The Red Soils of East and Southern Africa

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THE RED SOILS OF EAST AND SOUTHERN AFRICA

Proceedings of an International Symposium,
Harare, Zimbabwe, 24-27 February 1986

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INTRODUCTION

These proceedings are the outcome of a four-day symposium held at the University of Zimbabwe in February, 1986. The symposium was organised to gather together unpublished research and data on red soils from different countries in the region. The choice of red soils in preference to other soil types was in recognition of the fact that red soils form some of the most valuable commercial agricultural land in much of the East and Southern African region. They also present some of the most intricate and intractable problems in agriculture.

Much research has been done on red soils in the various countries of the region but a great deal more is required to solve some of their inherent problems. A great deal of the research done on these and other soils in this region is contained in mountains of paper which gather dust on the shelves of government departments or in consultants, reports and, in some cases, a vast amount of relevant data are safely locked away in the archives of former colonial Powers. One of the major objectives of the symposium was to collect some of this information and present it in a readily accessible form by way of the proceedings.

In the editing process, some papers have been modified in the interests of clarity of brevity or both. However, in every case, care was taken not to change the technical content and conclusions of the papers. Any interpretation of facts and figures is therefore the sole responsibility of the individual authors.

EDITORS
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We must also express our grateful thanks to the technical staff of the Department of Land Management for unstinting logistical support.
INTRODUCTION

Compared to the soils of the higher latitudes, many soils of the intertropical areas are morphologically more striking due to their redder colours and their generally deep weathering profiles. Consequently, the bright colours were used as differentiating criteria and terms such as 'red earths', 'dark red latosols' or merely 'red soils', proliferated in soil science literature. The intertropical areas have been free from glaciation in recent geological times and consequently rejuvenation of the soils through such processes has not interrupted weathering and soil formation processes. Africa being geologically an old continent, is being rejuvenated by peneplanation processes which results in displacement of the material but weathering and soil formation continues unabated with only minor changes induced by the geomorphic changes. Consequently, even in areas such as the zones around the Rift Valley, where uplift caused a disequilibrium with associated erosion and deposition, it is not uncommon to find red soils.

This paper examines the genesis of the red soils, explains their classification with respect to soil Taxonomy (Soil Survey, Staff 1975) and elaborates on some of the management-related properties incorporated in Soil Taxonomy.

Physiographic environment

Much of Africa is flat with plateau landscapes of various geomorphic ages. Weathering and soil formation has taken place over long periods of time; peneplanation processes have reworked materials and consequently, deep profiles with stone-lines are frequent. In these situations, the colour of
the soil is related to the nature of the parent material.

Figs 1 and 2, show the distribution of the soil moisture and temperature regimes of Africa. Van Wambeke (1982) has subdivided the moisture regimes to differentiate them further as shown in Fig. 3. The Figures illustrate that much of the continent, having aridic or ustic soil moisture regimes, is subject to soil moisture stress for prolonged periods during the year. Despite high soil temperatures, these moisture regimes are not the most efficient ones for weathering and mineral alteration. Consequently, much of the origin of the red colours must be associated with the nature of the parent materials, past climates, a long period of soil formation or a combination of all.
Figure 1 - CALCULATED SOIL MOISTURE REGIMES
Figure 2 - CALCULATED SOIL TEMPERATURE REGIMES
Figure 3 - Subdivisions of Soil Moisture Regimes

New York State College of Agriculture and Life Sciences
Department of Agronomy
Cornell University

Calculated Soil Moisture Regimes (Tentative Subdivisions)

Aridic
Xeric
Agricult
Typic
Xeric
Dry
Typic

Temperate

Tropical

Aridic
Typic
Usic

Dry Tropical
Typic

Tropical

The Aquic Moisture Regime is not shown on this map.
Origin of red colour in soils

Weathering of primary alumino-silicates, particularly the ferro-magnesian minerals, releases substantial quantities of iron. The fate of the iron is a function of the nature of the pedoenvironment and the degree of the weathering process. In a freely draining environment, the released iron settles on the secondary alumino-silicate clay minerals and coats them. At an advanced stage of weathering, the clay minerals are essentially kaolinite with subordinate amounts of 2:1 minerals such as illites, vermiculites and aluminum interlayered chlorites; smectites are rare in such situations. The clay surface acts as a template for the concentration of the iron. D'Hoore (1954), Fripiat and Herbillon (1971), and, Eswaran and Sys (1974) have shown that the saturation point for kaolinite is about 12 to 14 per cent Fe₂O₃. The iron has an important staining effect and imparts a red colour to the soils. The iron may also be present as discrete particles or aggregates or it may coat other granulometric fractions. In the yellow or reddish-yellow soils, the iron mineral is dominantly goethite but, with increasing redness, haematite tends to dominate the colloid system. X-ray amorphous particles of iron oxyhydrates may also be present in varying amounts but little is known of their contribution to soil colour.

In some soils, an accumulation of organic matter or manganese masks the red colours. Finely divided manganese has a significant darkening effect, and soils on basic or ultrabasic rocks, despite having a very high free-iron content, may not appear very red; such soils have often been described as 'chocolate soils'.

Colour differentiation within a profile may result from podzolization processes. Organic matter reduces the iron to ferrous forms that are then translocated down the profile, as chelated complexes. The intensity is insufficient to result in a Spodosol, but the process occurs in most soils and operates imperceptibly. In a perudic soil environment, such translocation and subsequent accumulation as large diffuse nodules, takes
place even in a freely draining environment. The upper part of these soils is yellowish and becomes redder with depth—and epiaquic features, and epiaquic subgroups are provided for in Soil Taxonomy for some Ultisols and Oxisols.

In the presence of a fluctuating water table, segregation of iron becomes a very important process leading to colour differentiation and formation of mottles, nodules and concretions. The genesis of plinthite is related to these processes. A subsequent dissection of the landscape with an associated lowering of the ground water table may lead to a hardening of the plinthite to form petroplinthite, and if the supply of iron is great and rapid, a petroferric contact may result. Slope water charged with ferrous iron intensifies the formation of these forms. When an impermeable layer reduces the hydraulic conductivity, these forms grow by accretion and all of these processes are iterative.

Colour differentiation may also arise because of seasonal flooding with water stagnation on the surface and slow percolation, initiating a process termed 'ferrolysis' (Brinkman, 1970). Iron released by preferential weathering in the upper part of the profile, owing to alternate oxidizing and reducing conditions, migrates and acculates in the lower part of the profile. Ferrolysis may play an important role in the epiaquic processes mentioned previously.

The quantity of iron released is also a function of the nature of the parent material; more specifically, it is a function of the kinds of weatherable minerals present which include iron-containing clay minerals. Soils derived from basic rocks or biotite schists and migmatites have a very large supply of iron, and under equivalent pedoenvironmental conditions they tend to be redder. With the same amount of free iron, clayey soils tend to be redder than their coarse-textured counterparts.
Use of soil colour in Soil Taxonomy

In Soil Taxonomy, soil properties are differentiating, accessory or accidental. Differentiating characteristics are suitable for identifying taxa. For example, moist chromas and values of less than 3.5 are used as a differentiating characteristic for the mollic and umbric epipedons. Hues redder than 5YR are used as a differentiating characteristic for the rhodic great groups such as in the Rhodustalfs.Accessory characteristics are important for characterizing taxa and accidental characteristics may be important soil properties but do not have significant use in classification. The phosphate status of a soil is an example of the latter.

Although earlier classifications used soil colour, this attribute is only employed in the Rhodic great groups and subgroups in some orders of Soil Taxonomy. Soil colour is not an important differentiating characteristic because,
- soil colour is a function of the parent material,
- soil colour is not indicative of a soil formation stage, except for a given parent material under similar pedoenvironmental conditions,
- other properties which better serve the purpose of differentiating criteria are readily available, and
- few other properties can be inferred from soil colour due to lack of knowledge of the relationships.

However, at the lowest categoric level in Soil Taxonomy -- the soil series -- colour is a useful differentiating criterion.

In the Brazilian classification (Bennema, 1966) the use of colour separates some of the Latosols. Recent studies, particularly those on phosphate fixation, moisture retention and charge characteristics, suggest the use of soil colour as an indicator of such properties in the Oxisols due to the fact that the composition of the Oxisols is generally more homogeneous and because there are few other properties that could be used as differentiating characteristics in these soils.
Red soil classes in Soil Taxonomy

Some of the subgroups of the Alfisols and Ultisols where red soils are identified are shown in Table 1. The definition of the prefix 'rhod-' varies in the taxa where its use occurs. In the Udalfs and Ustalfs, the "rhod" definition emphasizes the hue and reads as:

"that have an argillic horizon that has throughout its thickness a hue redder than 5YR, a colour value, moist, less than 4, and a colour value, dry, no more than one unit higher than the moist value."

In Udults and Ustults, the definition drops the hue requirement and reads:

"1. an epipedon that has a colour value, moist, less than 4 in all parts, and
2. an argillic horizon that has a colour value, dry, less than 5 and not more than the value, moist."

The 'rhodic' subgroups in the two Orders have corresponding requirements.

The modal pedons in the Alfisols and Ultisols have a deep profile frequently extending to more than 2m. Both have an argillic horizon but base saturation at a depth of 1.8m differentiates them, with the Alfisols having more than 50% (by ammonium acetate at pH 7) and Ultisols less than 50%.

Concept and definition

For purposes of this paper, red soils are defined as:
"those soils that have a hue of 5YR or redder, and have a CEC (in NH₄OA₃) at pH 7) of 24 meq per 100g clay or less an ECEC of 18 meq per 100g clay or less. In addition, they have less than 6% of weatherable minerals or less than 10% of muscovite in the 20 to 200 micron fraction. They may have an argillic or oxic horizon but do not have a cambic horizon. They have a thermic, isothermic or warmer soil temperature regime."
TABLE 1. **SUB-GROUPS IN ALFISOLS AND ULTISOLS IN WHICH RED SOILS ARE FREQUENT.**

<table>
<thead>
<tr>
<th>SUBGROUPS</th>
<th>Oxic</th>
<th>Rhodic</th>
<th>Udic</th>
<th>Ultic</th>
<th>Lithic</th>
<th>Plinthic</th>
<th>Ustic</th>
<th>Humoxic</th>
<th>Typic</th>
</tr>
</thead>
</table>

**ALFISOLS**
- Plinthustalts
- Palustalts  X  X  X  X  X
- Rhodustalts  X  X  X  X  X
- Paludalts  X  X  X  X  X

**ULTISOLS**
- Sombrihumults
- Palehumults  X  X  X  X  X
- Plinthohumults
- Tropohumults  X  X  X  X
- Plinthudults
- Paleudults  X  X  X  X
- Rhodudults
- Tropudults  X  X  X  X
- Plinthustults
- Paleustults  X  X  X  X
- Rhodustults  X
The above definition narrows down the range of soils, having similar constraints and potentials for use and management, to a more homogeneous group. The definition excludes the red Mediterranean soils of north Africa and confines the soils to the region south of the Sahel and most of southern Africa. The definition will also eliminate the recent soils around the rift valley of Rwanda, Uganda, Tanzania and Malawi and also the soils around Mt. Cameron. The mountainous areas with sloping land which frequently have soils with cambic horizons are also eliminated. Most of the red soils of Africa are derived from basement complex rocks such as mica-schists, biotite gneiss, migmatites and some granites or granodiorites, or as in Southern Africa, on limestones or on old basic igneous rocks. Soils on ferruginous shales may also have very red colours.

**Diagnostic horizons and features**

Most of the diagnostic horizons and features are present in the red soils, but the application of these concepts to the African scene has shown that some present problems in identification while others require re-evaluation.

a. Argillic and oxic horizons

The definition of the argillic horizon is very specific in Soil Taxonomy. One of the requirements is the presence of clay skins when peds are present; an arbitrary amount of 1% cutans in thin-sections is specified which has been the source of debate and disagreement since its introduction in about 1960. Many of these soils have, in addition, oxic properties, which complicate the picture. The pedoenvironment is normally conducive to clay translocation, but field morphological evidence is not always convincing. The transported nature of the parent material, the intense biological activity and the oxic nature of the soil material are suggested as possible reasons for the lack of evidence of clay translocation.
To overcome some of these problems, the concept of the 'Kandic horizon' was developed to emphasize the increase in clay in essentially oxic materials irrespective of the presence or absence of clay-skins or cutans. The kandic horizon is only permitted in soils with less than 40% clay in the upper 18 cm and in addition, the kandic horizon meets the charge requirements of an oxic horizon. The clay increase takes place within a vertical distance of 15 cm and the kandic horizon is at least 30 cm thick. (There are other requirements which are not spelled out here. Kandi taxa are only identified in Alfisols and Ultisols, for example, Kandiustalf or Kandiustult. If there is more than 40% clay in the top 18 cm layer, despite a clay increase which meets the requirements of an argillic or kandic horizon also meets the oxic horizon requirements. A special great group is proposed for those oxisols with a clay increase -- the 'Kur'-great group as in Kurustox or Kurorthox.

b. Plinthite

Plinthite is an iron-rich, humus-poor mixture of clay with quartz and other diluents. It is frequently associated with hydromorphic conditions but relict plinthite soils may be well drained. It has the potential to harden and does so when the soil is truncated by erosion and the plinthite is exposed to the surface. Such soils were once thought to be very extensive in Africa but detailed mapping suggests they cover less area than originally supposed.

c. Petroferric contact

A petroferric contact is a boundary between soil and a continuous layer of indurated material in which iron is an important cement and organic matter is absent or present only in traces. This is one of the forms of laterite which behaves like a lithic contact and is frequent in soils from Senegal in the north, to Angola in the south. The contact is impermeable to both water
and roots and the soil material above the contact is generally of alluvial-colluvial origin.

d. Petroplinthite
The term is not used in Soil Taxonomy but was introduced by Sys (1968) and studied by Eswaran and Raghumohan (1973). These laterite gravels are a diagnostic feature of many soils on old geomorphic surfaces. They may form distinct bands which have been termed "stone-lines" separating the allochthonous from the autochthonous parts of the soil. Currently, if petroplinthite is present, it is considered at the family level as skeletal or fragmental materials. Sys (1968) has proposed petroplinthic subgroups in the Alfisols, Ultisols and Oxisols. The International Committee on Oxisols (ICOMOX) considered a proposal to bring some of these soils into the "pale" great groups (ICOMOX 1978) but did not receive support from U.S soil scientists.

e. Sombric horizon
At high altitudes in Central Africa, the soils have a dark subsurface horizon which has been termed a 'sombric horizon'. The current definition in Soil Taxonomy is weak. At the tenth International Forum on Soil Taxonomy held in Rwanda and Burundi, a proposal was made to change the definition (Appendix I). The origin of the horizon is still disputed; some attributed it to a buried feature while others consider translocation and accumulation of humus as processes promoting the formation of this horizon. Irrespective of its origin, it is a useful and easily identifiable horizon and serves well as a diagnostic horizon for taxonomic purposes.

**MANAGEMENT CONSTRAINTS TO CROP PRODUCTION**

Most soils have some kind of constraint to crop production. The degree of the constraint varies and the discriminatory use of the soils depends on the appreciation of the constraints and potentials and the matching of these with crop performance. Only some of the major constraints are presented here.
*Moisture Stress*

Moisture stress is perhaps the single, most important factor restricting crop production in many areas of Africa. The Oxisols and the oxic subgroups of the Alfisols and Ultisols are more prone to moisture stress owing to their very low water-holding capacity.

Red soils are, in general, more susceptible to drought conditions than others. The high amount of sesquioxides tends to aggregate the clay particles, thus reducing the effective storage capacity of the soil. If the arithmetic difference between 1/3 bar and 15 bar water is used as a measure of the available water (and calculated on a volume basis), the red Oxisols and Ultisols generally store less than 1mm of water per cm of soil. These drought hazards are accentuated in soils with shallow stone-lines or soils with petroplinthite or gravel where the effective volume of soil exploited by the roots is further reduced, worsening the situation. Apart from providing calcium to the plants, liming acid soils increases the effective volume exploited by the roots and enhances the ability of the roots to withstand moisture stress.

Red soils in general, also have high infiltration rates that vary between 8 and 15 cm per hour. This rapid infiltration is not a favourable property, and coupled with the low water holding capacity, the soils frequently behave like sands or loamy sands.

Since soil moisture is such an overriding factor, a knowledge of the soil moisture regimes (with soil temperature regimes) will aid in a first approximation of crop production potentials. The Figs. for pedo-climatic assessment for specific crops (Van Wambeke, 1982) illustrate such an approximation. The crop requirements are taken from FAO's agroecological methodology (FAO/UNESCO 1978) and estimates are based on the soil moisture and temperature regimes of Soil Taxonomy (Soil Survey Staff, 1975).
**Soil acidity constraints**

The red soils as a group have a range of soil pH, and in the acidic members, Al toxicity and/or Ca deficiency is an important constraint to soil use. On a continental basis, soil acidity is a problem in areas with udic or perudic soil moisture regimes and, to a lesser extent, in the soils with ustic soil moisture regimes. The intensity of the problem is also a function of the absolute amount of Al on the exchange complex and this in turn is related to the mineralogy of the soils. In soils with high amounts of 2:1 minerals, such as illites, chlorites and vermiculites, due to the higher exchange capacities the amount of Al is also much higher than in a kaolinitic system. Consequently, soil acidity is generally not an intense problem in Oxisols or in low charge systems as in other soils.

The red Alfisols, though generally having a high base saturation, may acidify in the surface horizons under continuous cultivation. Management of such soils requires much care. The technology for soil acidity management has been well studied and sufficiently validated. Liming, particularly deep liming, rectifies most of the imbalance. The raising of the soil pH to an optimal level has additional benefits. The lime is an amendment to the soil and provides the badly needed nutrient, calcium, to plants. With deep liming, the volume of soil exploited by the roots is also increased, making the plants less susceptible to moisture stress. In soils with a low charge and particularly those with a net positive charge, increasing the pH results in an increase in the CEC with a concomitant increase in the ability of the soil to retain nutrient cations. Some Oxisols and a few Ultisols show this enhancement effect clearly.

Though the technology of managing soil acidity is well established, the problem in Africa is, in general, the inavailability of lime. Absence of a ready source makes this a prohibitive practice in parts of the continent. Wherever
available, volcanic ash or cinders is a desirable alternative. Acid tolerant germ plasms is not necessarily a good solution to the small farmers as such cultivars are in a sense "delicate" and need advanced management.

* **Nutrients constraints**

In many red soils, deficiencies of N and P are common while localized deficiencies of K, Mg, Zn and S also occur and are intensified under continuous cultivation. Mulching, application of farm-yard manure (when available) and fertilization rectify these conditions. These are, however, not readily available to the small farmer and for many countries in Africa, the only solution appears to be massive government support and intervention. Traditionally, the national planners and agronomists have looked upon the use of soil amendments as part of the management inputs of the farmer. To have productive agriculture in many parts of Africa, national planners should consider soil amendments as a form of capital investment such as large scale drainage and irrigation projects. This approach would educate the farmers in the use of fertilizers, pesticides etc., and later they can be slowly weaned out of it. The use of foreign exchange to purchase fertilizers will be balanced by the attainment of self-sufficiency in food and fiber production and in some cases, even an export capability.

* **Physical constraints**

Red soils with an ustic soil moisture regime are particularly susceptible to crusting, compaction, erosion and of course, soil moisture stress. Continuous cultivation accentuates some of these detrimental processes. The extent to which soils exhibit these problems as well as the kinds of soils which exhibit them, are not well known. Nevertheless, it is established that red soils, in general, are more prone to these constraints than other kinds of soils.
RESEARCH PRIORITIES

African governments and bilateral and multilateral programme participants have spent millions and even billions of dollars in agricultural research in the last few decades. Population growth in Africa is increasing at about 3%, while food production is only increasing at about 1% or even decreasing in some countries. The "Green Revolution" had a tremendous effect in Asia but appears to have had little impact in Africa. The technology being developed by the International Agriculture Research Centers such as IITA, ICRISAT and IRRI, does not seem to be reaching the small farmers of Africa. Answers to questions like these are probably the first step to developing a more concerted plan of action.

One basic problem in many African countries, is the absence of an effective infrastructure; in general, national agricultural research institutions are weak, many governments do not consider research expenditure as an investment or cannot afford this investment. In some countries, extension services are weak or non-existent and as a result, the vertical transfer of agrotechnology is difficult and finally, in some instances, government involvement in farm production tends to be a burden rather than a support to the production system. When these constraints are coupled with an absence of marketing facilities for the small farmer in addition to other socio-economic problems, the small farmer does not have an incentive to produce.

Agricultural technologies, customized to any agro-ecological zone in the world are perhaps avialble. The question is to make these available to the farmers and this is the realm of agrotechnology transfer. There are some prerequisites for the horizontal transfer among and between scientists and institutions, to take place and these form some of the basis for the research priorities.
Soil Resource inventories

Much of the agronomic and plant-breeding research in Africa, as in many parts of the world, is site-specific. As a result, research results may only be extrapolated to other areas with difficulty though this is constantly done. Many valuable research findings are being lost or not utilized because of a lack of site characterization. Characterization and documentation of research and transfer sites should be viewed as a first priority of research.

The second priority is good soil resource inventories at different scales using modern soil survey procedures. Problems in countries include:

a. soil maps are not available,
b. soil maps are old and consequently not reliable,
c. soils data are not reliable,
d. the soil surveys were not made for the objective at hand,
e. there is no in-country capability to make soil maps,
f. there is no in-country capability to use soil survey information.

Soil survey provides the only data base for national planning and development and for the transfer of research results. It is thus sufficiently important to warrent donor assistance in many countries of Africa.

Research methodology

Developments in the last few decades suggest an imbalance in the allocation of funds to soil and agronomic research. Considerable emphasis has been laid on breeding of new cultivars due to the success achieved by breeders. However, the gap between experimental yields and farmers' yields tells us that the science of matching crop requirements to soil conditions is still in its infancy. The problem that still remains is the knowledge about soil conditions and how to manipulate them for improved production.
Research is expensive and a luxury to many countries. How can research be made more cost-effective, inexpensive and quick? There are no easy solutions but one alternative that is becoming increasingly useful is simulation analysis. Soil-weather-crop simulation models have several direct and indirect applications. When such models are coupled with a decision-support system with a good soils, crop, climate and management data base we have a solid basis for agrotechnology transfer. Conceptually, the decision support systems (DSS) may be employed for several purposes including the screening of a cultivar or technology for a particular soil or soil condition before the actual field testing, thus saving tremendous costs. Once the soils of a country are mapped, the DSS could be used to simulate management practices for each area and suitable management practices could be selected for field testing. Use of DSS does not preclude conventional research which should be continued.

One particular advantage of the DSS is that it forces the scientist to consider the system as a whole and this of course requires multi-disciplinary and team effort. The DSS would also screen the masses of data and only employ the essential, the minimum data sets, thus saving considerable costs in generating future data bases. Thus, the third priority is the use of modern information technology in agricultural research.

A fourth priority in Africa is the strengthening of research institutions. The problem consists of availability of qualified scientists and funds for research. In addition, scientists must demonstrate to decision makers that research is productive. A common problem in many countries is that research organisations lack experience in managing research and selling research findings.

In conclusion, there is a tremendous potential for African agriculture. There are many problems, some of which require large investments while others may be solved by a
re-evaluation or re-organisation of research. The management of research programs is one area which has not received much attention in the past but which requires as much attention as research itself.
Appendix 1. Definition of the Sombric horizon

A 'sombric horizon' is a subsurface horizon exclusive of the spodic horizon, which has an increase in organic matter as compared to the overlying horizon. The higher organic matter content imparts dark colours by which it can be recognized as a distinct horizon. It may share some properties of andic soil materials such as low bulk density and high NaF pH, but does not have sufficient reactive aluminum to meet the KOH Al or the oxalate Al requirements of andic soil materials.

It normally occurs in the cambic, oxic or argillic horizons. If a stone-line is present, the horizon may transgress the stone line. The upper boundary is gradual and may have tongues of organic-stained material. It may form part of the epipedon but is recognized by a lighter coloured overlying horizon.

Some sombric horizons may be formed purely by tongues of organic materials extending to the saprolite. To qualify for a sombric horizon, the material in the tongues must meet the requirements provided below and also the tongues must occupy more than half the bodies termed as sombrovites (see ICOMOX circular No. 4). These sombrovites or the enclosing soil materials must meet the requirements given below and occupy more than half the pedon.

The sombric horizon meets the following requirements:
a. has a colour value of less than 4 and a chroma of less than 4, moist, a value of less than 5.5 dry, and value and chroma are more than one unit darker than the overlying horizon;
b. there is at least 0.6% organic carbon and an absolute increase of more than 0.2% organic carbon than the overlying horizon;
c. the horizon is at least 25cm thick unless there is a lithic, paralithic or petroferric contact within 50cm of the soil surface, when it is at least 10cm thick.
REFERENCES


SUMMARY

Red soils of Africa fall into four major soil units of the FAO/UNESCO legend: Nitosols, Luvisols, Ferralsols and Acrisols. Some basic characteristics of these soils and a correlation with other systems of classification are given. The poorer red soils, principally, Ferralsols and Acrisols -- have a low inherent fertility; degrade easily; have low contents of primary minerals and reserves of weatherable minerals; and have a low exchange capacity. Red soils are widespread throughout the region. In southern Africa they are reasonably productive and a large proportion of agricultural production relies upon them. In East Africa they tend to be far less productive, yet are expected to support large numbers of the rural population.

The rest period requirement of red soils depends upon the level of inputs. Some, such as Nitosols, can be continuously cultivated given appropriate management, while others require at least eight years of fallow for a cropping of two years. For nearly all red soils at a low level of input more land must be in fallow than is under cultivation. Red soils suffer at least five types of degradation, and their extent and relative severity is reviewed in the paper. The evidence for productivity losses is irrefutable and decline in yields may be dramatic with only moderate intensities of degradation. This is supported by the interim conclusions from a project to analyse the nutrient losses from erosion on a red soil in Zimbabwe. At a relatively modest
erosion level of 15 tonnes/ha the amount of nitrogen and phosphorus lost in the eroded sediments is equivalent to the nutrients in Z$27 of fertilizer (1985 prices). At the higher levels of erosion typical of much degraded rangeland, the corresponding cost would be in excess of Z$90 per hectare. (1Z$ = U.S.$0.60 at time of writing).

A large number of management options remain open for use on red soils. These include the improvement of traditional shifting cultivation practices, rotations, green manuring, mulching, various systems of tillage, tied ridging, agroforestry and fertilizers. None is satisfactory by itself. Red soils will require a sensitive farming systems approach towards the development of appropriate practices that meet technical needs and societal requirements.

