, substrata, underlying material, etc. all are useful only if the audience has similar experience to the speaker.

It was inevitable that soil scientists unfied and quantified their vocabulary for use in classifying soil. Something had to be done to define how red is red and how sticky is sticky as well as where the topsoil stops and the subsoil starts. Classification in any science is only a half-way house that reflects the state-of-the-art in that science. Thus, as long as there is research the classification will be changing. The system of classifying soil used in the U.S., and clearly the most widely used in the world, is Soil Taxonomy. Published in 1975 as the result of 25 years of direct work and testing it continues to undergo alteration as new data are made available. Soil Taxonomy can be thought of as the main stacks of a major library. It is the repository for all the information we know about soil properties. As such it is probably of greatest use only to specialists in soil classification. Most users of soil, and soil information, are very much use related in their approach to soil information. Just as users of a library are aided by speciality functions such as reserve rooms, special collections, etc., the user of soil survey information is best aided by technical or special use classifications of soil properties.

Soil Taxonomy does not take into account the spacial arrangement of soil properties, the slopes, aspect or surface conditions. For the most part these are classified in the process of developing a map legend within each individual soil survey. Although we set out only to discuss Soil Taxonomy and woodland interpretations it is impossible to do so without citing the mapping aspect of the soil survey program. The mapping

attempts to provide spacial homogeneity. Each map unit attempts to be more homogeneous than the area as a whole. Although a map unit adopts a soil taxonomic name, it does not have the same range of properties defined in the taxonomic name. A map unit is both more confined and more diverse than the taxonomic unit used to name it. For example, a map unit of Norfolk in North Florida has a mean annual soil temperature of near 70 deg.F while a Norfolk map unit in Virginia has a mean annual soil temperature near 60 deg.F. Frost free season and rainfall have similar ranges accepted in the taxonomic range of characteristics. A county soil survey will be more homogeneous in these properties than in the series description. In a like but contrasting fashion the Norfolk series by definition has between 18 and 35% clay in the argillic horizon. Inclusions in mapping units often violate this limit and several other limits of the series. Inclusions of different taxa in a map unit do not invalidate the mapping unit if they are described and taken into account in the interpretation made of the mapping unit. Inclusions do make the range of some soil properties in a mapping unit larger than the range of properties defined by the series.

For the above reasons, there are two levels of interpretations available in the National Cooperative Soil Survey program. For each soil series there is a "form 5" Soil Survey Interpretations form that is prepared by all individuals reviewing the series establishment or revision. The form 5 is considered as a guideline for authors of individual county soil surveys where the interpretations should be "fine-tuned" for the conditions of the map units in that county.

Limitations of Woodland Interpretations

To this point attention has been given only to the soil property and map unit property variables of the soil survey. Woodland interpretations are also subject to management and varietal variations totally outside the influence of soil properties measured and considered in either soil classification or soil mapping. The following non-soil factors need to be considered in interpreting soil units for woodland uses, particulary their potential productivity. It needs to be firmly stated that present potential productivity values published in soil survey reports are for naturally seeded stands and do not address the following situations often because no data are available to National Cooperative Soil Survey personnel.

1. High yielding vs. pen pollinated varieties:

   This selection may be responsible for several feet of growth in a site over 50 years but no 50 year data are yet available.

2. Plantations vs. natural seeding:

   Cultural practices to control competition at various stages

of growth have not been evaluated on a large number of soil units.

3. Bedding and fertilizer practices:

Returns from these investments should be different on different kinds of soils but data are not complete by soil unit.

4. Insect and disease control:

Should be positive in all sites but past occurrences interjects variability in existing data.

5. Standard site index curves vs. height-age curves by soil unit:

In the National Cooperative Soil Survey soil-site-tree growth data are reported at 50 year age via selected site index curves. Recently, it has been determined that the shape of age/height curves for individual kinds of soils, as defined by series criteria, differ considerably from these standard curves. This is not surprising since the standard curves were developed from averaging all sites, many soil types, on which a given species was found growing. Utilizing soil series specific age/height curves considerably narrowed the standard deviation values of age/height data on loblolly and slash pine. A standard deviation of 5.2 feet at 50 years was obtained for loblolly pine making the presently used 10 feet site classes unduly coarse. It should be pointed out that age/height curves are not available for all soil series.

Summary

Soil classification is a method of communication. It will solve no problems in and by itself. To be useful in communicating, extrapolating, or transferring experience and technology from one site to another it is desirable to control as many variables as possible and group or classify as many of the uncontrollable variables as possible. The more quantitatively the uncontrolled variables are classified the more predicable the results. All classification systems are like computers and obey the computer acronym GIGO (garbage in garbage out). Soil Taxonomy and the map unit guidelines enforced in the National Cooperative Soil Survey program reflect the statye-of-the-art practiced at a national level and designed to provide units for a multitude of interpretations. Sufficiently homogeneous property and spacial units can be abstracted from the published surveys for many of the woodland uses but if the tree response data have not been available they cannot be created by classification.