INTRODUCTION

The red soils of the tropics are striking in appearance. As a group of soils easily distinguishable to the non-specialist, red soils appear relatively rich in agricultural potential. In reality, however, many are the poorest of tropical soils while a few, unfortunately only small in area, do indeed have considerable fertility.

In very broad terms, red soils include all tropical and equatorial soils that have low silica-sesquioxide ratios of clay fractions, low base status, low clay activity, low content of most primary minerals, low content of soluble constituents and a high degree of aggregate stability (Kellogg, 1949). But like all generalizations the broad description hides some important differences in agricultural properties, management and resistance to degradation processes.

The nomenclature of red soils can be extremely confusing especially with regard to terms such as "laterite" and "latosol" which have been used and abused out of all recognition to their original meanings. Table 1 seeks to set some order amongst competing
<table>
<thead>
<tr>
<th><strong>TABLE 1. - CORRELATION OF THE NAMES OF RED SOILS ACCORDING TO THE MAJOR CLASSIFICATIONS.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FAO</strong></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>The Poorer Red Soils</strong></td>
</tr>
<tr>
<td><strong>Ferralsols</strong></td>
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<tr>
<td>Orthic Ferralsols</td>
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<td></td>
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<tr>
<td>Rhodic Ferralsols</td>
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<tr>
<td>Humic Ferralsols</td>
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<tr>
<td>Plinthic Ferralsols</td>
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<tr>
<td><strong>Acrisols</strong></td>
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<tr>
<td>Ferric Acrisols</td>
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<tr>
<td></td>
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<tr>
<td>Plinthic Acrisols</td>
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<tr>
<td><strong>The Better Red Soils</strong></td>
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<td><strong>Luvisols</strong></td>
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<tr>
<td>Chromic Luvisols</td>
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<tr>
<td></td>
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<tr>
<td>Ferric Luvisols</td>
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<tr>
<td>----------------</td>
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<tr>
<td>Lateritic podzolic</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitosols</th>
<th>Ultisols/Alisols</th>
<th>Ferrisols</th>
<th>Hygroferrisols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dystric Nitosols</td>
<td>Tropudults/alfs</td>
<td>Ferrisols, Kc</td>
<td>-</td>
</tr>
<tr>
<td>Eutric Nitosols</td>
<td>Tropudalsfs</td>
<td>Eutrophic brown soils, Hd</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>some fersiallitics</td>
</tr>
</tbody>
</table>

* Note: correlation only tentative; mapping units do not correspond closely to FAO units.
classifications for the names of the major African red soils. This paper distinguishes between two broad groups -- the poorer and the better red soils -- and utilizes the FAO legend which classifies four generalized soil units of red soils in order of quality and suitability:

Nitosols > Luvisols > Ferralsols > Acrisols

It is not the purpose of this paper to detail the properties of each soil unit (the reader is referred to Volume VI of the FAO/UNESCO Soil Map of the World, 'Africa', Chapter 6 on 'Land Use and Soil Suitability').

Of the four major soil types, the Ferralsols are the classic red soils of Africa both in terms of their areal distribution and striking red appearance. In central and southern Africa, the Nitrosols have also drawn attention as a red soil because of their considerable agricultural potential, their occurrence on the localized but widespread basic dykes, and their rich red-brown colouration. It is perhaps debatable whether the Luvisols and the Acrisols should have been included amongst the red soils since they show far greater variability in colour, but since they occur in catenary sequence with Ferralsols, are red in some horizons and present interesting contrasts, they are included here.

Table 1 correlates the soil names of the relevant FAO soil units with those in Soil Taxonomy, CCTA Soil Map of Africa and a few other commonly occurring names. The correlation with the Zimbabwe classification is extremely tentative (Thompson and Purves, 1981). The following are the major distinctive features of the four main soil units and associated mapping units of the FAO classification:

**Nitosols**

In Africa these are primarily soils of the humid and semi-arid tropics and, because they are only intermediate in their stage of weathering and have an apparent continuous renewal of
reserves by the weathering of base rich minerals, they have a relatively high cation exchange capacity. This makes Dystric Nitosols widely used for food crops and intensive cultivation even on steep slopes. FAO (1977) describes Eutric Nitosols as ranking "amongst the best soils of the tropics" (p. 209). Unfortunately, they are very susceptible to erosion and structural breakdown and they occupy barely two percent of Africa.

Luvisols

Chromic and Ferric Luvisols are widely represented in Africa occupying up to ten percent of the continent. Ferric Luvisols (along with some Plinthic variants) are typical of much of the seasonal tropics, occurring under tree savanna and woodland (e.g. the fersiallitic soils of the Zimbabwe Highveld), where weathering is relatively severe and the clay fraction has a correspondingly low exchange capacity. Base saturation may be fairly high but naturally low levels of organic matter create a significant degradation hazard. Chromic Luvisols are also deficient in organic matter and phosphorus but are somewhat more abundant in bases. In southern Africa these soils have typically supported ranching and some food crops. In East Africa they are often used for subsistence cropping and, where rainfall is sufficient, groundnuts and cotton can be grown successfully. Their low water-holding capacity is the major constraint to intensification of use, and these soils may show dramatic yield declines if allowed to erode (Stocking & Peake, 1986).

Ferralsols

Widespread throughout central and East Africa, Ferralsols are deeply weathered, stoneless and clayey. Virtually no weatherable minerals remain in the upper two metres, rendering the soil very limited in potential fertility. Nutrients are almost wholly bound in the organic matter and plant cover, while the clay content determines the water and base saturation capacities. Under natural rainforest organic matter may be as high as 5% and carbon:nitrogen ratio 10:12 with adequate phosphorus and other cations mainly supplied by the organic fraction. Clearance of
vegetation interrupts the high input to organic cycling, depleting the nutrient store and causing an alarming drop in fertility. All major nutrients become deficient, either through leaching or fixation. Yields decline correspondingly such that the only viable form of low-technology agriculture is shifting cultivation. In contrast, most Ferralsols have a stable, fine structure, allowing good root penetration and reasonable moisture retention along with free drainage. In their natural state Ferralsols are resistant to erosion but with the loss of organic matter this also may change dramatically. Some sort of fallowing system is always advisable in the utilization of Ferralsols. Humic Ferralsols are largely confined to the highland parts of East and central Africa and support mixed extensive agriculture. Orthic Ferralsols extend into Tanzania and Zambia and support only very low densities of rural population. The agricultural value of Rhodic Ferralsols is somewhat higher and they occur further south supporting mixed subsistence agriculture and, in the Eastern Highlands of Zimbabwe, some perennial plantation crops. Plinthic Ferralsols are at best used for extensive ranching.

Acrisols

These are the weathered ferrallitic soils of the savanna zone (as opposed to the Ferralsols, the leached ferrallitic soils of high rainfall zones). They have low cation exchange capacity and low total exchangeable bases; they are deeply weathered; and they have sandy to sandy loam textures with weak structure. Young (1976) describes these as the 'dead' soils of Africa, having already been altered by weathering, mineral translocation and clay synthesis, having almost nothing to commend them. They are the old soils of the Brachystegia (miombo) woodland savanna, occurring throughout the 500 - 1000 mm rainfall zone. Their agricultural potential is well summarised by FAO (1977): "Every effort should be made to prevent the establishment of large-scale agricultural modernization projects on these soils." (p. 202). Extensive livestock with some subsistence cassava, beans, sorghum and millet are the main viable uses. In Zimbabwe, however, Ferric Acrisols
above 1000 m altitude support tobacco production and some intensive food crops where sufficient fertilizer is provided and residue management is practised. Indeed the soil texture is somewhat favourable to high quality tobacco leaves, and with high K fertilizers they can produce well.

Finally, in this introduction it is worth reviewing the associations of red soil in East and southern Africa and the dominant groupings to be found. In East Africa, Ferric Luvisols dominate the plains with Ferric and Plinthic Acrisols on the wetter southern plains. Around the Lakes Region the red soils are primarily Ferralsols and Acrisols, especially between the Rift Valley and Lake Victoria. To the west of the Rift into Zaire and northern Zambia, Orthic and Rhodic Ferralsols predominate. This band of Ferralsols extends partially into southern Africa, especially around the wetter areas of Lake Malawi, but gives way on the plateau regions of Zambia to Chromic Luvisols and in Zimbabwe to Ferric Luvisols. Dystric Nitosols occur on base rich rocks in the Zaire Basin and Eutric Nitosols in the Zambezi and Limpopo Basins.

SUSCEPTIBILITY TO DEGRADATION

Rest Period Requirements

One useful way of looking at the fertility and management of tropical soils is to examine their ability to sustain continuous cropping without undergoing degradation. Degradation itself will be considered in the next sub-section, but the signs of it would include a drop in crop yield, decline in structure and nutrients or other deleterious physical, chemical and biological changes. Under traditional farming, natural fallows are the response to degradation and the means to recuperation. Various systems of true shifting cultivation and bush fallowing have developed according to environmental circumstance and social preference, but each has a certain proportion of the 'cultivation cycle' under fallow, ley or non-arable use. If that proportion becomes unduly foreshortened, degradation is the result. The use of more advanced farming methods can, to an extent, mitigate
the problem but experience has shown that it is still impossible to grow annual crops every year without either soil degradation or inputs at an impracticable and uneconomic level (Young & Wright, 1979).

The rest period requirement is the number of years of fallow or non-arable use in a cultivation cycle that is necessary to maintain the soil (a) in a long term steady state, (b) at a reasonable level of productivity, (c) in a physical condition where erosion is unlikely, and (d) where it is able to meet crop water requirements. In concept it is identical to the cultivation factor, R (Ruthenberg, 1976):

\[ R = \frac{C}{C \times F} \times 100\% \]

where \( C \) = years of cultivation, and \( F \) = years of fallow and non-arable use. The value for \( R \) thus varies from 0 (no cultivation) to 100 (continuous cultivation) and essentially expresses the intensity of land use over a cultivation cycle of several years. Normally, shifting cultivation has an \( R \)-value < 30, semi-permanent cultivation \( R = 30-70 \) and permanent cultivation \( R > 70 \).

In assembling published and anecdotal evidence on rest periods, the FAO/UNFPA Project on Land Resources for Populations of the Future distinguished between three levels of inputs and six climatic divisions. Table 2 presents the data on the cultivation factor for tropical red soils of Africa and Asia.

At the low level of inputs, falling is the only means of soil recuperation. In the areas where this farming system prevails, Ferralsols and Acrisols are the principal soils of the rainforest and Luvisols in the savanna zone. From over 70 data sources on these agriculturally-important environments, Ferralsols and Acrisols (although there may have been some difficulty in distinguishing between the two in the sources) seem to be able to support cultivation in only one year in four. Therefore, if

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>LOW INPUTS</th>
<th>INTERMEDIATE INPUTS</th>
<th>HIGH INPUTS</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(a) (b) (c) (d) (e)</td>
<td>(a) (b) (c) (d) (e)</td>
<td>(a) (b) (c) (d) (e)</td>
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<tr>
<td>Ferralsols</td>
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<tr>
<td>All</td>
<td>25 25 (30) 30 35</td>
<td>50 50 (60) 55 60</td>
<td>75 75 (75) 80 80</td>
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<tr>
<td>Humic</td>
<td>50</td>
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<tr>
<td>Acrisols</td>
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<td></td>
</tr>
<tr>
<td>All</td>
<td>25 25 (30) 30 35</td>
<td>65 60 (60) 70 75</td>
<td>75 75 (75) 80 90</td>
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<tr>
<td>Luvisols</td>
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<tr>
<td>All</td>
<td>25 35 50 30 50</td>
<td>65 65 75 70 75</td>
<td>80 90 90 85 90</td>
</tr>
<tr>
<td>Nitrosols</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>50 75</td>
<td>50 90 75 70 90</td>
<td>90 90 90 90 90</td>
</tr>
<tr>
<td>Dystric</td>
<td>25 30 (40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eutric</td>
<td>(40) 75 75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

(a) Warm tropics, rainforest zone, 270-365 days growing period
(b) Warm tropics, savanna zone, 120-269 days growing period
(c) Warm tropics, semi-arid zone, 75-119 days growing period
(d) Cool tropics, rainforest zone, 270-365 days growing period
(e) Cool tropics, savanna zone, 120-269 days growing period

Values in brackets refer to soils unlikely to occur in that climatic zone.
annual crops are to be grown with low inputs in the rainforest zone at least eight years of fallowing would be necessary in any clearance of the bush and cropping for two years. On most Acrisols fallowing should be even longer. The Luvisols of the savanna, the most important agro-climatological zone in the region for the production of food crops, will support cultivation one year in three at low inputs. Therefore, for all soils except Nitosols more land must be in fallow than is under cultivation.

At the intermediate and high levels of input, fallows may continue but are supplemented by planted leys and by fertilizer. Evidence from Africa suggests that, under favourable circumstances, Ferralsols and Acrisols can be almost continuously cultivated provided there is careful management through the use of grass-legume leys in the occasional rest periods. By contrast, South American opinion assesses Ferralsols and Acrisols at high input to be somewhat less resilient, having an R of only 65 and 50 respectively. Some caution is warranted then in the use of red soils even at high input levels of fertilizer and of management.

Types of Degradation

FAO (1979) categorizes six types of soil degradation and parameters by which they can be measured. These are:

Water erosion; to include splash, sheet and gully erosion; measured as soil loss.

Wind erosion; including removal and deposition of particles; measured as soil loss.

Excess of salts; salinization and sodification; measured by electrical conductivity and exchangeable sodium percentage.

Chemical degradation; including leaching of bases and toxicity problems; measured by decrease in base saturation and increase in toxic elements.
Physical degradation; an adverse change in porosity, permeability, density and structural stability; measured by bulk density and permeability.

Biological degradation; processes that increase rate of mineralization of humus; measured by depth of humus layer.

Table 3 summarises the significant characteristics of red soils that are related to these types of soil degradation. Concentrating on the major hazardous characteristics (after Young & Wright, 1979), Ferralsols have:

* very low supply of available plant nutrients;
* strong acidity, high in active aluminium;
* very low levels of available phosphate;
* no reserves of weatherable minerals;
* topsoil organic matter easily lost.

Acrisols have most of the degradation hazards of Ferralsols with some additional physical and chemical problems when cultivated:

* low supply of plant nutrients and trace elements;
* strong acidity, low calcium, high active Al;
* topsoil organic matter easily lost;
* weak structure;
* argillic B-horizon internal drainage.

Luvisols have been described as a 'mid-point in the spectrum from poor to good tropical soils' but they still suffer;

* only moderate nutrient content;
* low to moderate organic matter;
* weak topsoil structure.

Nitosols are the safest and most fertile of the red soils, but at low input levels a distinction must be made between Dystric and Eutric Nitosols. The rainforest Dystric Nitosols suffer;

* some acidity problems and nutrient fixation;
* moderately high erosion hazard.
TABLE 3.- SOIL DEGRADATION AND RED SOILS

<table>
<thead>
<tr>
<th>TYPES OF DEGRADATION</th>
<th>FERRALSOLS</th>
<th>ACRISOLS</th>
<th>LUVISOLS</th>
<th>NITOSOLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water erosion</td>
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<td>**</td>
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<td>*</td>
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<tr>
<td>Wind erosion</td>
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<tr>
<td>Excess salts</td>
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</tr>
<tr>
<td>Chemical</td>
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<tr>
<td>Physical</td>
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<tr>
<td>Biological</td>
<td>***</td>
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</tr>
</tbody>
</table>

- not significant ** significant
* can be a problem *** severe problem

PRODUCTIVITY LOSSES ON RED SOILS

General Considerations

The one common characteristic of red soils is that they degrade easily. Although from Table 3 it appears that chemical and biological forms of degradation are more important than erosion, it is nonetheless true that water erosion is usually the catalyst for overall degradation on tropical soils. Indeed, it would be invidious to attempt to separate the loss of nutrients, structure and organic matter from the erosion process itself. Where red soils are undergoing erosion, they will inevitably be undergoing other forms of degradation.

In reviewing world evidence for decline in productivity with erosion (Stocking, 1985a), yield-potential of soils was found to be mainly reduced by a change in intrinsic soil properties. The degree of this productivity decline is controlled by:

* change in soil and profile characteristics resulting from erosion; e.g. truncation of the profile, blockage of pore spaces, removal of organic carbon etc.

* climatic characteristics.
No single parameter consistently explains the loss of yield potential, but the most important are:

- the water available to the plant (reduced soil depth, and reduced water holding capacity of the remaining soil);

- nutrient status of the soil (nutrient depletion, loss of organic matter, change in pH etc);

- structural stability of the soil, or its bulk density (which influences root development).

The red soils of Africa suffer on all counts. In the savanna zone the reduced available water capacity is undoubtedly the limiting factor; in the rainforest zone, nutrient status will be more important. Problems of structural stability will apply to Acrisols and Luvisols in any climatic regime.

What makes productivity decline especially prevalent in red soils is that these soils have abrupt changes in physical and/or chemical characteristics between topsoil and subsoil. For example, Luvisols in Nigeria have a concentration of nutrients and organic matter in the top few centimetres (Lal, 1984), such that any erosion of topsoil or increased leaching causes a dramatic decline in productivity. Acrisols and Ferralsols which have already-marginal and limiting levels of organic matter would be even more prone to plummeting yields when they are degraded.

Evidence for crop yield losses on Luvisols with degradation have been summarised by Stocking & Peake (1986). Irrefutably, tropical Luvisols -- the 'mid-point' soil of the tropics -- show dramatic yield declines, with the same trend as that demonstrated on US experiments (Fig. 1) but of an order of magnitude greater.
FIG. 1. - MAIZE YIELD (INSET: ORGANIC MATTER) AS A FUNCTION OF CUMULATIVE EROSION ON A TEMPERATE LUVISOL, 12 PERCENT SLOPE AT ZANESVILLE, OHIO (DATA FROM BORST et al, 1945).

Indonesian experiments on an Acrisol (Ultisol) and a Ferralsol (Oxisol) (Fig. 2), while speculative in their interpretation because of the experimental design, seem to indicate that each 10 mm of soil loss reduces maize yield by about 2 tonnes/ha, which is some twenty times greater loss than corresponding results in the United States. These are only
tentative conclusions, but they do illustrate the potential magnitude of the impact of degradation on tropical red soils.

FIG. 2. - YIELD DIFFERENCES BETWEEN MULCHED AND UNMULCHED TILLAGE TREATMENTS AGAINST CUMULATIVE EROSION, INDONESIA (AFTER SUWARDJO & ABUJAMIN, 1985).
This and other evidence on productivity losses highlights that tropical soils in general are extremely sensitive not only to degradation but also to the impact of that degradation. This means that only a relatively modest amount of degradation -- erosion, loss of organic matter etc. -- causes a substantial decline in productive potential of the soil. Unfortunately, there is very little direct evidence in terms of declining yields in relation to degradation from East and southern Africa. Where yields have been monitored, their potential decline has been masked by fertilizer, other inputs and the lack of any suitable control plots. However, the indirect evidence, published and anecdotal, is substantial. For example, Ferralsols at Yangambi, Zaire, produced only about 20% of the yield of rice and groundnuts in their second year, while cassava was relatively little affected (Sanchez, 1976). In Tanzania, Moberg (1972) provides a detailed account of the consequences of erosion on the characteristics of a Ferralsol, all of which potentially affect productivity. Among the most serious are:

- pH lowered to extent that Al-toxicity possible;
- C and N halved in top 15 cm;
- Ca and Mg considerably lowered;
- Zn and P depleted to deficiency levels.

Moberg also notes that fertility is affected to at least 150 cm probably because of the reduction in root activity which allows less recycling of nutrients. Important here is that soil erosion demonstrably affects productivity, and loss in productivity itself further reduces productivity.

**Nutrient Losses in Zimbabwe**

At Henderson Research Station in Zimbabwe during the 1950s and 1960s an important series of experiments was conducted on soil loss and runoff. The results of this work have been widely published and now form the basis for the Soil Loss
Estimation Model for Southern Africa. A little-known sub-programme of this work was the monitoring of nutrient losses on eroded soils from the same experimental plots for five years storm-by-storm. For various reasons this nutrient research was never analysed and its significance never appreciated until 1984. FAO are now supporting a project on the analysis of the data which includes a significant red soil type of southern Africa. Details of the data base and the history behind the project are in Stocking (1985b). To date the analysis is only partially completed but it already shows the scale and extent of nutrient losses as soils erode. The following is a very abbreviated account of some preliminary results; the full report will be available later in 1986.

TABLE 4. - REGRESSION EQUATIONS OF NUTRIENT LOSSES AGAINST SOIL LOSS FOR ANNUAL DATA FROM 16 EXPERIMENTAL PLOTS OVER 5 YEARS ON SERIES I SOILS (CHROMIC LUVISOLS), HENDERSON RESEARCH STATION, ZIMBABWE.

<table>
<thead>
<tr>
<th>REGRESSION EQUATION</th>
<th>$R^2$</th>
<th>DEGREES OF FREEDOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log_e N = -6.01 + 0.965 \log_e SL$</td>
<td>0.983</td>
<td>79</td>
</tr>
<tr>
<td>$\log_e OC = -4.18 + 1.00 \log_e SL$</td>
<td>0.980</td>
<td>79</td>
</tr>
<tr>
<td>$\log_e P = -8.49 + 0.943 \log_e SL$</td>
<td>0.943</td>
<td>79</td>
</tr>
</tbody>
</table>

$N = $ Nitrogen; $OC = $ organic carbon; $P = $ phosphorus;
$SL = $ soil loss; all figures in kg/ha.

The four soil types in the experiments are all Luvisols but only two could be considered as red soils (Chromic Luvisols or Zimbabwe Fersiallitic 5SE and 5E soils), of which one, denoted Series I in the experiments, is reported here. Nitrogen, organic carbon and phosphorus losses were monitored and these have correlation coefficients, $r$, varying from 0.971 to 0.992
against soil loss on an annual basis: i.e. all very significantly related to erosion (Table 4). In terms of expected nutrient losses, Table 5 shows the losses of nitrogen and phosphorus at four erosion levels typical of various land uses and conditions in Zimbabwe. These losses are extended in Table 5 to the economic cost of replacing those lost nutrients by the application of fertilizer. Erosion of 15 tonnes/ha is quite usual on arable lands under commercial crops. Even at this level the equivalent of some Z$27 of the two major applied nutrients is being lost annually according to these experimental results on a red soil. In the mission report on the project (Stocking, 1985b) it is argued that actual nutrient losses are probably significantly greater than those measured on the experimental plots. Therefore, the estimates in Table 5 should be seen as a minimum. Consequently soil erosion and degradation can be considered to be having not only a very severe physical detriment to the soil but also an economic impact which is potentially ruinous to the countries concerned. This is the hidden face of degradation; a face that can, up to a point, be masked by nutrient inputs in the form of fertilizer but which inevitably will be revealed when structure collapses and organic matter levels reach critically low proportions. This happens quickly on Acrisols and Ferralsols, and slowly but inexorably on Luvisols and Nitosols.

**TABLE 5. - EQUIVALENT FERTILIZER COST (AT 1985 PRICES) OF THE LOSS IN NUTRIENTS ON SERIES I SOILS (CHROMIC LUVISOLS) AT FOUR LEVELS OF EROSION.**

<table>
<thead>
<tr>
<th>SOIL EROSION</th>
<th>LOSS OF N</th>
<th>NITROGEN EQUIVALENT IN AMMON. NITRATE</th>
<th>APPROX. COST</th>
<th>LOSS OF P</th>
<th>PHOSPHORUS EQUIVALENT IN SINGLE SUPERPHOS.</th>
<th>APPROX. COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>t/ha</td>
<td>kg/ha</td>
<td>kg/ha</td>
<td>Z$/ha</td>
<td>kg/ha</td>
<td>kg/ha</td>
<td>Z$/ha</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>26</td>
<td>8.00</td>
<td>0.6</td>
<td>8</td>
<td>1.50</td>
</tr>
<tr>
<td>15</td>
<td>26</td>
<td>75</td>
<td>23.00</td>
<td>1.8</td>
<td>22</td>
<td>4.40</td>
</tr>
<tr>
<td>50</td>
<td>84</td>
<td>243</td>
<td>75.00</td>
<td>5.5</td>
<td>69</td>
<td>14.00</td>
</tr>
<tr>
<td>75</td>
<td>124</td>
<td>358</td>
<td>111.00</td>
<td>8.1</td>
<td>100</td>
<td>20.00</td>
</tr>
</tbody>
</table>

*Note: 1 Z$ = approx. 0.60 US$*
Thus, the evidence of the susceptibility of red soils to productivity decline is such as to raise serious questions as to the productive life of these soils, their continued use with current systems of farming, and the development of alternative sustainable forms of land use.

**MANAGEMENT OPTIONS FOR RED SOILS**

Discussion is confined to the poorer red soils, the Ferralsols and the Acrisols; those that present the most intractable management problems because of initially low fertility and readiness to degrade structurally and chemically. Essentially, there are three broad management options:

(i) Maintain traditional land uses at an intensity no greater than that with which the environment can cope without undue harm.

(ii) Introduce modifications and improvements to traditional land use.

(iii) High technology solutions involving completely new systems of land use and dependency on inputs.

Only the first two are considered; the third is problematic, not only technically -- i.e. will it really work? -- but also socio-economically.

**Traditional Land Use**

Shifting cultivation and bush fallowing are the natural responses to land use on the poorer red soils. Examples of it occur throughout the forest zone of Africa where, on air photographs, a complicated patchwork of circles and blocks at different stages of regeneration are clear evidence of its occurrence. There is no doubt that, from the classical work of Nye & Greenland (1960) on shifting cultivation, an ecological balance of nutrients and organic matter can be achieved and
the system can be quite efficient in the forest zone. According to Young (1979) a ratio of between three and six years fallow to one year of cultivation is sufficient in the rainforest environment to maintain organic matter at 75% of its natural level. The savannas are less efficient regenerators, needing between ten and twenty years recovery to one year cultivation (Note: these figures should be taken as the requirement on a soil already partially degraded, as indeed the majority are).

When population densities increase and land becomes scarcer the well-known vicious cycle of degraded bush fallow commences. Some rural communities change their cropping patterns in response so that, instead of sorghum, a less demanding crop such as millet or cassava is planted. But this is only a short term palliative because these crops are themselves less nutritious; their one advantage is that they will produce something on poor soils every year, thus sustaining a poor population at lower and lower levels of nutrition and health.

These trends have led some to try to calculate the critical population density (Allan, 1965) or the population supporting capacity (FAO, 1982). According to FAO's calculations and its map of Africa for Potential Population Supporting Capacity at a low level of inputs (i.e. traditional farming) most of East Africa cannot support more than 0.5 persons/ha while the better-watered parts of Zambia, Zimbabwe and Malawi are more favoured, taking up to 1 person/ha. Some parts such as the Rufiji Basin in Tanzania and the lower reaches of the Zambezi could potentially support up to 2 persons/ha. Note that at this low level of inputs large parts of Kenya, Tanzania and Malawi have a present population well in excess of the calculated supporting capacity.

Improved Management Systems

The key to improved management systems on red soils lies in the maintenance and retention of organic matter. Loss of organic matter is central to every form of soil degradation
prevalent on red soils: compaction, breakdown of soil structure, low water capacity, low nutrient retention, retarded infiltration and soil erosion. All these in turn lead to a decline in soil productivity and greater susceptibility to both drought and waterlogging (Flaig, Nagar, Sochtig and Tietjen, 1977).

Improved management systems must, therefore, address the question of soil organic matter and must be able to demonstrate consistently adequate levels. What are the possibilities?

**Crops rotations** may affect the humus content of the soil through quantity and quality of residues, canopy cover and protection against erosion, and biological nutrient fixation. At best it can only be a partial answer to the management of poorer red soils. Many traditional systems already employ some rotations.

**Planted fallows** can be more efficient than natural regrowth in improving the soil and this is a well-researched area especially in East Africa. Grass/legume mixes such as *Cynodon* and *Stylosanthes* are especially valuable. Experiments at IITA in Nigeria report a 3% increase in organic carbon after three years of weed fallow and a 31% increase when planted with *Psophocarpus palustris*.

**Green manures** depend for their effectiveness on their nitrogen and lignin content and the amount of residue incorporated. Legumes are more immediately effective but grasses and other weeds with high C:N may have a longer term beneficial impact. The major disadvantage with green manures and planted fallows is that they give little economic return in the season in which they are planted.

**Farmyard manure** is renowned for its effectiveness. Under tropical conditions it is usually the case that a green crop fed to cattle and then added to the soil as manure
is more effective and economic than ploughing under the original green crop. Nevertheless, large quantities of FYM are required at regular intervals and this can be a costly and laborious exercise for what may be only marginal yield increases in the first year.

**Minimum tillage and no till** are especially effective on red soils as soil conservation measures. In comparison with conventional tillage, organic matter levels and permeability are considerably higher. Unfortunately such systems of tillage require costly machinery and inputs of herbicides, making them almost certainly out of the reach of small farmers.

**Contour tillage and ridging** are practices that require only small modifications to conventional tillage and produce very considerable benefits in reduced soils loss and increased surface water retention. A system of ridging on the contour has been developed in Tanzania by ox-cultivators using a standard plough, which has the advantage of only requiring half the surface of the field to be ploughed while the annual weeds are buried as a green manure under the ridges.

**Tied ridging** occurs sporadically throughout East Africa and is clearly the most effective form of mechanical soil conservation for small farmers. On well-structured red soils, its major immediate benefit is in additional water storage but its longer term benefit lies in its opportunities for practising multiple cropping and interplanting. The principal disadvantage is the labour required but this may be partly solved by the development in Zimbabwe of a simple but effective ox-drawn tied ridger.
Fire control and improved shifting cultivation. The major experience here has been at Yangambi in Zaire on Orthic Ferralsols where Jurion & Henry (1969) have attempted to retain the most useful features of shifting cultivation while improving productivity mainly by fire control. It is problematic whether their improved systems have general applicability and are practical for shifting cultivators.

Inorganic fertilizers. Fertilizers are temptingly seen as the panacea for nutrient losses. On red soils, nutrients applied 'out of the bag' to what is an inherently infertile soil must inevitably lead to severe problems of acidification, nutrient imbalance and trace element deficiency. Economically it is questionable whether applying high-value fertilizers for only marginal increases in yield is worthwhile, without other measures to increase organic matter levels.

Alley cropping and agroforestry practices are becoming trendy, not least because of the publicity by the International Council for Research in Agroforestry, based in Nairobi. On research stations, alley cropping, the mixing of bands of woody species and of crops, has considerable benefit on soil properties and in overall yield increases. The major problem for all agroforestry systems is the relatively high level of management expertise that is required to achieve on the farm the potential benefits that have been demonstrated on experimental trials.

Where To Now?

The previous section has argued on the central importance of organic matter levels in red soils and has briefly listed some possible options. What is obvious is that no single measure is satisfactory to counter the inevitable degradation problems accompanied by the present-day usage of these soils. A balanced approach is desirable which may include crop residue mulching,
no-till, crop-animal-tree mixed land use, planted fallows, rotations and modest levels of inorganic fertilizers.

'Do more research' is an obvious retort to the question, 'What do we do now?' Basic research into subjects such as organic matter cycling is probably a luxury today. Problems of application are the more pressing. In this vein, several areas of research seem to warrant immediate attention:

* the lifespan of a soil. How long can the various management options for red soils be sustained before irreparable damage occurs? If the lifespan were known, then these could be included in economic projections, probably overturning many cherished beliefs in commercial cultivation, mechanisation and inorganic fertilizers.

* relationships between degradation and yield. There is almost no information in East and southern Africa to indicate how the productive potential of soils declines. Again, if such information were known, this could be accounted for in standard economic analysis.

* farming systems research and on-farm experiments. Throughout the region the classical pattern of inappropriate research station trials prevails. Proof that a technique works on a research station (or even on a supervised trial on a farm) is a very long way from proof that it will work under real farming conditions. Management options need to be tested for their integration with current farming systems, their acceptibility within patterns of labour availability and resource allocation, and the risks that small farmers undertake in accepting any new technique or practice. This can only be done on the farm.
DEVELOPMENT IMPLICATIONS FOR RED SOILS IN AFRICA

Land is under great pressure in both East and southern Africa and it is clear that the red soils will have to accommodate a large part of that pressure. Can they cope? And what can we conclude on the individual soils?

The Nitosols are already heavily utilized for a wide range of food and plantation crops. Their basic fertility and structure are such as to allow intensive agriculture especially in southern Africa. Provided that adequate inputs of fertilizer are supplied, soil conservation measures such as contour bunding, strip cropping and rotations are practised, and organic matter levels are maintained, there is no reason why these soils should not continue to rank amongst the most productive of the sub-continent. Most of these soils have been under colonial and European agriculture, on relatively well-managed, medium-technology farms. A disturbing trend which is becoming evident in Zimbabwe is the retention of land holdings on these soils under intensive commercial cultivation, often with supplementary irrigation, but inadequate inputs, poor management and inappropriate technology. Structural breakdown and excessive erosion are already obvious. It is clear that the productive base of a high proportion of commercial crops on Nitosols is being rapidly degraded.

Likewise, Luvisols support a wide range of crops (where water is not limiting) and productive grassland. It is in East Africa where the greatest pressure on Ferric Luvisols is to be found. In the drier parts of the Kenyan and northern Tanzanian plains, pastoralism has predominated especially amongst the Masai. Pressure on this rangeland has intensified within the last five years to such a degree that large areas of former grassland are being opened up on short term lease to commercial cultivators. Parts of the Masai steppe of Mara Region in Tanzania and Narok in Kenya are very recently under the plough with no conservation and provision for the traditional pastoralism. The herds of
cattle, sheep and goats are now transferring to the more marginal soils and the adjacent game reserves such as Serengeti and Ngorongoro. The potential conflict between conservation and agricultural development is intense. Hitherto well-preserved and reasonably fertile Luvisols will suffer dramatic decline in productivity with erosion and will be 'mined' of their transitory nutrient reserve which, in any case, is concentrated in only the top few centimeters of the profile. The prognosis for these soils (and adjacent marginal areas) is poor unless short-term, commercial exploitation is checked and more sustainable farming systems and controls are introduced.

Much has been written about the evils of shifting cultivation and the degradation of Ferralsols which support such systems through northern Zambia, into Tanzania, Uganda and Zaire. There are no easy answers to the development of agriculture on Ferralsols (see van Wambeke, 1974; FAO, 1974; 1984). In the high rainfall parts of Zimbabwe, Ferralsols under good management produce perennial crops satisfactorily and some vegetables. But elsewhere, where shifting cultivation predominates, fallows must be incorporated into the agricultural cycle whether or not land use is traditional or modernized. Not all fallows are equally efficient in restoring productivity and it depends whether the Ferralsol is in the rainforest, savanna region or cool tropical zone. Nevertheless, fallows can achieve:

- replenishment of surface organic matter, improving nutrient reserves and cation exchange;

- development of root system to draw up Ca, Mg & K from lower layers into the soil-vegetation nutrient cycle;

- improvement of soil structure by roots and organic matter;

- increase in available moisture.
(see Greenland & Nye, 1959; van Wambcke, 1974). The fact that fallow periods are increasingly being squeezed as population pressure increases and as other more fertile soils are being taken over, thus transferring marginal subsistence cultivation to Ferralsols, inevitably means that the chemical and physical state of these soils will collapse in a short time period. It is difficult to assess the precise developmental implications because Ferralsols are normally only used for poor subsistence cultivation with minimum capitalization and external inputs, relying on family labour and virtually no institutional support. This inevitably means that Ferralsols will continue to:

* degrade rapidly in the cropping cycle;

* weeds, climate, diseases and pests will be the major constraints to food production, making development an unattractive economic proposition;

* new technologies for sustainable management and productivity will be beyond the means and capacity of existing cultivators;

* shifting cultivation will be stable only at low land use intensity, thereby militating against infrastructural investments for such a dispersed agricultural system (ter Kuile, 1984).

Technically, Ferralsols present interesting but by no means insuperable development challenges. The limiting constraint to agricultural development on Ferralsols is inevitably the peoples and farming systems they currently support.

Acrisols not only have the deficiencies of Ferralsols but are also acid. They support only very extensive shifting cultivation such as the chitemene system of Zambia and
crops such as finger millet (*Eleusine coracana*). The account by Vieweg & Wilms (1974) is a salutory warning in respect of continuous cultivation of Acrisols: despite fertilizer applications on research plots in southern Tanzania, yields declined to zero in six years. Of all the red soils this is perhaps the one with the greatest contrast between low input agriculture and high technology. For all practical purposes, however, the high cost and the risk element of intensive inputs makes the possibility of obtaining satisfactory and consistent yields from Acrisols extremely unlikely. Development efforts would be far more usefully applied on other soils for the time being.

**REFERENCES**


THE ROLE OF BIOLOGICAL PROCESSES IN TROPICAL SOIL FERTILITY: POTENTIAL FOR MANAGEMENT

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INTRODUCTION

The demand for increased food productivity in the tropics puts man's ingenuity to the test. Great advances have been made, through the "Green Revolution" and other programmes, to apply scientific principles to farming in these areas. This spread of high-input farming systems is clearly one direct path to solving the problem. It is also apparent that there are economic, ecological and social limits to the extent to which such high technology systems can be implemented on a permanent basis. Nonetheless it is also clear that the various types of traditional agriculture (e.g. shifting cultivation systems) cannot be indefinitely sustained as population pressures force the shortening of the fallow cycle and eventually impose the practice of continuous cultivation on low fertility soils unable to sustain it.

Solutions must be found to raise or sustain fertility which do not lean entirely on the same economic and social base as the high-subsidy, high technology, farming characteristics of the temperate zones. One obvious, but hitherto neglected, approach is to utilise the biological mechanisms which regulate the natural fertility of soil. The productivity of natural eco-systems is sustained by the tight integration of the vegetative system with the biological system of soil. The capacity of the latter to deliver nutrients to the plant and to maintain a favourable physical condition in soil is furthermore related to a complex interaction between a rich community of organisms and a diverse input of organic materials. These
processess may be subject to considerable disruption by the conventional practices of intensive agriculture. Enhancement of natural fertility may be, however, achieved by some of the management practices currently receiving favour in both tropical and temperate agriculture such as minimum tillage and agroforestry.

**Biological regulation of nutrient cycling in soils**

The soil is the habitat for a very diverse range of living organisms including fungi, bacteria and invertebrate animals. The food resource which supports these organisms is the dead plant material (plant litter) shed by the vegetation. The soil organisms utilise this food source by the process of decomposition. Many of the mineral elements on which plants depend for growth can only be taken up when they are in inorganic form (e.g. nitrogen as ammonium or nitrate).

These forms of the elements may be in short supply in the soil but are abundant in organic form in the plant litter. It is during the decomposition of the plant litter by soil organisms that the organic-N is converted to inorganic-N thus replenishing the supply in the soil. The same argument may apply to other elements such as phosphorus and sulphur.

A second effect of decomposition is that of humus formation. An increase in the humus content of soil improves its physical quality and its nutritional status. In coarse-textured soils, or those in which the clays have a low cation exchange capacity, nutrient retention and availability to plants is strongly dependent on the maintenance of organic colloids. Conditions which favour the formation of soil organic matter, particularly the stable fractions, are thus an advantage. Seasonal hydrogen ion equilibria are also affected by both decomposition processes and plant nutrient uptake mechanisms. Many biological processes affect the ionic balance of soil in the same way. This may result, under different circumstances, in changes in nutrient availability, including the creation of limiting conditions or the accumulation of toxic levels, for specific ions.
The rate at which plant litter is decomposed is closely regulated by the climate and other environmental factors. Rates of decomposition are highest under warm wet conditions and are totally inhibited when litter is in a dessicated state. In strongly seasonal environments a major regulator of decomposer activity is therefore the rainfall pattern (Anderson and Swift 1983).

Most frequently the dry season is the time when plants in natural ecosystems such as forest shed their leaves. The dry hot conditions, however, prevent any decomposition and a large accumulation of dead leaf litter builds up on the forest floor. At the onset of the rains, however, decomposition is initiated.

Weight loss in the first period may be abiotic in origin, due to the leaching effect of tropical rainfall. In particular leaching probably accounts for the very rapid initial decline in the potassium content of the leaves. This element is known to be highly mobile and is largely accumulated in the vacuolar sap in the leaves - a site from which it may be readily lost. The remainder of the action is biological and divided between that of animals and micro-organisms.

It is the latter, a complex community of fungi and bacteria, that are responsible for the major chemical transformations in decomposition: dissipating the plant polysaccharides as carbon dioxide and, most importantly, converting the proteins to ammonium. They are also responsible for the mineralisation of other elements - for instance converting organic-phosphorus to inorganic phosphate. The release of these and other mineral ions (calcium and magnesium) from both the plant tissue and from the microbial tissues in which they initially become accumulated, is, however, stimulated by the action of the invertebrate animals of the soil and litter.
The invertebrate community is a very diverse one with practically every major group of terrestrial invertebrates represented, ranging in size from protozoa to earthworms. What is of particular interest however is not so much their taxonomic diversity as the variety of feeding activities they display. Some, such as certain termites, millipedes and earthworms, feed directly on plant litter. Others, including some protozoa and nematodes feed on bacteria. Many groups, particularly some taxa of collembombola (spring-tails) and mites feed on fungi. Representatives of nearly all these groups also feed on particulate organic matter. This is the detritus formed from initial decomposer action - partially chewed leaves, faecal pellets and proto-humus (Lavelle, 1983, 1984).

Animal activity is usually delayed until some microbial decomposition has taken place. The initial effect of the animal-feeding is thus to bring about further decomposition. The secondary effects of animal action are, however, probably more significant to the overall process. Firstly, amongst these is the breaking open of plant and microbial cells which results in the release of the mineral elements mentioned earlier (Anderson and Ineson, 1983). Secondly, the animal activity stimulates secondary waves of microbial action by breaking up the litter into smaller particles, increasing the surface area for microbial colonisation and exposing new surfaces for enzymatic action.

The pattern described above is one commonly observed in soft leaf litters. Other types of litter or crop residues may, however, show a different pattern. The decomposition rate of different litters is often markedly divergent even under identical environmental conditions and when exposed to the same decomposer microflora.

These differences in 'decomposability' are attributable to differences in the intrinsic characteristics of the materials. High 'quality' litters, those which are rapidly decomposed,
have high N and P contents, high concentrations of readily metabolised sugars and low lignin contents. Low quality materials are characterised by the inverse state of these variables. They also often carry biologically active contents of allelopathic compounds (i.e. molecules which are inhibitors of biological activity).

The accumulation of surface and soil organic matter in tropical ecosystems is a balance of the rates of inputs and decomposition (Anderson and Swift, 1983). The potentially high rate of decomposition associated with high temperature and rainfall is modified locally by resource quality as well as by seasonal drought, moisture holding characteristics of the soils and soil chemistry. The quality of input also varies. Hence surface and soil organic accumulation varies considerably within the tropics (Sanchez, Gichura and Katz, 1982).

The time over which mineral nutrients are released from a resource is largely by its rate of decomposition. The efficiency of transfer of nutrients from the plant litter of the soil to the plants is at a maximum when the timing of nutrient release is synchronized with that of plant uptake. Variation of any of the factors that affect decomposition rate (e.g. the spectrum of quality in mixed litter or climatic change) may cause an uncoupling of decomposition and plant nutrient uptake.

Soil organic matter

Soil organic matter is an important source of nutrients in addition to those released by the decomposition of plant litter or crop residues. Soil organic matter is not one well-characterized soil component but can be regarded as a series of more or less well-defined fractions with different qualities. These fractions form a continuum which can be subdivided into three main categories.
The first, which is the most easily decomposable, has a half-life of less than two years. It consists of dead microbial and animal cells and their metabolites (e.g. mucus, exudates). The second fraction consists of stabilized organic matter and has a half-life in the order of ten years. It is synthesized from fresh organic matter by soil organisms and extracellular chemical condensation reactions. Part of it becomes complexed with clay minerals, which make it less susceptible to decomposition and mineralization.

The third fraction is formed in a similar manner but is very resistant to microbial attack with a half-life of typically more than a hundred years. Although the rate of nutrient release may be very slow, this organic matter component can be quantitatively important, as a nutrient reservoir.

These organic fractions release nutrients at different rates. Thus the relative amount of the fractions in soil is another determinant of nutrient availability.

MODIFICATION OF SOIL PHYSICAL PROPERTIES BY BIOLOGICAL ACTIVITY

Soil fertility is the ability of the soil to satisfy plant demands for nutrients, water and an adequate aerated physical matrix for the growth of roots. It is often thought that biological aspects of soil fertility are solely concerned with nutrient supply but this is not so. The activities of a wide range of organisms affect physical properties of the soil they inhabit.

For instance, although the original size and composition of soil particles is determined by parent material, the degree of aggregation and the spatial distribution (both vertical and horizontal) of different size fractions is strongly influenced by soil organisms (such as earthworms and termites). In particular the amount, type and distribution of the clay fraction of the soil may be particularly influenced by the transport activities
of the termites. This is of course important in determining nutrient availability through exchange phenomena. The proportion of different clay minerals can also be modified by the activity of specific microbial groups, and the adsorption characteristics can be masked by organic complexing as a result of biological activity. Fungi may also play an important role in binding together soil particles with their hyphae. Changes in the aggregation and size distribution of soil particles affect water content and movement, pore space, aeration and hence the retention and supply of nutrients, water and oxygen to the plants as well as affecting the activities of the soil biota.

Many biological effects are mediated through their effect on the water regime of soil. Water is essential for soil organisms, for plant growth, and as a medium for nutrient transport. In the humid tropics it is largely the movement of nutrients which is of concern, apart from soils where water-logging is a problem. In the drier tropics, available soil water is generally the major determinant of ecosystem structure and function. For any particular rainfall pattern the soil water regime is determined by the infiltration rate, the water holding capacity of the soil, soil water conductance, and soil depth.

The distribution and rate of decomposition of soil organic matter is under the primary control of the soil biota and is critical in the recycling of nutrients. Thus the effects of soil biota on water dynamics operate mainly through the increase in water holding capacity associated with soil organic matter accumulation. This is of particular importance in sandy soils in the sub-humid tropics. The main direct biotic effect on the water dynamics is the uptake of water by plant roots. Uptake of water by roots in non-saturated soil is determined by the amount and distribution of roots and their ability to absorb water against the retention characteristics of the soil. Mycorrhizal hyphae extend root contact with soil and may increase
water uptake. In very dry soil, roots may exude water into the soil, which facilitates nutrient uptake. The greater the uptake the less the risk of leaching, or in soil with impeded drainage the less the likelihood of water-logging. Although most natural ecosystems show very little loss of nutrients through leaching, disturbance of the plant cover can lead to increased losses, particularly of nitrate, because this ion is not retained by the ion exchange complex in most soils. In agro-ecosystems the plant cover may be intermittent, leading to increased risk of this type of loss.

**THE EFFECTS OF CULTIVATION ON BIOLOGICAL PROCESSES**

The brief description given above reveals a highly integrated system of regulation of nutrient flow within the plant-litter-soil system of natural ecosystems. It has been postulated that nutrient cycling is stabilised in part because of the diversity of decomposition patterns. The combination of slow and fast release rates and variation in the timing of nutrient availability from different components of the litter and soil organic matter ensure availability to the plant at all times of the growing season. The tight coupling in space and time of nutrient demand and availability is emphasised as an essential feature of the sustained productivity of natural ecosystems. Conversion of natural ecosystems such as forests to agricultural land may disrupt this system by altering the regulatory controls on the processes of decomposition.

Firstly, there is a dramatic change in the environment within which decomposition of land for cultivation modifies both the macro-climate and micro-climate of the soil and brings about environmental changes which affect the activities of decomposer organisms. For instance the removal of vegetational cover results in a greatly increased daily amplitude in the soil temperature. Aeration is increased, aggregate size is reduced and pore volume is increased (although the latter may be offset by a
subsequent increase in compaction). As a result the drainage and aeration characteristics of the soil are altered and the chemistry changed by accelerated oxidative breakdown of the humus. Even more significantly the practice of cultivation may alter both the site and physical state of litter decomposition. In particular, ploughing reduces the particle size of litter and buries it within the soil. This process enhances decomposition and results in accelerated nutrient release. The burning of litter is another practice that profoundly affects the activity of soil organisms both by removing potential food resources and by changing the pH and other factors in the soil environment.

A major consequence of these changes is that the abundance and diversity of composition of the decomposer community of the soil is markedly lowered. The major effects are on the soil animals, the micro-organisms seeming to be far more resilient. One result of this may be that decomposition is shifted to a more microbially-dominated system. What the implications of this shift are for soil fertility, is unclear. They are probably not severe as far as the rate of mineralisation is concerned; the effect on soil humus formation is, however, totally unknown and likely to be quite significant.

Perhaps the most profound effects on decomposition processes are, however, those due to changes in the nature of the litter input itself. In this respect not only the amount of litter but its composition, and the timing of its incorporation are affected by agricultural practice. The most obvious difference between the cultivated and forest system is the decreased amount of plant litter input in the former. The above-ground litter production in a Nigerian forest over the one year period November 1973 to November 1974 was estimated as 855g m⁻² (Swift, Russell-Smith and Perfect, 1981). This input to the decomposers was composed of leaves, twigs, small branches, palm fronds and a variety of hard and soft fruits. Large branches, roots, root exudates and above-ground leachates
were not investigated but were important additional components. In contrast the measured input from a neighbouring field of cowpea, which included the entire vegetative growth (leaves, stems and roots) which was ploughed back into the soils after harvest amounted to only 197g m\(^{-2}\). These quantitative differences have an obvious significance with regard to the nutrient reservoir of plant litter at any one time (Table 1) and the amount of carbon and energy to fuel decomposition. Cultivation not only stimulates the rate of decomposition of soil organic matter but also diminishes the extent to which it can be replaced by the activity of decomposers.

The cowpea litter is clearly different in character to that of the forest; in particular it lacks the hard, woody materials which decompose more slowly. This may have two important effects. Firstly, it is generally thought that this lignified component is the main source of the molecules from which the soil humus is synthesised by microbial enzymes during decomposition. Secondly, it means that the overall rate of mineral

**TABLE 1.** - THE ANNUAL INPUT OF MINERAL NUTRIENT ELEMENTS TO THE SOIL FROM PLANT LITTER IN TWO DIFFERENT BUT NEIGHBOURING ECOSYSTEMS IN NIGERIA.

(N.B. THE COWPEA INPUT IS TOTAL LITTER, THE FOREST IS ABOVE GROUND LITTER ONLY).

<p>| Elemental input (g m(^{-2}) y(^{-1})) |
|---|---|---|---|---|---|</p>
<table>
<thead>
<tr>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
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</thead>
<tbody>
<tr>
<td>Forest</td>
<td>9,2</td>
<td>0,60</td>
<td>3,0</td>
<td>14,0</td>
</tr>
<tr>
<td>Cowpea</td>
<td>4,1</td>
<td>0,47</td>
<td>3,1</td>
<td>2,1</td>
</tr>
</tbody>
</table>
element release is accelerated and reduced to a short time period following the onset of the rains. In the forest this is characteristic of leaf litter - as illustrated earlier. But the woody material decomposes much more slowly and provides a slow trickle of nutrients in the later weeks of the rainy season. All the cowpea litter has the characteristics of the forest leaves - consequently all the nutrient eggs are in one basket. The timing of litter input to the decomposers in agricultural systems is also commonly dictated by management practices particularly the cutting and ploughing-in of standing residues.

The latter practice also changes the context in which decomposition takes place. Like the other changes mentioned earlier it can result in an accelerated rate of decomposition because of the more stable environment within the soil as compared with the surface and the readier accessibility of the litter to the soil organisms.

Yet further changes may be brought about in the decomposer environment by the introduction of fertilizer chemicals and pesticides. The application of fertilizers may contribute to increased rates of soil organic matter decomposition, though this effect has not been clearly distinguished from those associated with tillage practices. Since humus is the main cation exchange site in acid soils, an understanding of this process is critical. Crop plants, particularly fertilized crops, have high resource quality characteristics and generally decompose faster than natural vegetation under comparable conditions. Grain crops differ from fodder or root and tuber crops in the distribution of resource qualities in different parts of the plants. Hence the consequences of harvest for the nutrient balance of the system are different for different crops.

Pesticides have a direct effect on the soil biota and indirectly modify rates of decomposition in a manner analogous to the antiherbivore defence compounds of natural vegetation. The impacts on non-target organisms and associated processes include
reduction of soil fauna, litter comminution and changes in soil physical structure, as well as the poorly quantified effect on soil microorganisms. For example, there is evidence that persistent pesticides, such as DDT, can have long-term effects on soil fertility (Perfect et al., 1979).

The overall effects on decomposition of the change from a forest to a cultivated ecosystem can be summarised as a lowering of the nutrient input and an acceleration of the rate of mineralisation, coupled with a narrowing of the period in which mineralisation takes place. These latter two effects may have a major consequence for the availability of nutrients to the crop.

The initiation of decomposition will commonly occur before seed planting and it is possible to predict that maximum nutrient release may occur before the crop is sufficiently established to benefit from the availability of nutrients. Under conditions of heavy rainfall and leaching this could result in the loss from the system of a significant component of the nutrient return. This lack of integration between the release of nutrients by decomposition and their uptake by plant roots contrasts strongly with the 'tight' cycling described earlier for the forest ecosystems.

**POTENTIAL FOR MANAGEMENT**

As the above account indicates, the introduction of cultivation inevitably modifies the biological processes which sustain natural soil fertility. What opportunity is there for manipulating soils in such a way as to restore or repair these natural systems and thence to economise on the requirement for fertiliser and other agricultural subsidies?

It should be emphasised initially that the depth of understanding of the biological processes that maintain the system is still very superficial. Whilst a substantial body of information is now available from natural ecosystems, soil biological processes are rarely investigated by agriculturalists. One of the reasons for this is the success of high-input farming, which
effectively by-passes the soil biology through its use of fertilizers, pesticides and mechanized preparation of soil. This success leaves little apparent reason why soil processes should be taken seriously but it is noticeable that the adoption of minimum tillage systems in temperate regions is refocusing attention on soil ecology.

An attempt is now being made to stimulate the basic research needed in this area by the launching of an international programme of collaborative research. The programme, called 'Tropical Soil Biology and Fertility (TSBF)' is sponsored by the International Union of Biological Sciences (IUBS) as part of their 'Decade of the Tropics' (see Solbrig and Golley, 1983; Swift, 1984, 1985, Swift and Sanchez, 1984). The objective of the TSBF programme has been stated as follows:

"to develop a predictive understanding of the functioning of biological processes in tropical soils, and their role in contributing to sustainable soil fertility; and hence to provide a means for the maintenance and improvement of soil fertility by influencing these processes through management practices" (Swift, 1985).

In approaching this target the TSBF scientists have postulated four experimental principles which are derived from the understanding of the functioning of soil biological processes in the maintenance of soil fertility outlined briefly in previous paragraphs. From these principles specific hypotheses, testable by experiment can be derived. It is proposed that these hypotheses be tested by collaborating scientists in a network of research sites around the tropics.

The ultimate aim of the programme is an improvement in management practices to increase the efficiency of nutrient cycling and the sustainability of favourable physical conditions in tropical soils. The management practices envisaged are largely of a low-input technology kind - e.g. manipulation of organic inputs - but are important features of the programme design in its capacity to embrace a wide range of farming systems.
Higher input systems are not excluded, indeed the investigation of ways in which the efficiency of fertilizer use can be enhanced by means of biological manipulation, may turn out to be one of the most significant components of the research programme.

Nonetheless the most suitable systems may be those that, to some extent, mimic natural systems - such as those of agroforestry.

During a fallow period or with the introduction of a tree species there is an increase in the litter input, particularly of woody materials and roots. There is also increased diversity of plant species and phenologies. In consequence, the timing and quality of resource input becomes more variable. This leads to increased formation of soil organic matter (Greenland and Nye, 1959). It is also interesting to speculate that the composition and properties of soil organic matter formed under natural vegetation are modified by the diverse resource quality and different physico-chemical and biotic characteristics of this input.

When a permanent tree cover is established the depleted nutrient capital of the upper soil horizons is replenished through cycling of nutrients from deeper horizons. The diversity of resources leads to a wide range of decomposition rates which spread nutrient release over a longer period of time than during cultivation. Uptake is stabilized by the development of a more or less continuous root mat of plant species with different requirements, mycorrhizal relationships and phenological characteristics. The overall consequences of all these features is a re-integration of the vegetation and soil sub-systems leading to improved conservation of elements. The most critically limiting factor is the time taken for the recovery phase under natural follow. Managed fallows can dramatically reduce the length of cultivation cycle and provide an intermediate practice between shifting agriculture and continuous cultivation. For instance, fallow under "kudzu" (Pueria phaseoloides), a nitrogen fixing creeper, for 1-2 years has the same restorative effect as 25 years of forest
fallow (Swift and Sanchez, 1984). Mixed cropping such as alley-cultivation with leguminous trees, may provide another intermediate position with many of the benefits of fallow.

In the combination of farming systems better adapted to tropical soils, and an enhanced understanding of methods of sustaining and manipulating the natural resources of soil, may lie the best hope for management of tropical soils.

**ACKNOWLEDGEMENT**

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REFERENCES


HARD SETTING SOILS

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SUMMARY

It is suggested that hard setting soils are widespread in Africa. Their properties are described and a physical explanation is given for hard setting behaviour in terms of effective stress and water dispersible clay.
INTRODUCTION

In many parts of the world farmers recognise a particular form of soil behaviour in which the soil sets hard as it dries and is thereafter difficult or impossible to cultivate until the profile is rewetted. Amongst soils showing such behaviour are some tropical red soils. Various aspects of this behaviour have been discussed in detail by a number of workers but only in Australia is this form of behaviour specifically identified, mapped, and given the name "hard setting" (Northcote, Hubble, Isbell, Thompson and Bettany 1975). The most recent Australian definition is :

"Compact, hard, apparently apedal condition forms on drying. Surface not disturbed or indented by pressure of forefinger. Surface seal is not necessarily associated with hard setting." (McDonald et al., 1985).

Large areas in the Australian wheat belt have soils with duplex profiles in which the upper horizon is hard setting and it is clear that many African soils would also be classified as hard setting in terms of the above criteria (e.g. see Charreau & Nicou, 1971 and Jones & Wild, 1975 (West African savanna); Sinclair, 1985 (Botswana); Nyamapfene, 1982 (Zimbabwe)).

In this paper we wish to propose a physical explanation for hard setting and consider those features which may predispose a soil to this type of behaviour. It is suggested that it may be useful to specifically identify those soils with a hard setting surface horizon since there is likely to be a common set of management strategies for avoiding, minimising or ameliorating the physical problems posed by these soils.

WHAT FEATURES DISTINGUISH A HARD SETTING SOIL?

Particle size distribution

Because hard setting soils are apparently structureless (apedal) it is clear that they contain too little clay to shrink
and crack on drying (Charreau & Nicou, 1971) but, since they set hard on drying they must contain sufficient clay and silt to bridge between sand grains in order to hold them together in a rigid matrix. Mullins & Panayiotopoulos (1984) have demonstrated that artificial mixtures of sand with as little as 2% kaolinite can exhibit hard setting behaviour. At the other extreme, because the porosity of sand alone is unlikely to exceed 50% (Panayiotopoulos & Mullins, 1985), no more than this percentage of clay (or clay plus silt) can fill the spaces between sand grains before the clay becomes a continuous matrix in which the sand is embedded. These limits are in agreement with the reports of the textures of hard setting soils, which span the range from loamy sand (and even some sands) to sandy clay.

Cementation?

It is implicit in the definition of hard setting that, at least at a microscopic level, such soils are uncemented since a cemented soil is hard both when dry and when wet and thus cannot become hard on drying.

Variation of strength with water content

It is a characteristic of hard setting soils that they soften when wet so that the process of hardening on drying is reversible. Charreau & Nicou (1971) give an example of a sandy soil, containing 4 to 6% silt and clay, whose penetration resistance does not change much until it has dried to half the moisture content at field capacity but thereafter the resistance rises sharply with decreasing moisture content. An even more sudden and sharp increase of penetration resistance with decrease in moisture content is shown (Fig. 1) by a sand, loamy sand and sandy loam from Botswana containing 11, 15 and 24% clay and silt (<50 um) respectively. On the other hand, results for some Australian hard setting soils (Fig. 2) show a more gradual increase in strength with decrease in moisture content.

A PHYSICAL EXPLANATION FOR HARD SETTING

Mullins & Panayiotopoulos (1984) have presented an explanation for the measured strengths of artificial mixtures of sand
Figure 1
AVERAGE PENETRATION RESISTANCE ENCOUNTERED BY 5 MM DIAMETER CYLINDRICAL FLAT ENDED PROBE DRIVEN 10 MM INTO CORES OF A SAND (o--o), LOAMY SAND (●--●) AND A SANDY LOAM (■--■) FROM BOTSWANA, DRIED TO A RANGE OF MOISTURE CONTENTS (FROM SINCLAIR, 1985).
Figure 2
CRUSHING STRENGTH VERSUS MOISTURE CONTENT OF UNDISTURBED CYLINDICAL CORES (40 mm LONG, 22 mm DIAMETER) FROM FOUR HARD-SETTING SOILS IN NORTHERN NEW SOUTH WALES, AUSTRALIA. ▲ SANDY CLAY LOAM SUBSOIL ★ SANDY CLAY LOAM VIRGIN SOIL ◆ ◆ ◆ UNDER NATURAL SCRUB VEGETATION, EQUILIBRATED AT MATRIC POTENTIALS OF -1 MPa, -100 OR -10 kPa.
and kaolin and the variation of this strength with moisture content (Fig. 3) in terms of the concept of effective stress and the Coulomb-Mohr theory of strength. The same framework of explanation is applicable to the behaviour of hard setting soils and is summarised here as a preliminary to a discussion of the factors which may influence hard setting behaviour.

**Theory**

In a soil with little or no structural development and with a matrix dominated by sand grains, the clay and silt (hereafter referred to as the 'fine material') is likely to fill the spaces between sand grains in a combination of two possible ways:

(i) As bridges or annuli connecting adjacent grains
(ii) As material attached to the surface of individual grains but not involved in bridging.

Since (ii) contributes nothing to strength, only the volume fraction of fine material in form (i) will affect strength. If failure of the soil occurs as failure within the bridging material rather than at the areas of contact with the sand grains, then it is reasonable to assume that strength is equal to the bulk strength of the fine material multiplied by the fractional area of failure plane which it occupies.

The strength of the fine material itself is a result both of the bonding between the particles and of the matric potential (soil water tension), which has a similar effect to an externally applied confining pressure (effective stress). Although air enters into the spaces in between sand grains during drying, it is not until very low values of matric potential (<-1 MPa) are reached that air entry is likely to occur within the matrix of the fine material. Thus matric potential can make a major contribution to soil strength. Indeed, Mullins & Panayiotopoulos (1984) have demonstrated that, excluding very dry and nearly saturated conditions, the increase in strength during drying out of mixtures of sand and kaolin can be accounted for almost entirely in terms of the matric potential. This explanation provides a clue as to how strength may be expected to vary with moisture content, in that not only moisture content but
Figure 3
CRUSHING (A) AND INDIRECT TENSILE (B) STRENGTH VERSUS MOISTURE CONTENT FOR SAMPLES OF FINE SAND MIXED WITH: 0 (●); 0.5 (○); 2 (▲) AND 8 (△) g KAOLIN/100g MIXTURE. ERROR BARS OF ± 1 s.e. ARE DRAWN WHEN THEY EXTEND BEYOND THE SYMBOL.
also matric potential are important factors. Thus, if there is a sharp drop in matric potential over a narrow range of moisture contents, this may result in a correspondingly sharp increase in strength (see Fig. 3).

The theory so far is a simple extension of the concepts which form the basis of most modern soil mechanics (Terzaghi & Peck, 1967) so that it is curious that, whilst hard setting has often been thought of as an unusual form of soil behaviour, the friable behaviour of soils which is often taken for granted actually requires a more complicated physical explanation (Braunack, Hewitt and Dexter, 1979).

**Hard setting and water dispersible clay.**

The proportion of fine material involved in bridging between sand grains can be maximised by dispersing or slurrying it and then allowing the soil to dry out. In this process the fine material will remain behind the retreating water menisci to be left mainly as annular bridges between sand grains. It is therefore understandable that the strength of soil in the dry state can be considerably enhanced if it has been remoulded or disturbed in a wet state prior to drying, in comparison to soil which has not been mechanically disturbed. For example, Sinclair (1985) observed that the tensile strength of a range of hard setting soils after drying, was increased on average by a factor of 50 as a result of previously remoulding each soil at a matric potential of \(-10\) kPa prior to drying, in comparison to the strength of the same sieved (<2 mm) soils when they were packed into cylinders, allowed to wet up and then dry out without disturbance.

Because hard setting can recur after a cultivated soil has been through a cycle of wetting and drying, it is worth discussing what happens after a cultivated seedbed is rewetted. In this case, the soil initially consists of man made aggregates with no bonding between them. Only if the process of wetting can disperse fine material will there be anything to bridge between these aggregates and cause the soil to set hard during drying. The following experimental evidence (described in
Sinclair, 1985) is given to demonstrate that a direct relationship can be established between water dispersible material and the strength of hard setting soils.

25 different air dry, sieved (<2 mm) hard setting soils, spanning the range from sand to sandy loam, were gently packed into cylindrical moulds (38 mm long and 19 mm diameter), wetted by capillary action under a vacuum, dried at 60°C for 48 hours and then strength tested. Their (indirect) tensile strength, \( Y \), was determined by measuring the force required to fail each sample when placed between two flat platens with its axis parallel to the platens. Dispersible clay (<2 µm) was measured by the pipette method after mechanically stirring 50 g of each soil in 200 ml of distilled water. These values were multiplied by the dry bulk densities of the soils (measured as packed for strength testing) in order to obtain \( X \), the mass of dispersible clay per unit total sample volume. Values for \( X \) varied between 6.6 and 22 mg/cm³. \( X \) and \( Y \) were found to be significantly related (\( r = 0.61 \)) as follows:

\[
Y = -0.17 + 38X
\]

where \( Y \) is in kN/m². In contrast, it was found that there was no significant relationship between \( Y \) and the total mass per unit volume of clay (as determined after complete dispersion).

Whilst dispersible clay was found to be significantly correlated (\( r = 0.81 \)) with organic carbon and with fine (2 to 10 µm) silt (\( r = 0.87 \)), these variables were not themselves significantly correlated with tensile strength. This implies that, although it may be possible to find relationships between organic matter content or the proportion of a given (fully dispersed) particle size fraction and the strength of hard setting soils, such relationships are in reality only a reflection of a more fundamental relationship with dispersible clay.

Another set of factors which influence the amount of dispersible caly is the exchangeable cations and the concentration and composition of electrolytes in the soil solution (Rengasamy, 1983).
CONCLUSIONS

The relationship which has been established between hard setting and dispersible clay means that hard setting is most likely to occur in those sandy soils which are structurally unstable. A further implication is that soil management practices which lead to a deterioration in structural stability may also lead to an increase in the severity of hard setting. Adem, Tisdall and Olsson (1982) and Adem and Tisdall (1984) have shown that, with careful control over the timing and number of cultivations, and over the rate of wetting by irrigation combined with measures to conserve soil organic matter, it is possible to overcome many of the physical limitations imposed by hard setting behaviour. It is clear that some useful insights may be gained from the Australian experience once the phenomenon of hard setting is also recognised as a specific form of soil behaviour in Africa.

ACKNOWLEDGEMENTS

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SOME RED SANDY SOILS OF BOPHUTHATSWANA

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SUMMARY

Bophuthatswana lies to the south east of the Kalahari Basin and parts of the country are covered with aeolian sand. In the west of the country the Kalahari sand gives rise to regosols which are unsuitable for arable farming, but further east the mantle of aeolian sand is thinner and gives rise to red and yellow sandy loams and sandy clay loams with favourable moisture characteristics for arable cropping. Such soils occur in Ditsobotla and Taung districts.

Ditsobotla is the principal dry land cropping area of the country due partly to the occurrence there of red and yellow soils derived mainly from aeolian sand. Under the annual rainfall of 500 to 580 mm, soil properties that enhance the availability of soil water tend to increase cropping potential. Soil characteristics, including sandy texture, soft plinthite and gley cutanic horizons are therefore described in relation to soil moisture and crop yields.

At Taung the annual rainfall of 460 mm is too low for dry land cropping but 4 000 ha are irrigated with water from the Vaal River. The red and yellow sandy loam and sandy clay loam soils derived mainly from aeolian sand have favourable moisture characteristics for overhead irrigation. The infiltration rate, available water capacity and plant available water capacity of the soils are therefore described in relation to irrigation and crop production.
INTRODUCTION

The state of Bophuthatswana is made up of a number of discrete land units inside South Africa and studded mainly along the Botswana border. It lies to the south-east of the Kalahari Basin and in moving from west to east across the country the depth of aeolian sand tends to decrease whilst the rainfall increases (Fig 1). The deep Kalahari sand of the Ganyesa and Tlhaping-Tlharo districts in the west gives rise to deep coarse textured red and yellow regosols which are unsuitable for crop production. Moreover, the climate there is too dry for arable farming. In the Taung and Ditsobotla districts, however, there is only a thin mantle of aeolian sand which has been mixed with the underlying material to produce red and yellow soils with a sandy loam or, more commonly, sandy clay loam B horizon. These soils produce higher yields than clay soils under low rainfall. The rainfall at Taung is too low for dry land cropping but it is possible to irrigate the soils. At Ditsobotla the rainfall is just sufficient for dry land crop production.

Some red and yellow sandy soils of the Ditsobotla dry land cropping zone and the Taung irrigation scheme are described below with special reference to their crop production potential.

SOME SOILS OF SOUTH EASTERN DITSOBOTLA

Location and Climate

South Eastern Ditsobotla is situated at an altitude of 1350 to 1380m on an axis of uplift marking the divide between the Molopo River to the north and the Harts River to the south. The land is flat and water drains towards the numerous pans that occur in the area. The district forms part of the highveld
Figure 1: Sketch map of Bophuthatswana showing Kalahari and Quaternary sand and mean annual rainfall.

EXPLANATION

- Boundary showing component units of Bophuthatswana
- Botswana boundary
- Mean annual rainfall (mm)
- Boundary of Kalahari and Quaternary sand

Legend:
- Quaternary sand
- Kalahari sand

Scale: 0 - 50 Km
geomorphic province of South Africa which belongs to the 'African' erosion surface. Most of the land is covered with aeolian sand from which reddish and yellowish sandy soils have developed.

Climatic data from Mafeking (Table 1) shows a mean annual rainfall of 587mm but this possibly represents an upper limit for Ditsobotla. At Setlagoli, in Ditsobotla, the mean annual rainfall is 498mm. The rainfall is also rather variable and the incidence of drought (as measured by the period when the 12 month moving totals of rainfall fall below 75 per cent of mean annual rainfall) is 11 per cent at Mafeking and 23 per cent at Setlagoli. Moreover, the high evaporation rate reduces the effectiveness of the rainfall for crop production. Nevertheless, dry land cropping is undertaken in areas receiving 500mm or more mean annual rainfall particularly on sandy soils. Consequently, Ditsobotla is a productive dry land cropping area whose principal crops are maize, grain sorghum and sunflower. In fact Ditsobotla lies on the border of the maize triangle of South Africa which is the region's principal granary.

Information on the cropping potential of the soils was obtained from the report of a soil survey of some 35 000ha in Ditsobotla (Instituut vir Bodemkunde Navorsing/ Institute for Pedological Research, 1980).

Soil Properties Affecting Productivity

Moisture

Low rainfall restricts crop production in Ditsobotla district and so any factor that raises soil available water content should increase cropping potential. The productivity of the soil therefore depends largely on morphology and depth.
### TABLE 1. CLIMATIC DATA FOR MAFIKENG AND TAUNG

<table>
<thead>
<tr>
<th>STATION</th>
<th>CLIMATIC DATA</th>
<th>JAN</th>
<th>FEB</th>
<th>MARCH</th>
<th>APRIL</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUG</th>
<th>SEPT</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>ANNUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAFIKENG</td>
<td>Rainfall, mm (41 year mean)</td>
<td>121</td>
<td>78</td>
<td>86</td>
<td>56</td>
<td>17</td>
<td>8</td>
<td>3</td>
<td>4</td>
<td>13</td>
<td>45</td>
<td>63</td>
<td>93</td>
<td>587</td>
</tr>
<tr>
<td></td>
<td>Evaporation, mm (Class A Pan 26 year mean)</td>
<td>223</td>
<td>177</td>
<td>170</td>
<td>130</td>
<td>115</td>
<td>94</td>
<td>106</td>
<td>148</td>
<td>196</td>
<td>227</td>
<td>218</td>
<td>233</td>
<td>2037</td>
</tr>
<tr>
<td></td>
<td>Temperature, °C (mean of max &amp; min, 21 year mean)</td>
<td>23.7</td>
<td>23.2</td>
<td>21.9</td>
<td>18.3</td>
<td>14.5</td>
<td>11.7</td>
<td>12.0</td>
<td>14.7</td>
<td>19.1</td>
<td>21.4</td>
<td>22.5</td>
<td>23.6</td>
<td>18.9</td>
</tr>
<tr>
<td>TAUNG</td>
<td>Rainfall, mm (41 year mean)</td>
<td>82</td>
<td>68</td>
<td>77</td>
<td>43</td>
<td>15</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>12</td>
<td>29</td>
<td>50</td>
<td>65</td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>Evaporation, mm (15 year mean)</td>
<td>320</td>
<td>250</td>
<td>226</td>
<td>174</td>
<td>132</td>
<td>106</td>
<td>137</td>
<td>181</td>
<td>250</td>
<td>305</td>
<td>325</td>
<td>341</td>
<td>2745</td>
</tr>
<tr>
<td></td>
<td>Temperature °C (mean of max &amp; min, 12 year mean)</td>
<td>26.0</td>
<td>25.2</td>
<td>22.8</td>
<td>19.4</td>
<td>15.0</td>
<td>11.9</td>
<td>11.1</td>
<td>13.9</td>
<td>18.2</td>
<td>21.6</td>
<td>23.9</td>
<td>25.1</td>
<td>19.5</td>
</tr>
</tbody>
</table>
Figure 2: Maize yields on deep sandy soils (10–15% clay) and deep clayey soils (35–55% clay) under different rainfalls (compiled from data in Möhr 1974)
Texture

The influence of soil texture and rainfall on maize yields in South Africa is seen in Fig 2. It shows that under the rainfall of Ditsobotla district sandy soils have a higher cropping potential than clayey soils. It is therefore fortunate that there is a covering of aeolian sand in this area.

Soil Colour

Soils with imperfect drainage tend to have a higher cropping potential than well drained soils in this area. Thus, yellow soils tend to be more productive than red soils. Clovelly form soils (orthic A, yellow brown apedal B), for example, have a potential of 3 000kg/ha maize and Hutton soils (orthic A, red apedal B) have a lower potential of 2 800kg/ha maize. Soil colour is, of course, an indication and not the cause of soil moisture status.

Soft Plinthite

Soils with soft plinthite have a favourable moisture regime under low rainfall. Soils of the Avalon form (orthic A, yellow brown apedal B, soft plinthite) have the highest potential of all soils in the area with an estimated maize yield of 3 600kg/ha maize by good management. The Bainsvlei form (orthic A, red apedal B, soft plinthite) has a somewhat lower potential of 3 300kg/ha maize.

Gley Cutanic Horizon

The gley cutanic horizon tends to dry out faster than the soft plinthic horizon and it therefore has a lower cropping potential under low rainfall. The Pinedene form (orthic A, yellow brown apedal B, gley cutanic B), for example, can yield 3 500kg/ha maize in Ditsobotla. There is no category in the soil classification (MacVicar et al., 1977) for a soil with an orthic A, red apedal B and gley cutanic B but it occurs in Ditsobotla and has been named a Bainsvlei variant by the Institute for Pedological Research (1980). Some profile descriptions and analytical results for red sandy soils are given in Table 2.
The soils in Ditsobotla are known to be very low in available phosphate and P fertilizer is recommended for both arable crops and planted pastures.

SOME SOILS OF THE TAUNG IRRIGATION SCHEME

Location and Climate

The Taung irrigation scheme is situated on broad, gently sloping (1 per cent slope) pediments of the Dry Harts and Harts Rivers at an altitude of 1075 to 1140mm. The Harts River joins the Dry Harts at Taung and the valley widens considerably below the river junction. The valleys of the Harts river belong to the Post African cycle of erosion and the pediments are mantled with sandy colluvium of aeolian origin upon which reddish and yellowish sandy soils have developed.

The mean annual rainfall at Taung is 460mm (Table 1) which is too low for dry land cropping. However, irrigation is possible because water is brought by canal from the Vaal River. The principal summer crops grown on the 4000ha Taung irrigation scheme are groundnuts, cotton and maize, and the main winter crops are wheat and peas. Perennial crops such as lucerne are also grown under irrigation. The Taung irrigation scheme adjoins the Vaalharts irrigation scheme which is the largest irrigation scheme in South Africa.

Soil Properties Affecting Productivity

Soil Moisture

Crop production at Taung depends on irrigation, and the irrigable value of the soils depends mainly on their texture and depth as these factors influence infiltration, drainage and available water capacity.

Infiltration

The commonly occurring soils of the area belonging to the Hutton, Shortlands, Bainsvlei and Oakleaf (orthic A, neocutanic B) forms (Table 3) have relatively high infiltration rates of
### Table 2. Some Red Sandy Soils of Ditsobotla

<table>
<thead>
<tr>
<th>FORM</th>
<th>HUTTON</th>
<th>SHORTLANDS</th>
<th>BAINSVELI</th>
<th>BAINSVELI VARIANT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERIES</td>
<td>Shorocks</td>
<td>Kinross</td>
<td>Bainsvlei</td>
<td>Bainsvlei</td>
</tr>
<tr>
<td>LOCALITY</td>
<td>Siberia, Profile DII</td>
<td>Klein Zoutpan, Profile D96</td>
<td>Vrede, Profile D24</td>
<td></td>
</tr>
<tr>
<td>TOPOGRAPHY</td>
<td>Flat surface, 0.5% slope</td>
<td>Flat surface, 0.5% slope</td>
<td>Level surface, 0% slope</td>
<td></td>
</tr>
<tr>
<td>VEGETATION</td>
<td>Grassland</td>
<td>Secondary Grassveld</td>
<td>Maize land</td>
<td></td>
</tr>
<tr>
<td>PARENT MATERIAL</td>
<td>Aeolian sand</td>
<td>Aeolian sand &amp; Colluvium</td>
<td>Aeolian sand</td>
<td></td>
</tr>
<tr>
<td>HORIZON</td>
<td>ORTHIC A RED APEDAL B</td>
<td>ORTHIC A RED STRUCT-RED B</td>
<td>ORTHIC A RED APEDAL B</td>
<td>SOFT PLINTHIC B</td>
</tr>
<tr>
<td>DEPTH (cm)</td>
<td>0-29</td>
<td>29-77</td>
<td>0-32</td>
<td>32-87</td>
</tr>
<tr>
<td>COLOUR</td>
<td>Dark brown</td>
<td>Yellowish red</td>
<td>Reddish brown</td>
<td>Yellowish red</td>
</tr>
<tr>
<td>COLOUR</td>
<td>7.5 YR 3/4</td>
<td>5 YR 4/6</td>
<td>5 YR 4/4</td>
<td>5 YR 4/6</td>
</tr>
<tr>
<td>MOTTLES</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Very few</td>
</tr>
<tr>
<td>CONCRETIONS</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Very few</td>
</tr>
<tr>
<td>PERMEABILITY</td>
<td>Rapid</td>
<td>Rapid</td>
<td>Rapid</td>
<td>Moderate to rapid</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>Apedal</td>
<td>Apedal</td>
<td>Apedal</td>
<td>Strong blocky</td>
</tr>
<tr>
<td>TEXTURE</td>
<td>Loamy sand</td>
<td>Sandy clay loam</td>
<td>Loamy sand</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>C. SAND %</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>M. SAND %</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>F. SAND %</td>
<td>60</td>
<td>49</td>
<td>72</td>
<td>56</td>
</tr>
<tr>
<td>SILT %</td>
<td>10</td>
<td>7</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>CLAY %</td>
<td>17</td>
<td>32</td>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>TEB meq/100g</td>
<td>4.5</td>
<td>5.7</td>
<td>7.6</td>
<td>12.6</td>
</tr>
<tr>
<td>CEC meq/100g</td>
<td>13.4</td>
<td>16.3</td>
<td>12.1</td>
<td>23.9</td>
</tr>
<tr>
<td>pH</td>
<td>5.8</td>
<td>5.8</td>
<td>6.3</td>
<td>6.4</td>
</tr>
</tbody>
</table>

**NOTE:** The Table was compiled from data from the Institute for Pedological Research (1980).
### TABLE 3. - SOME RED SANDY SOILS OF TAUNG

<table>
<thead>
<tr>
<th>SERIES</th>
<th>HUTTON</th>
<th>SHORTLANDS</th>
<th>BAINSVELI</th>
<th>OAKLEAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCALITY</td>
<td>Taung, Profile 112</td>
<td>Taung, Profile 37</td>
<td>Taung, Profile 120</td>
<td>Taung, Profile 94</td>
</tr>
<tr>
<td>TOPOGRAPHY</td>
<td>Upper slope</td>
<td>Middle slope</td>
<td>Lower slope</td>
<td>River terrace</td>
</tr>
<tr>
<td>VEGETATION</td>
<td>Acacia bush</td>
<td>Grass and small shrub</td>
<td>Irrigated arable</td>
<td>Irrigated arable</td>
</tr>
<tr>
<td>PARENT MATERIAL</td>
<td>Colluvium</td>
<td>Colluvium</td>
<td>Colluvium</td>
<td>Alluvium</td>
</tr>
<tr>
<td>LOCALITY</td>
<td>Taung, Profile 112</td>
<td>Taung, Profile 37</td>
<td>Taung, Profile 120</td>
<td>Taung, Profile 94</td>
</tr>
<tr>
<td>TOPOGRAPHY</td>
<td>Upper slope</td>
<td>Middle slope</td>
<td>Lower slope</td>
<td>River terrace</td>
</tr>
<tr>
<td>VEGETATION</td>
<td>Acacia bush</td>
<td>Grass and small shrub</td>
<td>Irrigated arable</td>
<td>Irrigated arable</td>
</tr>
<tr>
<td>PARENT MATERIAL</td>
<td>Colluvium</td>
<td>Colluvium</td>
<td>Colluvium</td>
<td>Alluvium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FORM</th>
<th>HUTTON</th>
<th>SHORTLANDS</th>
<th>BAINSVELI</th>
<th>OAKLEAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPTH</td>
<td>0-20</td>
<td>0-10</td>
<td>0-30</td>
<td>0-35</td>
</tr>
<tr>
<td>COLOUR</td>
<td>Dark reddish brown</td>
<td>Dark reddish brown</td>
<td>Dark reddish brown</td>
<td>Dark reddish brown</td>
</tr>
<tr>
<td>COLOUR</td>
<td>2.5 YR 3/4</td>
<td>2.5 YR 3/6</td>
<td>2.5 YR 3/3</td>
<td>2.5 YR 3/6</td>
</tr>
<tr>
<td>MOTTLES</td>
<td>NII</td>
<td>NII</td>
<td>NII</td>
<td>Abundant</td>
</tr>
<tr>
<td>CONCRETIONS</td>
<td>NII</td>
<td>NII</td>
<td>NII</td>
<td>Few CaC03</td>
</tr>
<tr>
<td>PERMEABILITY</td>
<td>Rapid</td>
<td>Rapid</td>
<td>Rapid</td>
<td>Rapid</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>A pedal</td>
<td>A pedal</td>
<td>A pedal</td>
<td>Weak</td>
</tr>
<tr>
<td>TEXTURE</td>
<td>Sandy loam</td>
<td>Sandy clay loam</td>
<td>Sandy clay loam</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>C. SAND %</td>
<td>11</td>
<td>16</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>M. SAND %</td>
<td>11</td>
<td>9</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>F. SAND %</td>
<td>65</td>
<td>57</td>
<td>49</td>
<td>47</td>
</tr>
<tr>
<td>SILT %</td>
<td>4</td>
<td>5</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>CLAY %</td>
<td>9</td>
<td>13</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>TEB meq/100g</td>
<td>2.9</td>
<td>3.6</td>
<td>8.6</td>
<td>9.2</td>
</tr>
<tr>
<td>CEC meq/100g</td>
<td>3.8</td>
<td>5.7</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td>ESP</td>
<td>6.6</td>
<td>2.7</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>pH</td>
<td>6.9</td>
<td>7.1</td>
<td>7.3</td>
<td>7.7</td>
</tr>
<tr>
<td>RESISTANCE (ohm/cm)</td>
<td>2400</td>
<td>2300</td>
<td>650</td>
<td>450</td>
</tr>
<tr>
<td>COND (mS/m)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>822</td>
</tr>
</tbody>
</table>

NOTE: The data in the Table was taken from Partridge et al (undated).
100mm/hr or more which reflect their sandy nature. However, many of the soils derived from aeolian sand suffer a reduction in infiltration rate after prolonged overhead irrigation due to the redistribution of soil particles.

**Available Water Capacity**

The available water capacity of various commonly occurring soils has been estimated at 100, 120 and 130mm/m (Partridge et al., undated). Hensley (personal communication) measured the available water capacity of a Hutton (Mangano series) soil at Taung as 84, 88, 137 and 112mm/m in the Ap₁, B₂₁, B₂₂ and B₂₃ horizons respectively.

Both these sets of estimates are reasonably high and where the soil is deep, relatively long irrigation cycles will be possible.

**Plant Available Water Capacity (PAWC)**

Work has been done by Boedt and Laker (1985) on the plant available water capacity of Vaalharts soils. Plant available water capacity is the amount of water held by a soil between field capacity of the soil and first stress in the plant. First stress was measured in the field by visual symptoms or leaf water potential. Plant available water capacity is intended to serve as a definite measure of the allowable soil water depletion before applying irrigation instead of using an arbitrary fraction of available water capacity.

The profile available water capacity of a Hutton (Mangano series) soil is shown in Fig 3. The increase in field capacity with depth is related to an increase in clay content of the soil, and the increase with depth of soil water held at first stress is related to an increase in resistance to uptake and transmission of water by the plant.

**Irrigation**

An irrigation scheduling experiment carried out by Boedt and Laker (1985) shows that if water use was reduced there was a reduction in yield (Table 4). When 125 per cent of profile
Figure 3: The profile available water content of a Hutton soil under wheat in the Vaalharts irrigation scheme (after Boedt and Laker, 1985)
TABLE 4. - IRRIGATION SCHEDULING ON WHEAT AT VAN LINDE 2, VAALHARTS, BY REFILLING SOIL TO FIELD CAPACITY AFTER EXTRACTING 50, 75, 100 AND 125 PER CENT OF PROFILE AVAILABLE WATER

<table>
<thead>
<tr>
<th>Treatment (% of PAWC)</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal water use</td>
<td>567</td>
<td>614</td>
<td>490</td>
<td>372</td>
</tr>
<tr>
<td>Yield (kg/ha) (LSD 1259)</td>
<td>4118</td>
<td>4540</td>
<td>3670</td>
<td>2993</td>
</tr>
<tr>
<td>Water Use Efficiency (kg·ha/mm)</td>
<td>7.3</td>
<td>7.4</td>
<td>7.4</td>
<td>8.0</td>
</tr>
<tr>
<td>No. of irrigations</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

NOTE: The data in this Table was taken from Boedt and Laker (1985).
available water was extracted yields dropped to unacceptable levels.

The sandy soils with infiltration rates of over 100 mm/h are not well suited to surface irrigation and overhead irrigation is recommended.

Alkalinity and Salinity

Many soils at Taung have a high pH of about 7.4 in topsoils and 7.7 in subsoils. The exchangeable sodium percentage is generally less than 5, but in some Bainvlei series soils, it exceeds 15.

Salinity has developed in depressions due to waterlogging caused by use of inappropriate methods of irrigation.
REFERENCES


PARTRIDGE, de VILLIERS and ASSOCIATES, Undated. Report on Soil Mapping for Possible Extensions to the Taung Irrigation Scheme, Bophuthatswana. Eksteen, Van der Walt and Nissan Incorporated, Pietersburg.
OCCURRENCE OF RED SOILS IN BOTSWANA

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P. Bag 103, Gaborone

SUMMARY

Red soils occur in Botswana subordinate to other soils. This is mainly due to the predominant occurrence of non-red Kalahari sands, and also some large alluvial/lacustrine areas with greyish soils. In the eastern hardveld, however, where the parent material is mainly hard rock, red soils occur in about equal proportions to other soils. Five examples of red soils are presented, two on granite/gneiss, one on basic rock, one on alluvium and one on aeolian sand. The soil properties, including the colour, are discussed, as well as soil variations, and some of the management problems are indicated.

There are no real outstanding differences between red and other soils in Botswana, which are directly related to the colour. This is also related to the fact that red soils with extreme properties, such as Ferralsols/Oxisols, do not occur. Generally red soils have lower fertility and poorer structure, but better drainage and workability.

INTRODUCTION

To date, for purposes of management, red soils in Botswana have not so far been considered as a special or separate group of soils.

The notes presented here are basically from the point of view of mapping and classification.
DEFINITIONS OF RED SOILS

Description of the Colour Red

According to the soil colour names as given in the Munsell Soil Colour Chart (Munsell Colour, Baltimore, US), 'red' qualifies soils with a hue of 2.5YR or redder (10R), and a chroma of 6 or more. Soils with lower chromas (2-4) may also be called red, having soil colour names like 'dusky red' or 'reddish brown.'

Soils with a 5YR hue have 'red' in the name when chromas are 6 or more (with values 4-6), namely 'yellowish red.' Other 5YR soils have 'reddish' in the colour notation in a range from 2.5/2 to 7/8 value/chroma combinations, such as 'reddish brown' and 'reddish yellow.' Finally, 'reddish' is also found in the 7.5YR hue, with value/chroma of 6/6 or more, namely 'reddish yellow.'

In some countries the Japanese version, the Revised Standard Soil Colour Chart, is used. Here, 'red' is only used for hues of 10R or redder, and names like 'reddish brown', orange, and in one case 'grayish red', are used in the 2.5YR and 5YR hue range (excluding low chromas). 'Reddish' is not used at all for 7.5YR hue, but instead 'orange' and 'brown' are used.

Criteria and Boundaries for Red Soils

It is necessary to define which part of the soil is diagnostic. Topsoils are often less red or have lower chromas than subsurface horizons. It would be wrong to disregard a red subsoil because of an epipedon that does not qualify. By its nature a red
subsurface horizon is in most cases a B horizon, and that part should be taken as diagnostic.

On the basis of soil colour names and the general impression of the soil scientist the boundaries of red soils should be established. The 10R soils and 2.5YR soils with high chromas are obviously red soils. The 7.5YR soils should not qualify as red soils, although some are called 'reddish yellow', which are more yellow or orange-yellow ('orange' in the Japanese Charts).

The lower chroma part of the 2.5YR soils might not be considered as red soils. Colour names are weak red to dusky red shades for chroma 2 (for part grayish red in the Japanese version), and reddish brown shades for chroma 4 (similar in the Japanese version). Considering the colour names given, the general practice of calling these soils red, should be accepted.

Difficulties arise with the 5YR soils. The soils with chromas of 4 or less look rather brown or reddish brown, and should not be considered as red soils.

The 5YR soils with higher chromas seem to be boundary cases, and could be classified in two ways; either as red soils, or with the boundary placed somewhere between the 5 and 2.5YR hues.

Comparison With Colour Criteria Used in Classification Systems

In Soil Taxonomy (Soil Survey Staff, 1975) the relevant boundary occurs in the Rhodo- great groups and Rhodic subgroups. The essential parts of the definitions read as follows:
Rhodustults - hue: 'mostly dark or dusky red.'
   argillic value dry  5 in all subhorizons,
   value moist    1 unit lower.
   - in the 1983 Keys to S.T. no hue definitions
     are given.
Rhodudults - 'most have dark red or dusky red argillic
   horizons'
   a few have dark brown or dark reddish brown.'
   - 1983 Keys: hue of argillic redder than 5YR.
   - value conditions are as for Rhodustults.
Paleudults - no hues indicated for the Rhodic subgroup.
Rhodustalfs - hue of argillic throughout redder than 5YR,
   - value moist  4, and value dry  1 value higher.
Rhodudalfs and Rhodic subgroups of other Alfisols have the
   same definitions.

Comparable colour criteria are not used for Oxisols or
other orders. It should be noted that with the above criteria,
chromas do not play a role but values do. As a consequence,
all lighter red or reddish soils are excluded from the
Rhoda- groups.

Three remarks or questions can be made on the definition
of Rhodo-. The first is that the definitions for the Ultisols,
should be brought in line with the Alfisols.

The second is, what is redder than 5YR? Is this to be
literally followed (4.5YR), or a hue closer to 2.5YR (Less
than 3.7YR). It seems that when computer programmes are used,
the latter has to be chosen.

The third is the restriction of the hue occurring throughout
the thickness of the argillic horizon. Transitional horizons
at the upper and lower boundary have often less reddish colours.
One could question if the colour requirement should be rigidly
applied, as the character of the argillic horizon is often
less clear at these positions in the profile. The predominant part of the argillic horizon should of course meet the requirements.

In the FAO Legend of the Soil Map of the World (FAO/UNESCO, 1974), the connotation Chromic is used, defined as 'having a strong brown to red B horizon (rubbed soils have a hue of 7.5YR and a chroma of more than 4, or a hue redder than 7.5YR)'. Part of these Chromic soil units do not qualify as red soils, if the considerations in the above text are followed.

In the revised legend (Third draft, Oct. 1985) third level specifiers are introduced. These include 'Rhodi-' for soils having a red to dusky red B horizon (rubbed soils have hues redder than 5YR, with a moist value of less than 4 and a dry value not more than one unit higher than the moist value). This is similar to the Soil Taxonomy definition, and does not need further discussion.

**Interpretation of the Classification of Red Soils in Botswana**

After considering the nomenclature of soil colours and the definitions of Rhodo- great groups and Rhodic subgroups, it seems logical to correlate the red soils as far as possible with the Rhodo- groups.

In Botswana, the interpretation Rhodo- is applicable if the hue of the argillic horizon is redder than 5YR, but not necessarily closer to 2.5YR (this is indicated as 5YR, 4YR, 3.5YR, etc).

For minor transitional horizons (AB, B1, BC), where the character of the argillic horizon is not clear, hues of 5YR are permitted. The value restrictions for Rhodo- are normally strictly applied.
Reddish soils that meet the hue, but not the value requirements for the Rhodo- groups of Alfisols and Ultisols, can also be considered as red soils. However, the results of soil mapping indicate that these mainly lighter soils form a minority of the red soils.

Similarly, soils of other orders, such as Entisols, Aridisols and Oxisols that meet these colour requirements, can be classified as red soils.

OCCURRENCE AND PROPERTIES OF RED SOILS

Distribution of red and other soils in Botswana

Red soils occur in Botswana subordinate to soils with other colours. The dominant soils are Arenosols/Psammments on Kalahari sands, of which only a minor portion is red.

In Fig. 1 a simplified distribution pattern of red and other soils is shown. It should be noted that from several areas, soil data are still lacking, (mainly in the western and southern parts), and that, therefore, this presentation is provisional.

The following units are distinguished:

1. **Hardveld with red soils in equal or dominant proportion to others**

   It is difficult to indicate precise proportions as soil colours are, to a large extent, around 5YR, and surveys were not carried out using 5YR 'Rhodic' criteria, but rather the 7.5YR 'Chromic.' Predominant in this unit are soils on the granite/gneiss basement complex, followed by sedimentary rock and sand, basic rock and alluvium.
Fig. 1—MAJOR OCCURRENCE OF RED AND OTHER SOILS IN BOTSWANA

REFERENCE
1 HARDVELD—RED SOILS PREDOMINANT
2 HARDVELD—RED SOILS SUBORDINATE
3 SANDVELD—RED SOILS PREDOMINANT
4 SANDVELD—RED SOILS VERY MINOR
5 ALLUVIUM—NON—RED SOILS
2. **Hardveld with subordinate red soils**
   These are mainly areas with a large proportion of non-red sandy and alluvial soils, as well as soils on basalt.

3. **Sandveld with dominant red soils**
   The SW part of the sandveld is characterised by red soils on Kalahari sands. The boundary with the yellowish part is gradual. The soils are fine sandy with a low clay content (Arenosols/Psammments).

4. **Sandveld with very minor red soils**
   This is by far the largest unit, formed by yellowish and grayish Kalahari sands, in flat positions and with a very low clay content, classified as Arenosols or Quartzi- and Ustipsamments. Red soils occur only very locally, in places which have some slope, such as in river valleys, on escarpments or on dunes. Here soils are often more clayey, which is partially ascribed to aeolian dust, and an argillic horizon may have formed (e.g. profile Pa 111).

5. **Alluvial areas without red soils**
   All depressional areas within the sandveld, such as the Okavango Delta, the Makgadikgadi salt pans and other recent or older lake bottoms have greyish or brownish soils (10YR to 2.5YR), such as Arenosol/Psammments, Fluvisols/Fluvents, Gleysois/Aquepts, Cambisols/Ustocrepts, Luvisols/Ustalfs and Aqualfs, Solonetz/Natrustalfs, Solonchaks/Salorthids and Vertisols.

**Examples and Properties of Red Soils**

In the Botswana classification, system symbols are used for the major groups of parent materials, which form the first differential criterion. The soil examples given here are from the following groups:
Mc 51, Sh 4 - G - Soils on igneous and metamorphic acid rocks  
Sh 16 - B - Soils on basic rocks  
S1 - A - Soils on alluvium  
Pa 111 - S - Soils on coarse-grained sedimentary rock, including sands

Profiles Mc 51, Sh 4, and Sh 16 are from the map unit 1, S1 from unit 2, and Pa 111 from unit 4. Profile descriptions and analytical data are given in the appendix.

The profiles selected are only partially representative of red soils as they occur in Botswana. They do not cover all parent materials, or variations in development, depth, etc. The examples chosen are all deep, well developed, and have an argillic horizon.

Mc 51 - Ferric Luvisol/Oxic Rhodustalf

This is a very common soil occurring on the granite/gneiss basement complex, found in eastern Botswana. Typically Mc 51 has low CEC, whereas profile Sh 4 has a relatively high CEC, forming the other end of the range (Oxisols do not occur). The CEC (clay) of these soils is mostly between 20 and 30 meq/100gm corrected for organic carbon. The field estimates of the clay content are normally higher than the laboratory results, which is ascribed to aggregate forming by iron oxides. This affects the CEC (clay), making it seemingly higher, and making it difficult to distinguish between Ferric/Oxic on the one hand, and non-Ferric/Oxic on the other hand.

Variation occur also in the base saturation (from 30 to 100), in the soil depth, in the texture (from sand to clay), in soil colour (more yellowish in less well drained places), in contents of carbonates, etc. This if reflected in the occurrence of associated soils such as: Regosols/Ustorthents, Arenosols/Ustipsamments, Chromic and Calcic Luvisols/Udic and
Typic Rhodo- and Haplustalfs, Nitosols/Paleustalfs, Acrisols/Ustults. Common phases are lithic, petric and petroferric.

Most of the management problems are related to the relatively low rainfall (about 400-500mm) and the low water holding capacity of the sandier and shallower varieties. Fertility is normally fairly low. Another common problem is the moderate to strong surface sealing, which increases run-off and affects germination.

**Sh 4 Eutric Nitosol/Rhodic Paleustalf**

This is an example of a better soil on the granite/gneiss basement complex. The differences are mostly related to variations in the composition of the rock and the position in the landscape. In the case of this profile it seems that a lateral enrichment in clay and other soil components may have occurred (pediment slope towards dolerites). In the other extreme case, acid leached sandy soils are found on higher slopes of watersheds.

**Sh 16 - Eutric Nitosol/Rhodic Paleustalf**

This is an example of a well developed and deep soil on dolerite. The location is in Central District (eastern Botswana), where rainfall is about 500mm. Soils on basic rock are mostly red with an argillic horizon, have a relatively high clay content, high CEC and high base saturation. Calcic horizons are more commonly found when compared to the granite area.

Variations occur, especially with regard to soil depth, but also to the type of rock. The soils formed on the Karroo basalt are less deep and less reddish (7.5YR), with otherwise similar soil properties. Vertisols have frequently formed in the alluvium derived from the basic rocks. Data from
soils on diabase in southeastern Botswana indicate that CEC and base saturation are lower, and that these soils intergrade to Ferric Acrisol/Oxic Rhodustult. An explanation may be that prevailing stronger leaching conditions existed in a past period due to higher rainfall.

The normal associations of soils on basic rock are classified as Chromic and Calcic Luvisols/Udic and Typic Rhodo- and Haplustults and Regosols/Ustorthents. Common phases are lithic and petric and occasionally petro-calcic occurs.

The management problems on these soils vary. They often occur on relatively sloping areas where sheet and gully erosion are active, the result is shallow soils and rock outcrops.

Where these problems do not occur, the high clay content may limit workability. Otherwise these soils are fairly good, with moderate fertility.

**S 1 - Eutric Nitosol/Rhodic Paleustalf**

There is a wide range of soils on alluvium. An important soil here is the Eutric Nitosol developed on alluvium. Although this soil is basically derived from a poor Karroo sandstone, it has relatively good soil properties, with high CEC and base saturation, and a fairly good structure. It is classified as Rhodic based on the overall colour of the argillic horizon which is more strongly expressed than the marginal hue of the B1 horizon.

Associated soils are the less reddish and less deep Chromic, Calcic and Orthic Luvisols/Typic and Udic Haplustalfs, as well as more sandy varieties (Arenic subgroups). On some older alluvial surfaces more leached red soils are found: Ferric Luvisols/Oxic Rhodustalfs.
As far as management is concerned, red alluvial soils indicate better drainage conditions compared to other alluvial soils. Red alluvial soils are amongst the better soils in Botswana, with no real limitations in most cases, apart from the general problem of moisture availability.

**Pa 111 – Arenic Ferric Acrisol/Arenic Oxic Rhodic Paleustult**

The location of this profile is on a sand dune in Chobe (N. Botswana), 100km south of Kazungula. Lacustrine clay plains with Vertisols occur on both sides of this 1km wide dune ridge. Average rainfall is 700mm. The profile is classified as Rhodic, ignoring the transitional hue of the B1 horizon. It is also classified as Ferric/Oxic although the CEC (clay) is more than 24 meq. Calculated CEC in sandy soils is normally too high, as the relatively important influence of the sand fraction is not corrected for. The low base saturation reflects the higher precipitation in this part of Botswana.

There is variation in the base saturation and the clay content of the red sandy soils. Luvisols/Paleustals also occur, sometimes with a petrocalcic horizon. The less clayey Luvic and Ferralic Arenosols/Quartzipsamments and Ustipsamments may also be found.

The acid sandy soils in northern Botswana are not under cultivation, as they have a fertility problem. Elsewhere in Botswana sandy soils are frequently used, mainly for reasons of their good workability. Fertility is always low. the red sandy soils are the best of the sands, as they have relatively high clay content as is the case in eastern and northern Botswana.
Conclusion

In Botswana the major contrast is not between red and non-red soils, but between sandy and non-sandy soils. Red colours alone do not directly reflect differences in other important soil properties such as structure or fertility aspects. Only in combinations with other factors such as topography and parent material may red colours indicate certain soil characteristics and hence management problems.

Red colours may be typical for tropical soils with extremely low values of CEC and base saturation, but these do not occur in Botswana. Thus, these indications do not play the great role that they may elsewhere in southern Africa.

Although there is no general principle, red soils as compared to other soils, in general, indicate the following:
- lower fertility
- better drainage conditions
- better workability.

There is too much variation in red soils to come to any further general conclusions. For example, red soils may in general have lower water holding capacity, but the opposite may be true for red sandy soils. The same applies to fertility.

A problem is the accurate determination of the clay content of red soils, thus influencing the classification, as the clay particles are frequently coated with iron oxides. Analytical results using normal pretreatment generally give lower values than determinations on dithionite deferrated materials.

References

SOIL SURVEY STAFF, 1975 Soil Taxonomy USDA Agric Handbook, No. 426
### STANDARD SOIL ANALYSIS RESULTS

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**Date:** 21-Feb-86

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APPENDIX

SOIL PROFILE DESCRIPTION SHEET  SOIL SURVEY OF BOTSWANA  FAO BOT/80/003

PROFILE NO. Me 51  SHEET NO. 2327 A3  GRID REF. NE 118 286  UNIT G6a

LOCATION, COORDINATES NW of Makwate, 5km E of Budungwe Hill, 23°15'16"S, 27°06'58"E

DATE 15-4-82  AUTHOR A. Remmelzwaal, B. Moganane

SOIL CLASSIFICATION (FAO) Ferric Luvisol
SOIL CLASSIFICATION (ST) Oxic Rhodustalf

ELEVATION 930 m  PHYSIOGRAPHIC POSITION plain

TOPOGRAPHY almost flat  MICROTOP.

SLOPE 0-1%  SURFACE COND.

LAND-USE / VEGETATION savanna

SPECIES Acacia nigrescens, Combretum apiculatum, Dichrostachys cinerea, Grewia bicolor

PARENT MATERIAL gneiss  DRAINAGE mod. well to well

MOISTURE COND. moist  SURFACE STONES -

ROCK OUTCROPS -  SALINITY -

EROSION / DEPOSITION -

HUMAN INFLUENCE -

REMARKS augering from 75cm

analytical clay contents lower than field estimates

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LOCATION, COORDINATES 8km SSE of Shoshong, 100m from Marutlwe hill, 23°05'50"S, 26°32'40"E
DATE 5-4-79 AUTHOR A. Remmelzwaal
SOIL CLASSIFICATION (FAO) Eutric Nitosol
SOIL CLASSIFICATION (ST) Rhodic Paleustalf
ELEVATION 1058 m. PHYSIOGRAPHIC POSITION upper pediment slope, 100m from dolerite hill
TOPOGRAPHY undulating MICROTOP -
SLOPE 3%, slightly concave SURFACE COND.
LAND-USE / VEGETATION dense to half-open savanna (lands areas as well)
SPECIES Dichrostachys cinerea, Acacia erubescens, Commiphora africana, Ehretia rigida,
Grewia spp., Paracanthoides spp.
PARENT MATERIAL Mahalapye granite DRAINAGE moderately well
MOISTURE COND. dry SURFACE STONES very few
ROCK OUTCROPS none (at 100m dolerite hill) SALINITY -
EROSION / DEPOSITION slight to very slight rill/gully and sheet erosion
HUMAN INFLUENCE borrow pit
REMARKS augering from 250cm, from 260cm weathered rock
(samples f and g finished for repeats) (also e, seems off for CEC and bases)

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<td>2.5YR3/6 3/6</td>
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**SOIL PROFILE DESCRIPTION SHEET**

**SOIL SURVEY OF BOTSWANA**

**FAO BOT/80/003**

**PROFILE NO.** Shl6  **SHEET NO.** 2326 A2  **GRID REF. ME** 416 453  **UNIT** B7 (-A16)

**LOCATION, COORDINATES** Ikongwe, 12km SW of Shoshona, 23°06'07"S, 26°25'48"E

**DATE** 20-11-80  **AUTHOR** A. Remmelzwaal

**SOIL CLASSIFICATION (FAO)** Eutric Nitosol  
**SOIL CLASSIFICATION (ST)** Rhodic Paleustalf (transitional to Petrocalcic Paleustalf)

**ELEVATION** 1100 m.  **PHYSIOGRAPHIC POSITION** flat area between dolerite hills

**TOPOGRAPHY** almost flat  **MICROTOP.** footslope, 20m from rockslope

**SLOPE** 1%  **SURFACE COND.** moderate surface sealing

**LAND-USE / VEGETATION** open area, but alternating with more bushy parts  
**SPECIES** a.o. *Acacia erubescens*

**PARENT MATERIAL** dolerite (colluviated)  
**DRAINAGE** moderately well dr.

**MOISTURE COND.** dry  
**SURFACE STONES** few stones (class 0-1)

**ROCK OUTCROPS** fairly rocky (class 1)  
**SALINITY**

**EROSION / DEPOSITION** moderate sheet erosion

**HUMAN INFLUENCE**

**REMARKS** analytical clay content sample c lower than field estimate

**HORIZON DESCRIPTION**

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<th>B2t</th>
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<td>-</td>
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SOIL PROFILE DESCRIPTION SHEET

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LOCATION, COORDINATES
18km SE of Serowe, along old Palapye road, 22°30'20"S, 26°49'20"E

DATE 14-8-79

AUTHOR A. Remmelzwaal

SOIL CLASSIFICATION (FAO) Eutric Nitosol

SOIL CLASSIFICATION (ST) Rhodic Paleustalf

ELEVATION 1013 m.

PHYSIOGRAPHIC POSITION alluvial plain

TOPOGRAPHY almost flat

SLOPE 1%

LAND-USE / VEGETATION shrubland, also fields with few Boscia albitrunca trees

SPECIES Colophospermum mopane

PARENT MATERIAL alluvium

DRAINAGE moderately well

MOISTURE COND. dry

SURFACE STONES

ROCK OUTCROPS

SALINITY

EROSION / DEPOSITION slight gully erosion

HUMAN INFLUENCE

REMARKS

HORIZON DESCRIPTION

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<td>black Mn</td>
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<td>very hard</td>
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<td>c 60-80</td>
<td>d 100-120</td>
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ABSTRACT

Initially an attempt has been made to discuss briefly the geological formation of Ethiopia, which has great influence on the variability of its soils.

The Geography of Ethiopia has been briefly discussed. Ethiopia is located in the Horn of Africa with a total area of 1,221,900 sq.km and has distinctively diverse geomorphology. The Great Rift Valley running SW-NE divides the country into the Somalian Plateau in the East and the Ethiopian Plateau in the West.

Soil formation is greatly influenced by rainfall and temperature. Depending on the altitude which varies from 110 m below sea level at L. Assale to 4550 m above sea level on Ras Dashen (Dejen), annual precipitation varies from about 100 mm in the Ogaden and coastal regions to over 2400 mm in the Western Highland. The mean annual temperature also varies from below 10°C in areas with an elevation of over 300 m to 39°C in the Rift Valley and coastal regions.

The land use practice of the country is very diverse. It is in the highlands that the agricultural practice is very intense, and the population density is very high. In these regions the precipitation is also relatively high. In the lowlands, pastoral livestock raising predominates followed by growing specific crops like cotton in the Awash Valley.
Most of the Research work being done by the Institute of Agricultural Research with its stations located in different agro-ecological zones focuses mainly on the yields of the crops tested. The dynamics of the uptake of certain elements from the soil and fertilizers are also being studied.

In the past, various organizations have done soil survey and classification work for different locations mainly for land use purposes. More recently, however, the Ministry of Agriculture of Ethiopia took the responsibility and established a Land use Planning and Regulatory Department. This newly established organization with the help of UNDP/FAO is in the process of classifying the soils of the country.

Out of the soils identified to exist in Ethiopia, Nitosols cover 150,089.5 sq.km. (12.2%), Orthic Acrisols 53,019.5 sq.km. (4.3%) and Chromic Cambisols - 5182.5 sq.km. (0.4%), the Red Soils of Ethiopia with the most recognizable agricultural value. These soils are predominantly developed on Trap series volcanics and felsic and metamorphic Pre-cambrian basement materials.

Red Soils of Ethiopia are distributed in the highlands and the lowlands of the Western Highlands.

The occurrence of red soils in Ethiopia increases from East to West. On the Chercher highlands which is in the Somalian Plateau, Nitosols and Chromic Cambisols occur. These soils are found also in the central highlands where soil differences are largely due to differences in topography.

Red soils also occur predominantly in the highlands and the lowlands of the Ethiopian Plateau. Here, Dystric Nitosols predominate followed by Eutric Nitosols, Orthic Acrisols and Chromic Cambisols. In most cases, these soils occur in association with each other.
Physically they are well drained, porous and clayey in texture, particularly the Nitosols. Chemically they have low pH, low CEC, low base saturation and low available P. In general, Ethiopian red soils are chemically poor soils, despite which they have great agricultural importance. In the highlands of the East, South and West these soils are cropped mainly to perennial crops like coffee (Coffea arabica) and ensete (Ensete ventricosum). In these areas where the population density is high, little is left for annual crops. In other parts cultivation of cereals and mixed cropping are practised.

Their iron and aluminium content is high, resulting in high P fixing capacity. Consequently they require phosphatic and liming fertilizers to give good yields of crops.
THE RED SOILS OF KENYA

THEIR OCCURRENCE, DISTRIBUTION AND MAJOR CHARACTERISTICS

F.N. MUCHENA and S.M. WOKABI
KENYA SOIL SURVEY
P.O. BOX 14733
NAIROBI
ABSTRACT

Red soils cover an important part of Kenya's land surface. They represent some of the most extensively used soils for agriculture. They occur on a variety of physiographical positions and are developed on a variety of parent materials. Most of them are found on dissected peneplains ("uplands"), volcanic footridges, footslopes, plateaus and plains. Parent materials are pre-Cambrian Basement System rocks, Tertiary volcanics or Cenozoic unconsolidated sediments.

Red soils in Kenya are found from sea level to an altitude of about 3 000 metres and have udic, ustic and aridic soil moisture regimes and isomesic, isothermic and isohyperthermic temperature regimes.

The physical and chemical characteristics of these soils vary widely depending on the soil type, degree of weathering and the type of parent material. The bulk of the soils have an acid reaction and have good physical characteristics.

For ease of presentation, the red soils have been divided into major classification units viz. Nitosols, Acrisols, Luvisols, Ferralsols, Arenosols etc. and their major physical and chemical characteristics are discussed separately and summarised in tabular form.
INTRODUCTION

Kenya lies almost exactly astride the Equator between 4° 20' South and 4° 15' North latitude and 34° and 41° 45' East longitude. It stretches from the shores of the Indian Ocean in the East to Lake Victoria in the West. Its total area is 583 000 square kilometres of which 569 000 square kilometres is land.

Kenya's landscape is an environment of great topographic diversity. It rises from sea level at the coast to 5 200 metres at the summit of Mount Kenya. As a result of this varied terrain various parts of the country experience an extremely varied climate both in precipitation and temperature. The variations in climate, topography coupled with variations in geology (parent material) has resulted in the formation of a wide range of soils with different morphological, physical and chemical characteristics.

This paper outlines the distribution, extent and broad range of characteristics of the red soils encountered in Kenya. In the context of this paper, red soils are considered to include those soils with a subsoil (B-horizon) whose rubbed moist hue is 5YR or redder and a chroma of 4 or more according to the Munsell Colour notation (Munsell Color Company, 1973).

The red soils are very much preferred for cultivation. They are extensively used for agriculture and they support a wide range of both annual crops and perennial crops. In Central Kenya they are intensively used for growing of coffee,
tea, maize, pineapples and legumes. In Western Kenya they are intensively used for growing of tea, coffee, maize, pyrethrum and bananas. In the high rainfall areas in Central and Western Kenya, the red soils may also be found under natural or improved pasture and are used for production of beef and dairy cattle. In the drier parts of the country, where these soils are cultivated, crops such as sorghum, millet, cowpeas, green beans, sunflower, cassava and pigeon peas are grown. Otherwise the bulk of the red soils in the semi-arid and arid parts of northern, southern and eastern Kenya (see Fig. 1) are under natural pasture and are used for extensive grazing for both domestic livestock and wildlife.

The red soils in Kenya have been classified in the past as Reddish Brown Lateritic Soils and Reddish Brown Latosols (Gethin-Jones and Scott, 1959). The deep red friable clay soils found in the highlands of Kenya have been referred to as "Kikuyu Red Loam." The Kenya Soil Survey has adopted the terminology of the FAO/Unesco Legend (1974) for the soil Map of the World as the basis for the national soil classification system. This system has been applied in the exploratory soil map of the country (Somboek et al, 1982) reconnaissance soil surveys (Gachene, 1986; Gelens, Kinyanjui and van der Weg, 1976; Michieka, Vleeshouwen and van der Pouw, 1978; Muchena and Njoroge, 1986; Rachilo, 1986; Trouber,
van der Pouw and van Engelen, 1985; van der Weg and Mbavi, 1975; van Kekem, 1986; van Wijngarden and van Engelen, 1986; Wamicha, Kiome and Okoth, 1986; Wielemaker and Boxem, 1982) semi-detailed soil surveys and detailed soil surveys. According to the FAO/Unesco (1974) terminology the red soils in Kenya can be grouped in the following broad categories: Ferralsols (rhodic and humic), Nitosols (eutric, humic, mollic and dystric), Acrisols (chromic and ferric), Luvisols (chromic and ferric), Arenosols (ferralic, humic and cambic) Cambisols (chromic and calcic) Xerosols (haplic and calcic), Phaeozems (luvic), Planosols and Solonetz. The Planosols and Solonetz form a very small portion of the red soils in Kenya.

**OCCURRENCE AND DISTRIBUTION**

Red soils cover an important part of Kenya's land surface. They occupy approximately 14 350 000 hectares which constitutes about 25.2 percent of the total land surface of the country. They occur from sea level to an altitude of about 3 000 metres. Fig. 1 shows the distribution of the red soils in Kenya. The bulk of them are found in the central, western, south-eastern and north-eastern parts of the country. Small proportions of them are found scattered in the coastal and northern parts of the country.

These soils are found on a variety of physiographic positions. Most of them are found on dissected peneplains ("uplands"), volcanic footridges, footslopes, plateaus and
Fig. 1

Distribution of Red Soils in Kenya

Legend (FAO terminology)
- Ferralsols (rhodic, humic)
- Nitosols (eutric, humic, mollic, dystric)
- Acrisols (dystric, humic)
- Luvisols (chromic, ferric)
- Arenosols (ferric, humic, cambic)
- Cambisols (chromic, calic)
- Nitosols, Acrisols and Cambisols
- Phaeozems (luric)
- Phaeozems (luric)
- Ferralsols and Cambisols
- Ferralsols and Cambisols
- Luvisols and Arenosols
- Luvisols and Arenosols
- Phaeozems and Solonetz
- Nitosols and Phaeozems
plains. They are found on a variety of parent materials ranging from Tertiary volcanics (olivine, basalts, nepheline phenolites, rhyolites, andesites, tuffs, etc.) pre-Cambrian Basement System rocks (biotite gneisses, hornblende gneisses, schists etc) to Cenozoic Unconsolidated Sediments. The parent materials are generally considered to be rich in ferromagnesian minerals.

CHARACTERISTICS AND PROPERTIES

In general most of the red soils encountered in Kenya have deep and well drained pedons. However, their morphological, physical and chemical characteristics are variable and are, to a great extent, dependent on the degree of weathering and soil development. In view of this the characteristics of these soils are discussed separately for each soil type (see Fig. 1). However, due to similarities in morphological characteristics, Luvisols and Acrisols, and Planosols and Solonetz have been grouped together. Table 1 gives some selected physical and chemical characteristics of these soils. Typical profile descriptions of some of the red soils are given in Appendix 1.

The colour is mostly red, dark red, dusky red, reddish brown or dark reddish brown. Vertical colour changes in the profile are gradual to diffuse. The red colour is mainly caused by a predominating presence of hematite. In some cases presence of higher amounts of goethite in relation to hematite may give yellowish red colours.
**Table 1: SOME SELECTED PHYSICAL AND CHEMICAL CHARACTERISTICS OF RED SOILS OF KENYA**

<table>
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<th>Survey area</th>
<th>Soil Class.</th>
<th>FAO/UNESCO (1974)</th>
<th>Organic C</th>
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<th>at pH 8.2</th>
<th>at pH 8.2</th>
<th>at pH 8.2</th>
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<th>at pH 8.2</th>
<th>at pH 8.2</th>
<th>Structure</th>
<th>Si/Al Ratio</th>
<th>clay fraction</th>
<th>color</th>
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<th>bulk density (g/cm³)</th>
<th>porosity (%)</th>
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<th>pH Cl⁻</th>
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<tbody>
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<td>17</td>
<td>7.5</td>
<td>1.8</td>
<td>30</td>
<td>0.3</td>
<td>pm</td>
<td>sb</td>
<td>55</td>
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<td>well crystallized kaolinite, traces of illite</td>
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<td>rhodic Ferralsol</td>
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<td>46</td>
<td>95</td>
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They usually have a moderate to strong crumb or subangular blocky structure in the topsoil which is underlain by a moderate subangular or angular blocky subsoil. An angular blocky structure dominates in the deeper subsoil. The peds are nutty rather than scalloped and are sometimes described as polyhedral (Sombroek and Siderius, 1981). Individual peds tend to break down under pressure to ever smaller entities showing shiny ped surfaces on all sides. The aggregate stability is high. This is reflected in low percentages of water-dispersible clay (less than 10%) and a high flocculation index (\( fi = 100 \times (1 - \frac{\% \text{ dispersed clay}}{\% \text{ total clay}}) \)) of more than 90 (Sombroek and Siderius, 1981). Ahn (1979) has attributed this aggregate stability to micro-aggregation of clay particles. Although these soils have a high clay content (usually 60-80 per cent or more clay) the effect of micro-aggregation makes them have loam-like handling qualities, and hence their former name "Kikuyu Red Loam." This micro-aggregation is partly responsible for their high porosity throughout the profile. The average pore space as a percentage of total apparent soil volume ranges from 55-60% (Pereira, 1957, Nyandat, 1976). The silt/clay ratio decreases with depth and ranges between 0.16 to 0.40. These ratios are indicative of a weathering stage not as advanced as in the red Ferralsols.
The clay mineralogy is predominantly of 1:1 type sometimes with traces of 2:1 days. In most soils kaolinite is dominant, followed by (meta) halloysite. Nitosols have considerable variation in chemical properties. Organic carbon content of the topsoil (A-horizon) may vary from 0.5 per cent to 3.0 per cent.

**Ferralsols**

These are strongly weathered mineral soils with an "OXIC" B horizon from which weathering has removed or altered a large part of the silica that is combined with iron and aluminium. The Ferralsols which are included in the red soils are rhodic Ferralsols and humic Ferralsols.

These soils have an ABC sequence of horizons with indistinct soil horizon differentiation. The OXIC B horizon has more than 15 per cent clay-sized particles (texture of sandy loam or finer). The textural change is usually small and gradual. The colour of the B in the moist condition is mostly red, dusky red, dark red or dark reddish brown. The structure is subangular blocky to porous massive and the aggregate stability is high. The bulk density ranges from 1.0 to 1.5 g/cm$^3$. The silt/clay ratios are low (0.1 to 0.3) indicating a high degree of weathering.

The clay mineralogy is predominantly kaolinitic. The Cation Exchange Capacity (CEC) values (NH$_4$OAc at pH 7.0; organic matter corrected) are mainly between 6 and 16 me/100g
clay. A few of the red Ferralsols have lower CEC - clay values, though none of these reach values below 1.5 me/100g clay and/or have a positive delta - pH (Muchena and Sombroek, 1981).

The red Ferralsols are, in general, low in fertility. Bellis and Boswinkle (1953-1962) conducting fertilizer trials in Kenya found out that crops grown on rhodic Ferralsols showed a marked response to phosphorus and nitrogen. The soils are moderately acid and have a low capacity to hold applied fertilizers. They have a high capacity to render part of applied phosphorus fertilizer unavailable to plants through fixation (Hinga, 1973).

**Nitosols**

These are well drained, very deep to extremely deep, red friable clay soils. They have an ABC sequence of horizons and show a very gentle clay illuviation resulting in a gentle clay bulge over a distance of at least 150 cm.

Cation Exchange Capacity (CEC) of the fine earth fraction may vary from 16 to 40 me per 100g clay. The base saturation too may range from as low as 15 per cent to as high as 80 per cent. The percentage of sesquioxides (Fe and Al) in the clay fraction is generally high. They also have high P-sorption capacity ranging from 2.4 to 2.7 percent (Hinga, 1973). The pH ranges from 4.0 to 6.5. Nitosols, compared to the red Ferralsols, show a higher inherent fertility.
Addition of phosphatic fertilizers results in substantial yield increases. As a result of the variation in chemical properties the Nitosols in Kenya have been subdivided into eutric, humic, mollic and dystric and all are included in the red soils.

**Luvisols and Acrisols**

These are soils with an ABC sequence of horizons, of which the A horizon is relatively low in organic matter and/or is acid. The B horizon is "argillic" and is characterised by illuviation of silicate clay minerals. Luvisols have similar morphological characteristics to the Acrisols. They are separated from each other solely on the base saturation of the lower part of the B horizon. The Luvisols have a base saturation (determined by NH$_4$OAc at pH 7.0) of more than 50 percent whereas the Acrisols have a base saturation of less than 50 percent. Included among the red soils of Kenya are chromic and ferric Luvisols and chromic and humic Acrisols.

Their colour varies from red, dark red to dark reddish brown with hues mostly 2.5YR and 5YR. They are characterised by a distinct increase in texture from the A horizon to the B horizon within a short distance. This is reflected by high clay ratios of B/A horizons which are generally over 1.4. The B horizon of these soils usually has an angular blocky structure which is often not very porous. However, some of the Luvisols and Acrisols have B horizons with
subangular blocky or prismatic structures. These soils have bulk densities ranging from 1.3 to 1.6g/cm³. The silt/clay ratio varies from 0.2 to 0.4. These soils have a tendency to form a strong sealing cap on the surface and are very susceptible to degradation. It has been observed that Luvisols with high silt or fine sand contents, high bulk densities and low organic matter contents are more affected in this respect (Gachene, 1982).

The chemical properties of these soils are variable. They have CEC values usually greater than 16 me/100g clay. The pH-H₂O ranges from 4.5 to 5.5 for most of the Acrisols whereas for the Luvisols it varies from about 5.5 to 6.8. The clay mineralogy is mixed comprising mainly kaolinite and illite.

Ferric Acrisols and Luvisols have variable amounts of iron and manganese concretions. In some cases the ferric Acrisols have large amounts of indurated plinthite which results in restricted rootability and relatively low water storage capacity. The chemical soil fertility of Acrisols is low whereas that of the Luvisols is moderate.

Arenosols
These are coarse textured soils (less than 15% clay) with an ABC sequence of horizons. They are commonly found on quartz-rich crystalline or sedimentary rocks or unconsolidated sediments derived from them. The Arenosols
which are included among the red soils of Kenya are some ferralic, humic and cambic Arenosols.

Their colour varies from yellowish red to red. They are characterised by low cation exchange capacity, low moisture storage capacity per unit volume and low chemical fertility.

**Cambisols**

These are 'young' and little weathered soils. They have an ABC sequence of horizons, the B horizon being "cambic." The B horizon is an altered horizon which shows incipient soil structure with significant amounts of weatherable primary minerals. Included among the red soils are chromic and calcic Cambisols.

The red Cambisols have relatively high natural fertility. They have, in general, a CEC of more than 24 me/100g clay. Their texture is variable but usually finer than sandy loam. The bulk of them are found on mountainous or hilly areas.

**Xerosols**

These are soils developed under dry climatic conditions and are characterised by an A horizon which has low organic matter content. Included among the red soils are haplic and calcic Xerosols which are well drained and have dark red, dark reddish brown or yellowish red colours.
Phaeozems

These are soils with a dark coloured topsoil (mollic A horizon) that is relatively high in organic matter and has a base saturation of more than 50 percent. These soils usually have an ABC sequence of horizons. Included among the red soils are some luvic Phaeozems which have dusky red to dark red subsoils. These soils are usually very fertile and have good structure.

Planosols and Solonetz

Included among the red soils in Kenya are small portions of soils that contain little soluble salts but much exchangeable sodium on the exchange complex (Solonetz) and soils with a pronounced and abrupt transition between a relatively light textured topsoil and a heavy textured compact B horizon (Planosol). Both Planosols and Solonetz have an argillic horizon but that of the Solonetz has an exchangeable sodium percentage of more than 15.

These soils have variable physical and chemical properties. The topsoils usually have subangular blocky structures whereas the subsoils (B horizons) have prismatic, columnar or angular blocky structures. The effective rooting depth of these soils is in most cases restricted to the topsoil (A and E horizons).
ACKNOWLEDGEMENTS

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MUNSELL COLOR COMPANY, 1973 Munsell Colour Charts.


Appendix I: Typical profile descriptions of some red soils of Kenya with analytical data.

rhodic FERRALSOL (KINDARUMA AREA)

A1 0-19 cm
Dusky red (2.5YR 3/2 moist); clay; moderate, medium, subangular blocky to crumby structure; very friable when moist, sticky and plastic when wet; abundant, fine roots; clear and smooth transition to:

AB 19-43 cm
Dark reddish brown (2.5YR 3/4 moist); clay weak to moderate, fine to medium subangular blocky structure; very friable when moist, slightly sticky and slightly plastic when wet; common very fine to fine pores; abundant fine roots; gradual and smooth transition to:

B2 43-109 cm
Dark red (2.5YR 3/6 moist); clay; weak, medium, subangular blocky structure; very friable when moist, slightly sticky and slightly plastic when wet; many very fine to fine pores; few fine roots; gradual and smooth transition to:

B31 109-149 cm
Dark red (2.5YR 3/6 moist); clay; moderate, medium to coarse, angular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; few, thin, clay cutans; many very fine to fine pores; few, fine roots;

Remarks
: At 230cm + hard plintheite

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humic NITOSOL (NAL - NAIROBI)

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<tbody>
<tr>
<td>A1</td>
<td>0 - 18</td>
<td>Dark reddish brown (5YR 3/3) moist and dry (5YR 3/4), clay; moderate to strong, fine and medium subangular blocky; few weak, thin clay skins; hard dry, firm moist, sticky and plastic wet; gradual smooth boundary to</td>
</tr>
<tr>
<td>ABt</td>
<td>18 - 37</td>
<td>Dark reddish brown (2.5YR 3/4) moist and dry, clay; strong medium and coarse (sub) angular blocky, common moderate clay skins; hard dry, friable moist, sticky and plastic wet; common micro-pores; many very fine and fine pores and few medium ones; gradual smooth boundary to</td>
</tr>
<tr>
<td>B21t</td>
<td>37 - 66</td>
<td>Dark reddish brown (2.5YR 3/4) moist, dark red (2.5YR 3/6) dry, clay; strong medium and coarse angular blocky; abundant thick clay skins; hard dry, friable moist, sticky and plastic wet; many micro to fine pores, common medium ones, diffuse smooth boundary to</td>
</tr>
<tr>
<td>B22t</td>
<td>66 - 116</td>
<td>Dark reddish brown (2.5YR 3/4) moist, dark red (2.5YR 3/6) dry, clay; strong medium and coarse angular blocky peds composed of fine ones; many thick clay skins; consistence and pores as B21, diffuse smooth boundary to</td>
</tr>
<tr>
<td>B23t</td>
<td>116 - 180</td>
<td>Dark reddish brown (2.5YR 3/4) moist, dark red (2.5YR 3/6) dry, clay; strong medium and fine angular blocky; cutans and pores as B22, consistence slightly firm when moist.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Horizon</th>
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<th>silt</th>
<th>clay</th>
<th>pH H₂O</th>
<th>pH KCl</th>
<th>C%</th>
<th>CEC soil pH 7.0</th>
<th>Base sat. %</th>
<th>P ppm</th>
<th>CEC clay</th>
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<td>18-37</td>
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<td>116-180</td>
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humic ACRISOL (MURANG'A DISTRICT)

Description of profile:

A_1 0-18 cm  
dark reddish brown (5YR 3/2 dry and moist); clay; strong, medium and coarse, crumby structure; very hard when dry; firm when moist, sticky and plastic when wet; few, very fine pores; many fine and medium roots; clear and smooth transition to:

AB 18-40 cm  
dusky red (2.5YR 3/2 dry and moist); clay; strong, medium, subangular to angular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; common to few, moderate clay cutans; few fine pores; 35% manganese concretions, 3 to 8 mm in size; few, fine and medium roots; abrupt and smooth transition to:

_B2t_ 40-70 cm  
dusky red (2.5YR 3/4 dry, 2.5YR 3/2 moist); clay; strong, fine and medium subangular to angular blocky structure; hard when dry, very firm when moist, sticky and non plastic; few, moderate clay cutans; no pores; 80% manganese concretions, 3 to 8 mm in size (some concretions are coated with iron); no roots.

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Horizon</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>pH</th>
<th>pH</th>
<th>C%</th>
<th>CEC</th>
<th>Base</th>
<th>P</th>
<th>CEC</th>
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<td>71</td>
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<td>21.2</td>
<td>44.8</td>
<td>18</td>
<td>40.8</td>
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chromic LUVISOL (KINDARUMA AREA)

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<th>silt</th>
<th>clay</th>
<th>pH H₂O</th>
<th>pH KCl</th>
<th>C%</th>
<th>CEC soil pH 7.0</th>
<th>Base sat.%</th>
<th>P ppm</th>
<th>CEC clay</th>
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<tr>
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<td>83-115</td>
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<td>36</td>
<td>6.6</td>
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<tr>
<td>115-200</td>
<td>B₂₃t</td>
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<td>40</td>
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<td>5.4</td>
<td>-</td>
<td>19.0</td>
<td>52.9</td>
<td>47</td>
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luvic PHAEOZEM (KAPENGURIA AREA)

**A11** 0-11 cm
Black (10YR 2/1 moist); clay loam; moderate fine and very fine subangular blocky, breaking down into moderate fine crumb; friable when moist, non sticky and plastic when wet; abundant very fine and fine roots; gradual wavy boundary;

**A12** 11-40 cm
Black (10YR 2/1 moist) clay; moderate; very fine crumb; very friable when moist, slightly sticky and plastic when wet; abundant very fine and fine roots; gradual wavy boundary;

**B1** 40-70 cm
Dark reddish brown (5YR 3/2 moist) clay; weak coarse angular blocky; consistence as A12; many micro pores; common fine and very fine roots; distinct smooth boundary;

**B2lt** 70-110 cm
Dusky red (2.5YR 3/2 moist) clay; porous massive; friable when moist, non sticky and plastic when wet; thin few clay skins; common very fine and fine roots; some signs of krotovinas; smooth gradual boundary;

**B22** 110-170 cm
Dark reddish brown (2.5YR 3/4 moist) clay; moderate coarse to very coarse angular blocky; firm to friable when moist, slightly sticky and plastic when wet; many micro and common fine pores; moderate common clay skins;

**B23** 170-250 cm+
Dark red (2.5YR 3/6 moist) clay; (no sample) (by auger).

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Horizon</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>pH H₂O</th>
<th>pH KCl</th>
<th>C%</th>
<th>CEC clay</th>
<th>Base sat.%</th>
<th>P ppm</th>
<th>CEC clay</th>
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<tbody>
<tr>
<td>0-11</td>
<td>A11</td>
<td>36</td>
<td>24</td>
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<td>11-40</td>
<td>A12</td>
<td>28</td>
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<td>4.52</td>
<td>36</td>
<td>64</td>
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<td>5.6</td>
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<td>44.8</td>
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<tr>
<td>70-110</td>
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<td>110-170</td>
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<td>3.9</td>
<td>-</td>
<td>22.1</td>
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dystric CAMBISOL (KAPENGURIA AREA)

A11 0-12 cm  Dark reddish brown (5YR 3/2 dry) and (5YR 2.5/2 moist) clay; strong, coarse and very coarse granular structure; very hard when dry, firm when moist, sticky and plastic when wet; clear smooth boundary;

A12 12-33 cm  Dark reddish brown (5YR 3/2 dry) and moist (5YR 2.5/2) clay; moderate medium subangular blocky breaking down into very fine granules; hard when dry, firm when moist, sticky and plastic when wet; common micro and few fine pores; abrupt and irregular boundary;

B21 33-78 cm  Dark reddish brown (5YR 3/4 dry, 5YR 3/3 moist) clay; moderate, medium and coarse angular blocky structure; hard when dry, firm when moist sticky and plastic when wet; common micro and few fine pores; abrupt and irregular boundary;

B22 78-97 cm  Some line, consisting of quartz gravel and manganese concretions; abrupt irregular boundary;

B3 97-120 cm+ Yellowish red (5YR 4/6 moist) clay; massive; friable when moist, sticky and plastic when wet; many primary minerals.

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Horizon</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>pH H2O</th>
<th>pH KCl</th>
<th>C%</th>
<th>CEC soil pH 7.0</th>
<th>Base sat.%</th>
<th>P ppm</th>
<th>CEC clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-12</td>
<td>A11</td>
<td>36</td>
<td>22</td>
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<td>4.9</td>
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<tr>
<td>12-33</td>
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ferralic ARENOSOL (KWALE LUNGALUNGA AREA)

Profile description

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<th>20-45 cm</th>
<th>45-300 cm</th>
<th>300-375 cm</th>
<th>375 cm</th>
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<tr>
<td>Ap</td>
<td>Dark reddish brown (5YR 3/2); loamy sand; porous massive structure breaking into single grains; soft when dry, very friable when moist, non sticky and non plastic when wet; common fine and few coarse roots; very little soil fauna; clear and smooth transition to:</td>
<td>Dark reddish brown (5YR 3/4); loamy sand; porous massive structure breaking into single grains; soft when dry, very friable when moist, non sticky and non plastic when wet; few coarse roots; very little soil fauna; gradual and smooth transition to:</td>
<td>Red (2.5YR 5/8); loamy sand; porous massive structure; soft when dry, very friable when moist, non sticky and non plastic when wet; very few coarse roots;</td>
<td>Red (2.5YR 5/8); sandy loam;</td>
<td>Coral limestone</td>
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</table>

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Horizon</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>pH H₂O</th>
<th>pH KCl</th>
<th>C%</th>
<th>CEC soil pH 7.0</th>
<th>Base sat.%</th>
<th>P ppm</th>
<th>CEC clay</th>
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<td>0-20</td>
<td>Ap</td>
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<td>45-150</td>
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<td>11.6</td>
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haplic XEROSOL (BURA AREA)

Profile description

A  0-10 cm  Dark reddish brown (7.5YR 4/4 dry; 5YR 3/4 moist); clay; massive to weak, very fine and fine, subangular blocky structure; slightly hard when dry; friable when moist, sticky and plastic when wet; slightly calcareous; common very fine and fine roots; pH-H₂O = 7.4; clear and smooth transition to:

AB  10-47 cm  Dark reddish brown (5YR 4/6 dry; 5YR 3/3 moist); weak, very fine subangular blocky structure; soft when dry, friable when moist, sticky and plastic when wet; moderately calcareous; abundant very fine and few fine pores; many, very fine and fine roots; pH-H₂O = 7.8; gradual and smooth transition to:

Bt  47-104 cm  Dark reddish brown (5YR 3/4 dry; 5YR 3/3 moist); clay; weak, fine to medium prismatic breaking to weak, fine to medium, angular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; patchy, thin clayskins; moderately calcareous; common, very fine pores; common very fine and few fine roots; pH-H₂O = 8.6; gradual and smooth transition to:

BC  104-152 cm  Reddish brown (5YR 5/6 dry; 5YR 4/4 moist); clay; weak, medium, angular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; strongly calcareous; common very fine and fine and few medium pores; pH-H₂O = 8.0;

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Horizon</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>pH H₂O</th>
<th>pH KCl</th>
<th>C%</th>
<th>CEC soil pH 7.0</th>
<th>Base sat.%</th>
<th>P ppm</th>
<th>CEC clay</th>
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</thead>
<tbody>
<tr>
<td>0-10</td>
<td>A</td>
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<td>100+</td>
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<td>0.41</td>
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<td>100+</td>
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<td>0.06</td>
<td>41.2</td>
<td>100+</td>
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PROPERTIES, EXTENT AND MANAGEMENT OF
RED SOILS OF LESOTHO

BY
N LEKENA\(^1\), L. LEKHOLOANE\(^2\) AND E.M. SEITLHEKO\(^3\)

\(^1\)Soil Conversation Planner, \(^2\)Soil Scientist (Ministry of Agriculture, and \(^3\)Geography Lecturer (National University of Lesotho) respectively.

INTRODUCTION

Lesotho is a small mountainous country with an area of 30,350 square kilometres and an elevation ranging from 1500-3400 metres above sea-level. The country is divided into four major physiographic regions, the lowlands along the western plateau, the Senqu Valley, Foothills, and the mountains. The lowlands range in elevation from 1500 to 1800m, the Foothills range from 1800 to 2400m in elevation and the mountains lie approximately between 2400 and 3400 metres.

RED SOILS OF LESOTHO

Red soils occupy approximately 6 percent of Lesotho. They are found almost exclusively in the Foothills and the lowland regions of Lesotho. They generally occupy gently sloping to moderately steep hill crests and moderately steep sideslopes. The well to moderately well drained red soils occupy higher lying land positions than other soils.

In the Foothills they are generally developed in deeply weathered basalt, where the movement of water through the profile is not restricted. In the lowlands these soils have developed in sandstone-controlled terrain, especially in the Elliot formation. In Table 1, the lithology of this formation has been described as buff red sandstone with thin clay shales and mudstones. It is therefore possible that the red colour of these soils may be inherited from the underlying rock.
### TABLE 1  Relationships between Geological Formation and Physiographic Regions.

<table>
<thead>
<tr>
<th>Formations</th>
<th>Geological Formation</th>
<th>Physiographic Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesotho</td>
<td>Basalt</td>
<td>Mountains, Foothills</td>
</tr>
<tr>
<td>Clarens</td>
<td>Fine grained buff sandstone, very occasionally bedded.</td>
<td>Boundary between Foothills and lowlands</td>
</tr>
<tr>
<td>Elliot</td>
<td>Buff red sandstones with thin clay shales and mudstones</td>
<td>Lowlands</td>
</tr>
<tr>
<td>Molteno</td>
<td>Coarse-grained white sandstone and grits with clay-shales and mudstones.</td>
<td>Lowlands</td>
</tr>
<tr>
<td>Burgersdorp</td>
<td>Buff sandstones, with purple and red clay-shales and mudstones.</td>
<td>Lowlands</td>
</tr>
</tbody>
</table>

About eight soil series in Lesotho have been identified as red soils. These occur mainly in the Lowlands and Foothills. The series names of the red soils are Leribe, Rama, Sefikeng, Hololo, Matela, Machache, Tumo and Matsaba. Genesis and properties of these soils will be discussed based on the current available soil survey information as well as the existing field and laboratory data gained from field investigations.
Genesis

Red soils in Lesotho are formed from the Red Beds, which are composed of red and brown felspathic sandstones and sandy shales. Ferric oxide forms one of the major components of the Red-Beds, and this was deposited simultaneously with the other rock-forming components (Stockley, 1947). Carrol and Bascomb (1967) in their notes on the soils of Lesotho noted that, truly red soils can form from Red-Bed material without being necessarily influenced by the weathering products of dolerite. Most Red-Bed rocks are fine-grained and the texture of the soils derived from them is dominated by the fine sand fraction.

In the Lowlanas, red soils cover crests and upper erosion slopes of spurred interfluves in some areas of Red-Bed sandstone. They appear to be formed by the colluvial reworking of the weathered products of sandstone and possibly dolerite. In the foothills the soils occur on pediment slopes at the foot of the basaltic mountains.

General Properties

Tables 2 and 3 contain some physical and chemical properties characteristic of the red soils of Lesotho. In addition to these properties, broader generalizations and statements can be made about the soils.

The red soils of planation surfaces and plateaux in the lowlands, Leribe, Rama, Hololo and Matela are medium textured throughout their profiles and are moderately acidic to strongly acidic. They are well drained and contain low activity clays dominated by kaolinite and sesquioxides, thus indicating a stronger weathering history.

The finer textured red soils of the Foothills are characterized by low pH values (4.3 - 5.0) in their surface horizons. This could be due to the leaching of basic cations during their development. Compared to the other soils in Lesotho they contain appreciable amounts of aluminium. Laboratory data
indicate aluminium saturation in these soils to be as much as 60 percent.

In the finer-textured Foothill red soils Machache, Matsaba, Sefikeng and Tumo, phosphorus fixation appears to be a problem. However, detailed research has not been done on this aspect. Fixation could be due to the rather inert clays and aluminium. Another characteristic of the soils is their comparatively higher water holding capacity, which could be attributed to their texture and their comparatively high organic matter content.

**MANAGEMENT**

**General**

Red soils in Lesotho are basically suited to most crops. The main limitations to their use, are related to erosion, fertility, organic matter content and acidity conditions in these soils.

In discussing the management of red soils in Lesotho, it is important to note that both physical and chemical properties of the soils differ from one physiographic region to the other. It should therefore be expected that their response to management and treatment will differ.

The lowland soils with the exception of the Hololo series are dominated by fine sands and silts in their upper horizons. This physical property tends to make them more susceptible to erosion. Proper management and erosion control measures and practices are essential. On steeper slopes of more than 5 percent. Terracing has been implemented.

Conservation of moisture and maintenance of natural fertility of the lowland soils are the most important management considerations. Addition of crop residues as well as minimum tillage practices on these soils, have appeared to contribute significantly towards enhancing higher moisture holding capacity as well as in improving the natural fertility of the soils.
### TABLE 2  Some Physical Properties of the Red Soils of Lesotho

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Dominant Clay Mineralogy</th>
<th>Organic Matter %</th>
<th>Clay %</th>
<th>Colour</th>
<th>Texture</th>
<th>Available water holding capacity (cm/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lowlands</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leribe</td>
<td>Kaolinite</td>
<td>1.0</td>
<td>18.4</td>
<td>5YR 3/4</td>
<td>loam</td>
<td>0.09</td>
</tr>
<tr>
<td>Rama</td>
<td>Kaolinite</td>
<td>0.8</td>
<td>13.4</td>
<td>5YR 4/6</td>
<td>fine sandy loam</td>
<td>0.06</td>
</tr>
<tr>
<td>Hololo</td>
<td>N/D</td>
<td>1.0</td>
<td>32.0</td>
<td>5YR 4/6</td>
<td>clay loam</td>
<td>0.05</td>
</tr>
<tr>
<td>Matela</td>
<td>Kaolinite</td>
<td>0.6</td>
<td>7.7</td>
<td>5YR 4/4</td>
<td>loamy fine sand</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>Foothills</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machache</td>
<td>Halloysite</td>
<td>4.0</td>
<td>42.5</td>
<td>5YR 3/3</td>
<td>silt loam</td>
<td>0.15</td>
</tr>
<tr>
<td>Matsaba</td>
<td>N/D</td>
<td>3.0</td>
<td>48.0</td>
<td>5YR 3/3</td>
<td>clay loam</td>
<td>0.17</td>
</tr>
<tr>
<td>Sefikeng</td>
<td>Halloysite</td>
<td>4.0</td>
<td>38.5</td>
<td>5YR 3/3</td>
<td>silt loam</td>
<td>0.16</td>
</tr>
<tr>
<td>Tumo</td>
<td>Kaolinite</td>
<td>2.0</td>
<td>25.2</td>
<td>5YR 3/4</td>
<td>silt loam</td>
<td>0.10</td>
</tr>
</tbody>
</table>

* Properties mentioned in this table refer to the surface horizons of the soil series.
** N/D - no data available,
TABLE 3  Some Chemical Properties of the Red Soils of Lesotho

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>pH</th>
<th>Aluminum (%)</th>
<th>CEC (meq/100g) Saturation</th>
<th>CEC (sum) Meq/100g</th>
<th>Base Saturation % NH₄OAC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lowlands</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leribe</td>
<td>4.8</td>
<td>13.0</td>
<td>5.3</td>
<td>10.6</td>
<td>51.0</td>
</tr>
<tr>
<td>Rama</td>
<td>5.2</td>
<td>8.0</td>
<td>3.4</td>
<td>6.3</td>
<td>65.0</td>
</tr>
<tr>
<td>Hololo</td>
<td>4.9</td>
<td>N/D</td>
<td>N/D</td>
<td>24.1</td>
<td>N/D</td>
</tr>
<tr>
<td>Matela</td>
<td>4.8</td>
<td>11.0</td>
<td>2.7</td>
<td>4.0</td>
<td>63.0</td>
</tr>
<tr>
<td><strong>Foothills</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machache</td>
<td>4.9</td>
<td>9.0</td>
<td>17.3</td>
<td>24.4</td>
<td>46.0</td>
</tr>
<tr>
<td>Matsaba</td>
<td>5.3</td>
<td>N/D</td>
<td>N/D</td>
<td>23.5</td>
<td>N/D</td>
</tr>
<tr>
<td>Sefikeng</td>
<td>4.3</td>
<td>59.0</td>
<td>13.6</td>
<td>21.7</td>
<td>13.6</td>
</tr>
<tr>
<td>Tumo</td>
<td>4.3</td>
<td>33.0</td>
<td>7.5</td>
<td>12.2</td>
<td>32.0</td>
</tr>
</tbody>
</table>

* Surface properties of profiles considered.
** No data available.

Source: Cauley et al. (1985). Carroll et al. (1979)
The lowland red soils are used extensively for the production of maize, sorghum, sunflower and fodder crops. The response of the crops is good under proper management.

Foothill Red Soils

The finer textured foothill soils are noted for their phosphorus fixation. Addition of large quantities of phosphate fertilizers is necessary on these soils. However, no long-term researchers has been done on these soils to measure the responses of different plants to different rates of phosphorus application.

Another major management concern in these soils is related to their high acidity. Liming has been practiced especially where wheat is grown on these soils. It appears that large quantities of lime are necessary to raise the pH in these soils to plant-tolerant levels. No long-term research data exist on this aspect as to what level the pH needs to be raised in order to achieve optimum yields. Compared to the Lowland red soils, the Foothill soils have relatively high levels of organic matter (Table 2) and better water holding capacity. The soils are mostly cultivated under wheat, sorghum, peas and fodder crops.

The red soils of the Foothills are well suited to farming if erosion is controlled through terracing and proper cropping practices such alternating row crops with cover crops. Tillage on these soils needs to be done at a certain critical moisture content, otherwise the clays on these soils tend to form clods which might hinder seed germination.
CONCLUSION

The red soils of Lesotho form an important group in the Lowlands and Foothills of the country. Although no detailed evidence exists as to the exact cause of their red colour, preliminary observations suggests that, in some of the soils especially those of the Lowlands, the colour may be mainly an inherited property from the parent material, whereas in those found in the Foothills the colour may be mainly a result of pedogenic processes.

As a group, they are used for cultivation of traditional crops such as sorghum, wheat and maize. If appropriate pH is maintained and adequate fertilizer applied together with proper soil management practices, good crop yields could be obtained on these soils.

REFERENCES


EXTENT, DISTRIBUTION AND PROPERTIES
OF RED SOILS IN MALAWI

M.W. LOWOLE and P. BANDA
INTRODUCTION

Location and Physical Environment of Malawi

Malawi lies between 9° 45' and 17° 16' south latitude, and 33° and 36° east longitude. The country is elongated, being about 900km in length and varying in width between 80 and 161km. The total area of the country is 118 845 sq km of which 94 396 sq km is land area; the rest being covered by lakes. The country is bordered to the north by Tanzania, to the east, south and south-west by Mozambique and to the west by Zambia.

Physiographically, Malawi can be divided into two major parts, namely:--

The Rift Valley

The valley is the southern end of the Great East Africa Rift Valley system. In elevation it ranges from about 37m at the southern end to 610m. The valley forms the eastern flank of the country.

The Upland

The upland is mostly plains and plateaux. These plains and plateaux lie between 763 and 1373m above sea level. The rest of the upland is mountains which rise above the general level of the plains and plateaux. The mountains have elevations which range from 1373m to nearly 3050m.

The geology of the Rift Valley is different from that of the Upland. The Rift Valley floor comprises old and new alluvial materials mostly. Colluvial materials from the uplands fringe the valley floor. On the other hand, most of the Upland is underlain by the Pre-Cambrian Basement Complex. The Basement Complex is composed of igneous and metamorphic rock. The most common types of rock of the Complex are the
hornblende-biotite gneisses. Muscovite schists, quartzites, granulites, pyroxene gneisses and granites also occur.

The climate of Malawi is influenced by the country's proximity to the Indian Ocean, the presence of the Lake, highlands and accentuated relief.

The most distinctive feature about the Malawi climate is that the rainfall is highly seasonal, with most areas having marked wet and dry seasons. The rainy season is from November to April and the dry season, when practically no rain falls, is from June to October. Highlands and some lakeshore areas receive the highest (over 1500mm) amounts of rain while rain-shadow areas receive about 600mm mean annual rainfall.

Temperatures vary with altitude. Since there is a wide range in altitude, there is a corresponding wide range in temperature. The lowest mean annual temperatures of below 16°C are experienced at high altitudes of mountains and plateaux. On the other hand, the highest temperatures are associated with the lowest parts of the Rift Valley where the mean annual temperature is at least 25°C and the daily maximum temperature can be as high as 40°C.

**RED SOILS IN MALAWI**

**Definition**

For the purposes of this paper, red soils comprise all soils with an horizon having a colour of red or shades of red, for example dusky-red, dark-red and yellowish-red. Also included in the red soils are those soils with brown, reddish-yellow, strong-brown, brown and light-brown. In terms of the Munsell colour notations, these colours have a hue of
with values of 3 or more and chromas of 4 or more, or with values of 3 to 4 and chromas of 3; or a hue of 2.5YR with values of 3 or more and chromas of 6 or more, or with values of 2 to 4 and a chroma of 4; or a hue of 5YR with values of 3 to 6 and chromas of 4 or more, or with values of 3 to 4 and a chroma of 3; or a hue of 7.5YR with values of 3 to 6 and chromas of 4 or more.

These red colours indicate the presence of significant amounts of ferric oxides the most prevalent of which are limonite (X-ray amorphous), goethite and, in some instances, even haematite. The red colours also imply good soil drainage since the ferric form of iron is dominant only in well-drained soils. Since the colours reflect the presence of iron in the soil, it is considered that these soils were formed from parent rocks containing significant amounts of iron.

The red soils in Malawi can be divided into three broad categories which are Luvisols (locally known as ferruginous soils), Nitosols (ferrisols) and Ferralsols (ferrallitic soils). The Ferralsols can be subdivided into Humic Ferralsols, Ferralsols with a petric phase and Orthic/Xanthic Ferralsols.

So the discussion of red soils in Malawi will be concentrated on the Luvisols, Nitosols, Orthic/Xanthic Ferralsols, Humic Ferralsols, and Ferralsols with a petric phase. Information and data have been drawn from Billing, 1978; Brown and Young, 1965; Lowole, 1983; Lowole, 1985; Meadars, 1983; Mitchell and Ntokotha, 1974; Pike and Rimmington, 1965; and Young and Brown, 1962.

Extent of Red Soils in Malawi

The land area of Malawi is 94 396 sq km. Of this, the area covered by red soils is about 52 575 sq km or about 56 per
cent of the land area. The areal extent of each of the different types of red soils in Malawi is presented in Table I.

**TABLE I : TYPES AND EXTENT OF RED SOILS IN MALAWI**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Areal Extent (km²)</th>
<th>Land Area of Malawi (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthic/Xanthic Ferralsols</td>
<td>31 098</td>
<td></td>
</tr>
<tr>
<td>Ferric Luvisols</td>
<td>12 950</td>
<td></td>
</tr>
<tr>
<td>Ferralsols (petric phase)</td>
<td>3 730</td>
<td></td>
</tr>
<tr>
<td>Humic Ferralsols</td>
<td>2 084</td>
<td></td>
</tr>
<tr>
<td>Dystric Nitosols</td>
<td>2 715</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>52 577</strong></td>
<td><strong>94 396</strong></td>
</tr>
</tbody>
</table>

It can be seen from the table that the Ferralsols constitute the dominant type of red soil in Malawi. The total area of Ferralsols is 36 912 sq km which is about 70 per cent of the total area covered by red soils.

**Distribution of Red Soils in Malawi**

The distribution of red soils in Malawi is firstly discussed with respect to other types of soils in the country. Thereafter the distribution of each type of red soil is discussed in relation to the causal environmental factors.

As already pointed out, Malawi can physiographically be divided into the Rift Valley and the Upland. The distribution of red soils, in relation to other types, is closely related to the physical divisions. There are only isolated areas
Figure 1: Distribution of major red soil units of Malawi
(From a map compiled by M. W. Lowole, 1984.)

Explanation
1. Ferric luvisols
2. Orthic ferralsols (predominantly)
3. Xanthic ferralsols
4. Humic ferralsols
5. Oystric nitosols
with red soils within the Rift Valley, all of which are remnants of the upland. Soils typical of the valley floor are grey soils of alluvial origin. On the other hand, the accompanying Soil Map of Malawi shows that most of the red soils occur on the Upland.

The soils have formed on those parts of the Upland which are underlain by hornblende-biotite gneisses and other rocks of intermediate or basic composition. Where the upland is hilly and composed of granites, quartzites and other siliceous rocks, Lithosols are the main soils. In short, red soils occur on the Upland where the underlying rocks are of intermediate or basic composition.

Each of the five types of red soils has resulted from specific causal environmental factors. Consequently, the distribution of these soils is directly related to the spatial occurrence of these factors. The accompanying Soil Map of Malawi shows the distribution of different types of red soils.

(i) **Humic Ferralsols**

The major areas of Humic Ferralsols are to the north of the country. Here they occur on the high plateaux of the Vipya and Nyika. Minor areas of these soils occur to the south of the country on Mulanje Mountain. Humic Ferralsols do not occur in the middle part of the country in significant areas.

One of the diagnostic features of the Humic Ferralsols is their high content of organic matter (above 7 per cent). This feature is a result of the combined effect of (a) high biomass production (b) high altitude (mostly above 1800m) which results in relatively low temperatures (13 - 16°C).
The large amounts of organic matter do not decompose and get removed fast enough because of the relatively low temperatures.

(ii) Dystric Nitosols

These Nitosols predominantly occur to the north of the country. The major areas are Nkhata-Bay lakeshore areas and the lower parts of the north Vipya Plateau. Other areas are East of Misuku Hills and Livingstonia Hills. To the south of the country, Dystric Nitosols occur on the interfluvies at the foot of Mulanje mountain. The soils do not occur in the middle part of the country in significant areas.

Nitosols are characteristically very deep (more than 2m), red, well-drained and very friable. The soils have resulted from the interaction of three main factors (a) high mean annual rainfall (over 1500mm) (b) intermediate or basic parent rocks, and (c) dissected topography.

The high rainfall and warm summer temperatures ensure a deep weathering front while the dissected topography ensures free site drainage; the basic parent rocks result in clayey soils on weathering.

(iii) Xanthic Ferralsols with a Petric Phase

The Xanthic Ferralsols are underlain by massive laterite and are mostly restricted to the south-west of Kasungu district in the middle part of the country. Minor areas of these soils occur just south of Nkhota-kota district. The soils do not occur to the north and south of the country in significant areas.

The feature that sets these soils apart from the other types of Ferralsols is the presence of massive laterite or
abundant laterite gravels at varying depths within 100cm depth. The soils have developed on that part of the Mid-Tertiary erosion plain which is almost flat, with slopes of less than 1 per cent. The massive laterite appears to be the result of leaching to which the landform has been exposed over a long period.

(iv) Orthic/Xanthic Ferralsols

Orthic/Xanthic Ferralsols are widely distributed in the country. The accompanying soil map shows that quite large areas are found in all parts of the country. However, the largest area of these soils, is in the middle part of the country where they occur to the north and south-west of Kasungu district and north and south-east of Mchinji district. To the north of the country the soils are found to the west of and between Mzimba and Rumphi districts. To the south of the country, they are found from Zomba to Thyolo districts.

Ferralsols are the most highly weathered soils. They normally occur in the humid tropics in areas with mean annual rainfall of over 1200mm. However, in Malawi these soils occur on gently sloping plains with mean annual rainfall of between 600 and 900mm only. So the Ferralsols in Malawi may have been formed in a much wetter period in the past.

(v) Ferric Luvisols

The largest area of Ferric Luvisols is in the middle part of the country where they extend from Ntchisi, through Lilongwe, to Dedza district. To the south of the country, the Luvisols mostly occur in association with Lithosols. Here the main area extends from Nyambi (in Machinga district)
to Likulilo Hills (in Nangoche district). In the north of the country Ferric Luvisols are of a very limited occurrence, the only significant area being around Ekwendeni.

Ferric Luvisols and Orthic Ferralsols have formed on similar landforms and under similar climatic conditions. However, the Luvisols have been formed only on those parts of the landforms where the predominant rocks are basic or intermediate in composition.

Properties of Red Soils in Malawi

The five types of red soils are significantly different from each other in terms of properties other than colour. The morphological and chemical characteristics of each of the soils are discussed below:

(i) Ferric Luvisols

Morphological Properties

Ferric Luvisols are normally dark-brown to a depth of about 20cm. From this depth to about 60cm, these soils are normally dark-reddish-brown. They are invariably dark-red or red below 60cm.

The texture of the upper horizons is typically sandy clay loam but it may be sandy clay. The subsoils are invariably sandy clay or clay.

Ferric Luvisols have good structure down to a depth of 60cm. The structure is normally strong to moderate fine blocky. However, below this depth the soils are apparently structureless.
Alternatively the horizons which appear structureless may in fact have a well developed micro-structure.

The soil consistence also changes with depth. In the upper 60cm the soils are hard or slightly hard when dry and firm when moist. In contrast, below 60cm the soils are markedly soft and friable. The soils are normally deep except where they occur on dissected sites.

Chemical Properties

Chemical properties of the Ferric Luvisols are presented in Table 2. The table shows that Ferric Luvisols in Malawi are acid to almost neutral and their base saturation is moderate to high. The acidic Luvisols either border those areas with high rainfall or those to which fertilizers have been applied over a long period. Organic matter ranges from low to high. The low levels of organic matter are associated with Luvisols on which traditional agricultural methods are practised. Nitrogen ranges from low to high. Available phosphorus is very variable, ranging from trace amounts to medium levels. The levels of available phosphorus tend to be low because most of the rocks from which these soils were formed have low contents of primary phosphorus to start with. In addition, the levels are rendered even lower because most of the phosphorus that is released during weathering is fixed by oxides.

Exchangeable potassium is normally medium or high. Such favourable levels of potassium imply that the rocks from which the soils are formed have high potassium content. Exchangeable calcium and magnesium are low. The cation exchange capacity
<table>
<thead>
<tr>
<th>TYPE OF SOIL</th>
<th>PH</th>
<th>OM %</th>
<th>N %</th>
<th>ppm</th>
<th>Exch. K me%</th>
<th>Exch. Ca me%</th>
<th>Exch. Mg me%</th>
<th>BS %</th>
<th>CEC me% (soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FERRIC LUVISOLS</td>
<td>5.3-6.7</td>
<td>0.5-4.5</td>
<td>0.04-0.20</td>
<td>+tr-24</td>
<td>0.25-0.57</td>
<td>2.53-3.26</td>
<td>0.87-1.90</td>
<td>60-90</td>
<td>5.44-8.50</td>
</tr>
<tr>
<td>DYSTRIC NITOSOLS</td>
<td>4.3-5.0</td>
<td>1.7-4.6</td>
<td>0.08-0.23</td>
<td>10-33</td>
<td>0.06-0.35</td>
<td>0.70-0.90</td>
<td>0.10-0.30</td>
<td>17-49</td>
<td>1.97-2.73</td>
</tr>
<tr>
<td>ORTHIC/XANTHIC FERRALSOLS</td>
<td>5.5-5.7</td>
<td>0.4-1.6</td>
<td>0.05-0.12</td>
<td>tr-22</td>
<td>0.11-0.36</td>
<td>2.20-4.50</td>
<td>0.72-0.96</td>
<td>44-70</td>
<td>3.36-7.50</td>
</tr>
<tr>
<td>XANTHIC FERRALSOLS (PETRIC PHASE)</td>
<td>5.0-6.0</td>
<td>0.5-2.0</td>
<td>0.04-0.1</td>
<td>tr-30</td>
<td>0.03-0.4</td>
<td>-</td>
<td>-</td>
<td>40-80</td>
<td>-</td>
</tr>
<tr>
<td>HUMIC FERRALSOLS</td>
<td>4.5-6.0</td>
<td>4-20</td>
<td>0.15-0.4</td>
<td>tr-15</td>
<td>0.09-0.8</td>
<td>-</td>
<td>-</td>
<td>15-30</td>
<td>-</td>
</tr>
</tbody>
</table>

* +tr = trace  
  - = Not available
(CEC) of the soil is mostly low indicating the predominance of kandites in the clay fraction. Nevertheless the medium levels of CEC show that some 2:1 clay minerals may still be present.

Agricultural Potential

In Malawi, Ferric Luvisols are agriculturally the most productive red soils. They have the best soil structure which facilitates root penetration, whilst the clay textures enhance moisture and nutrient holding capacity. Weatherable minerals and organic matter, still present in appreciable quantities, serve as sources of plant nutrients.

(ii) Dystric Nitrosols

Morphological Properties

Dystric Nitrosols are normally dark-reddish-brown from the surface down to about 40cm; but they may be dark-red from about 20cm to 40cm. The soils are invariably red below about 50cm.

From the surface down to about 25cm the texture of the Nitrosols is sandy clay loam; occasionally the topsoils are sandy clay. Below 30cm the soil texture is either sandy clay or clay with over 40 per cent clay.

The soil structure of the topsoil is fine crumb, but the subsoils do not have observable structural units. It is possible that the subsoil may be finely-structured. Clay cutans, characteristic of Nitrosols, are rather rare.
The soils are markedly soft when dry and friable when moist, right from the surface. In this respect they differ from Ferric Luvisols in which the soft and friable consistence starts below 60cm depth. The Nitosols are very deep with no sign of parent rock within 200cm.

Chemical Properties

The chemical properties of the Dystric Nitosols are presented in Table 2. These soils occur in high mean annual rainfall (over 1500mm) areas in Malawi. As a result, the soils are characteristically strongly acid and of very low to low base saturation. The CEC is also very low indicating the predominance of kandites in the clay fraction. The organic matter ranges from medium to high while the nitrogen levels range from low to high. Available phosphorous is variable, ranging from low to moderately high. Potassium ranges from very low to medium and both calcium and magnesium are very low.

Agricultural Potential

Since the Nitosols are deep and occur in high rainfall areas, they are very suitable for perennial crops such as tea, coffee and rubber. Cassava and bananas also do well on these soils.

(iii) Orthic/Xanthic Ferralsols

Morphological Properties

Topsoils of the Orthic/Xanthic Ferralsols are dark-greyish-brown or dark-brown. Subsoils are normally yellowish-red, reddish-brown, strong-brown or reddish-yellow; red subsoils also occur.
These soils normally have sand or loamy sand topsoils underlain by sandy clay loam. Subsoils with a sandy clay texture are also common. The sand fraction is normally coarse.

Characteristically these soils are massive throughout the profile. Occassionally soil structure may be weakly expressed in the subsoil if the subsoil texture is sandy clay.

The topsoils are normally loose or soft. If the texture of the subsoil is sandy clay loam, the subsoil consistence is soft and friable. However, if the subsoil texture is sandy clay or finer, then the soils become very hard when dry.

**Chemical Properties**

The data in Table 2 show that Orthic/Xanthic Ferralsols are moderately acid to acid with low to moderate base saturation. Both organic matter and nitrogen are either very low or low. Available phosphorus levels are variable, ranging from trace amounts to medium levels. Potassium ranges from low to medium while calcium and magnesium are either low or very low.

**Agricultural Potential**

These soils have rather low natural fertility. If textures are sandy loam or light sandy clay loam, the water holding capacity is low. Where the topsoil is overlying a compact, structureless horizon, root penetration may be hindered. However, most of these deficiencies can be corrected by improved agricultural practices such as use of fertilizers.
(iv) Xanthic Ferralsols with a Petric Phase

Morphological Properties

The Ferralsols with a petric phase are similar to the Ferralsols described above previously in many respects. However, they differ from them in that the former have a characteristic massive laterite layer within 100cm from the surface.

Chemical Properties

The data (Table 2) shows that the soils are moderately acid with moderately low to moderately high base saturation. Organic matter is low to medium while nitrogen is low or very low. Available phosphorus levels are variable, ranging from trace to moderate amounts. Exchangeable potassium levels range from very low to medium.

Agricultural Potential

Where the laterite is shallower than 50cm, the soils are not suitable for agriculture because the effective medium for root growth is severely limited and textures tend to be coarse. But where the laterite is deep the soils can be cultivated provided fertilizers are applied to make up for the low nutrient levels.

(v) Humic Ferralsols

Morphological Properties

The distinctive features of these soils are the high organic matter content in the topsoil and their location at high altitudes.
The soils are dark-brown or reddish-brown from the surface down to about 10cm. Below this depth, the soils are either red (under grass) or strong-brown (under forest) and are well-drained.

The texture of the topsoil is sandy loam. Subsoil textures range from sandy clay loam to clay.

The structure of the topsoil is fine crumb and that of the subsoil is either fine or medium subangular blocky. The soils are more than 120cm deep in most cases.

Chemical Properties

In Table 2, the data show that the soils are acid and have very low base saturation. These features are a result of the combined effect of high rainfall and free soil drainage which allows a large quantity of rain water to leach through the soils.

Organic matter in the topsoil is characteristically high, with the levels being as high as 20 per cent under forest. The relatively low temperatures, as a result of high altitude, slow down the decomposition and loss of organic materials.
Hence organic matter tends to accumulate. Nitrogen is correspondingly high. Available phosphorous is low to medium and exchangeable potassium ranges from very low to medium.

**Agricultural Potential**

Owing to the high elevation and low temperatures, the soils cannot be put to arable use. The areas with these soils are only good for wildlife.

**SUMMARY**

Red soils cover a large part of the land area of Malawi. The main types of red soils being the Orthic/Xanthic Ferralsols, Ferric Luvisols, Ferralsols with a petric phase, Humic Ferralsols and Dystric Nitosols.

The Orthic/Xanthic Ferralsols are widely distributed in the country while the other red soils tend to be more localized in occurrence.

The properties of the most prevalent red soils are such that the soils are potentially suitable for agriculture. However, the full potential of these soils can be realised only with continued improvement in all aspects of agricultural technology.
REFERENCES


DISTRIBUTION, EXTENT AND MAJOR CHARACTERISTICS OF RED SOILS IN TANZANIA

S.E. MUGOGO
Soil Survey of Tanzania

SUMMARY

Some general characteristics of red soils are described and briefly discussed in relation to the Tanzanian situation. An approximate correlation is made between Tanzanian red soil types and corresponding taxa of the U.S. Taxonomy, the F.A.O. UNESCO legend and the French classification. The distribution of the soils in relation to the country's various physiographic units is explained. Areal extent on a nation-wide basis and also extent in each of the physiographic units is described. Morphological, physical and chemical data are presented in tables and are accompanied by profile descriptions.

INTRODUCTION

Red soils are considered to have subsoil or whole soil Munsell colours with hues of 10R, 2.5YR and 5YR. Colour and drainage of the red soils are closely related. Most of the red soils are well drained. It has been suggested in the literature that red soils have high iron content. However, not all red soils have a high iron content.

The red soils of Tanzania fall into two broad categories namely Ferrallitic and Ferruginous soils (D’hoore, 1964).

Ferrallitic soils are normally found in areas with rainfall of more than 1,000 mm with an isohyperthermic temperature regime or isothermic in mountain areas and Udic or Ustic moisture regime. Where these soils are found in an aridic moisture regime it is assumed they were formed under Udic, iso-hyperthermic conditions. The main soil forming process
is ferrallitization which consists of accumulation of iron and aluminium oxides as a result of intensive weathering of primary minerals with a nearly complete elimination of bases and an important elimination of silica. The clay minerals are of the Kaolinitic group or are simple hydroxides of iron or aluminium, most often crystallized as goethite and gibbsite, but sometimes present in the amorphous state. Ferrallitic soils belong to various taxonomic units of the different international classification systems. These are Inceptisols, Ultisols and Oxisols in Soil Taxonomy (Soil Survey Staff, 1975) or (chromic) Cambisols, Ferralsols, Nitosols and Acrisols in the FAO Legend (FAO-UNESCO, 1979) or Sols Ferralitiques peuvevolues, Sols ferralitiques lessives and Sols ferralitiques typiques in the French classification.

Ferruginous soils are formed under drier conditions with an annual rainfall of 500 to 1200 mm. Ferruginous soils are fersiallitic in composition characterized by the following soil forming processes - rufe-faction, argillation, leaching and movement of clay and decarbonation if parent material is calcareous. Some ferruginous soils may occur in association with ferrallitic soils in humid areas. Ferruginous soils, common in Tanzania correspond to the following categories in international classification systems:-

Alfisols (Rhodustalfs, Haplustalfs and Paleustalfs) in Soil Taxonomy; Luvisols (chromic and ferric in the FAO Legend and Sols fersiallitiques lessives in the French classification.

DISTRIBUTION AND AREAL EXTENT OF THE RED SOILS

To have a better picture of the distribution and extent of the red soils in Tanzania, it is convenient to subdivide the country into nine physiographic zones, namely: Coastal zone (C), Eastern plateaus and mountain blocks (E), Southern highlands (H), Northern Rift zone and Volcanic Highlands (N), Central Plateau (P), Rukwa-Ruha Rift zone (R), Inland Sedimentary Plateaux (S), Ufipa Plateau (U), and Western highlands (W). These zones are indicated in Table 1.
### TABLE 1: FEATURES OF THE PHYSIOGRAPHIC REGIONS

<table>
<thead>
<tr>
<th>Mapping Unit Symbol</th>
<th>Physiographic region</th>
<th>Main features</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Costal Zone</td>
<td>Low altitude plains (below 750m) developed on mainly marine secondary and tertiary sediments</td>
</tr>
<tr>
<td>E</td>
<td>Eastern plateaux and mountain blocks</td>
<td>Low to medium altitude plains (150-1300m) with isolated mountain blocks (1000-2500m) developed on precambrian metamorphic rocks</td>
</tr>
<tr>
<td>H</td>
<td>Southern Highlands</td>
<td>High altitude plateaux (1500-2500m) developed on granites, precambrian metamorphic rocks and/or volcanic deposits.</td>
</tr>
<tr>
<td>N</td>
<td>Southern Rift zone and Volcanic Highlands</td>
<td>Medium to high altitude plains (150-1300m) with isolated mountain blocks (1000-2500m) developed on precambrian metamorphic rocks</td>
</tr>
<tr>
<td>P</td>
<td>Central Plateau</td>
<td>Medium altitude plains (1000-1300m) developed mainly on granites</td>
</tr>
<tr>
<td>R</td>
<td>Rukwa-Ruha riftzone</td>
<td>Medium altitude rift depression (800-1200m) filled up with lacustrine sediments</td>
</tr>
<tr>
<td>S</td>
<td>Inland Sedimentary</td>
<td>Medium altitude plains (750-1000m) developed mainly on Karroo sediments</td>
</tr>
<tr>
<td>U</td>
<td>Ufipa Plateau</td>
<td>High altitude (1500-2200m) uplifted plateau developed on metamorphic, sedimentary and granitic rocks</td>
</tr>
<tr>
<td>W</td>
<td>Western Highlands</td>
<td>Medium to high altitude plains (1200-1900m) developed on volcanic or sedimentary rocks</td>
</tr>
</tbody>
</table>
**TABLE 2:** ESTIMATED AREAL EXTENT OF THE RED SOILS IN TANZANIA AND THEIR RELATIVE EXTENT (%) IN THE PHYSIOGRAPHIC REGIONS

<table>
<thead>
<tr>
<th>SOIL</th>
<th>PROPORTION (%) OF RED SOILS IN THE PHYSIOGRAPHIC REGIONS</th>
<th>EXTENT OF THE SOILS</th>
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<tr>
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<td>C</td>
<td>E</td>
</tr>
<tr>
<td>Ferralsol</td>
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<td>25</td>
</tr>
<tr>
<td>Luvisol</td>
<td>*</td>
<td>21</td>
</tr>
<tr>
<td>Nitosol</td>
<td>*</td>
<td>52</td>
</tr>
<tr>
<td>Cambisol</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Total Areal</td>
<td>56080</td>
<td>197005</td>
</tr>
</tbody>
</table>

* Soil unit covers less than 5% of the physiographic system.

**FERRALSOLS**

The most widely occurring red soils are the Ferralsols. In total they occupy about 37% of the country as indicated in Table 2. They are predominant in the Inland sedimentary plateaux, western highlands, Ufipa plateau, Central Plateau and Costal zones.

They are also found to a lesser extent in the Eastern plateaux, Southern highlands and Rukwa-Ruaha rift zone. Ferralsols are found on the old stable land surfaces, their topography being flat or gently undulating. They are
also encountered on undulating to rolling plains, dissected uplands and foot­slopes. Where the topography is undulating to rolling (2-10%) the summits and upper slopes (0-2%) are usually occupied by other soil units, commonly the luisols. They occur on various igneous sediments. Ferralsols are well drained, moderately deep to deep dark red to red, friable sandy clay loams, sandy clays or clays with weak structure and weak profile development, low to very low natural fertility 15-60% clay, pH 4-7, O.C. 0.5 - 5%, TEB 2-6 meq% B.S. 20-100, CEC clay, 5 -16 meq %), no weatherable minerals and poor to moderate water storing properties depending on presence of "chemical barriers" (AWC 80-120, Smax 30-70 with chemical barrier, Smax 100-300 without chemical barrier). They may have high subsoil acidity and aluminium toxicity. A description of a typical red Ferralsol profile is given in Appendix 1:1. The soils are derived from gneissic rocks of the Usagaran System and mainly include well drained, deep, red friable clays. Response of nutrients and moisture holding capacity are low.

LUVISOLS

Luvisols are usually found on strongly dissected uplands and low hills transitional to high plateaux or mountains, low to medium altitude (500-1000m), on undulating to rolling footslopes and plains (2-10%) of semi-arid and semi-humid areas. They are very extensive in the Eastern plateaux and mountain blocks and Ufipa Plateau. In other physiographic regions they occupy less than 5% of the regions (Table 1). Luvisols are well drained, moderately deep to deep, dark red to red, friable clays with moderate to strong structure and evidence of clay illuviation (clay bulge, clay skins) with moderate natural fertility (clay 35-65%, pH 5 -7.5, O.C. 0.5-3%, TEB 10-20 Meq %, BS 20-90%, CEC 16-30 meq%, some weatherable minerals) and moderate moisture storing properties AWC 100, Smax 100-200). They may contain ironstone gravel or a continuous phase of ironstone at depth.

A description of a typical, representative red Luvisol is given in Appendix 2.1.
CAMBISOLS

These are relatively young soils associated with granitic rocks, continental deposits and intermediate and acidic metamorphic rocks. They occur on granitic hills and Inselberg footslopes. Occasionally they occur on gently undulating to undulating topography with slope gradients ranging from 2 to 8 per cent. Cambisols are well drained, moderately deep to deep, often gravelly, sandy loams and sandy clay loams with weak to moderate structural development and weak profile development, low to moderate natural fertility (clay percentage 10-20 in the top soil and 20-40 in the B horizon but there is no evidence of clay eluviation, pH 5-7, O.C. 0.5-3%, TEB 3-8, BS 30-80%, CEC 15-30 meq % and moderate to good moisture storing properties but have a tendency to surface capping, AWC 80-100, Smax 50-150.

A description of representative red cambisols is shown in Appendix 3.1.

NITOSOLS

Nitosols occur in dissected landscape on Quaternary erosion surfaces, generally on moderate and steep slope. They occur on undulating, rolling, hilly, dissected plateaux and plains of medium and high altitude developed on gneiss rock or on volcanic ash, lava and tuffs. They can also be encountered on flat to undulating and flat to rolling intramontane plains of medium and high altitude (1500-1800,) of humid and semi-humid regions mainly on gneiss. Nitosols commonly occur in the Southern Highland Zone and, to a lesser extent, in the Western Highlands (Table 1). Nitosols are well drained, deep, friable or firm clay loams, sandy clays and clays with moderate to strong structural development and profile development usually with clay skins and moderate to high natural fertility (clay 30-55%, pH 4.5-7, O.C. 3-8%, BS 20-60%, CEC 16-30) and favourable moisture storing properties (good internal drainage AWC 120 Smax 150-400). A description of a typical red Nitosol is shown in Appendix 4.1.
APPENDIX 1.1. DESCRIPTION OF A TYPICAL RED FERRALSOL PROFILE
(Profile 6a)

Location: Mlingano Agricultural Research Institute
Elevation: 180m a.s.l.
Physiographic position: convex upper slope
Land form: Rolling upland plain

The mean annual rainfall is 1,100mm, distributed bimodally with a high peak in April-May and a short rainy period in September to December with a weak peak in October-November. The mean annual temperature is 25°C and mean annual evapotranspiration is slightly higher than mean annual rainfall.

Profile description

Ap 0-10 cm Dark red (2.5YR 3/6,d) and dark reddish brown (2.5YR 2.5/4m) clay; moderate, fine and medium medium sub-angular blocky structure; slightly hard when dry, firm when moist, slightly sticky and slightly plastic when wet, many very fine and fine, few medium tubular pores, common fine roots; very few sand-sized grains, mainly quartz; clear smooth boundary.

Bul 10-30 cm Dusky red (10R 3/4m) clay; moderate medium and coarse subangular blocky structure; firm when moist, slightly sticky and slightly plastic when wet; many very fine and fine few medium tubular pores; patchy thin cutans, mainly in or near pores; patchy thin cutans, mainly in or near pores; common fine to very fine roots; few sand-sized grains, mainly quartz, clear wavy boundary.

Bu2 30-150+cm Dusky red (10R 3/4m) clay; weak medium to coarse subangular blocky structure, very friable when moist, slightly sticky and slightly plastic when wet; many very fine and fine tubular pores; very few very fine roots; few sand-sized grains of quartz and dark minerals.

CLASSIFICATION

USDA Soil Taxonomy: Typic Haplustox
FAO Legend: Rhodic Ferralsol
APPENDIX 1.2: ANALYTICAL DATA FOR PROFILE 6a

<table>
<thead>
<tr>
<th>DEPTH cm</th>
<th>HORIZON</th>
<th>PARTICLE SIZE DISTRIBUTION</th>
<th>BULK DENSITY g cm$^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SAND 50-20µ</td>
<td>SILT 20-2µ</td>
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<tr>
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<td>Ap</td>
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<tr>
<td>10-30</td>
<td>Bu1</td>
<td>40.4</td>
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<tr>
<td>30-150</td>
<td>Bu2</td>
<td>31.8</td>
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<tr>
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<th>% O.C</th>
<th>% N</th>
<th>C/N</th>
<th>p</th>
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<td>CaCl$_2$*</td>
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<tr>
<td>10-30</td>
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<td>4.1</td>
<td>1.50</td>
<td>0.140</td>
<td>11</td>
</tr>
<tr>
<td>30-150</td>
<td>4.7</td>
<td>4.3</td>
<td>0.90</td>
<td>0.075</td>
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<table>
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<tr>
<th>DEPTH cm</th>
<th>EXCHANGEABLE CATIONS meq/100 g soil</th>
<th>CEC NH$_4$OAc</th>
<th>CEC NH$_4$Cl</th>
<th>CEC CLAY</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>K</td>
<td>Ca</td>
<td>Mg</td>
</tr>
<tr>
<td>0-10</td>
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<td>1.2</td>
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<tr>
<td>30-150</td>
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<td>0.03</td>
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* 1:2,5
APPENDIX 1.3:  PHYSICAL DATA FOR PROFILE 6a

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<tr>
<th>SITE</th>
<th>DEPTH CM</th>
<th>BULK DENSITY g cm</th>
<th>GRAVIMETRIC MOISTURE PERCENT 1/3 bar</th>
<th>GRAVIMETRIC MOISTURE PERCENT 15 bar</th>
<th>AVAILABLE MOISTURE %</th>
<th>AWC mm/m</th>
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<tr>
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<td>23.60</td>
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<td>20.35</td>
<td>12.18</td>
<td>8.99</td>
<td>87</td>
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</table>
APPENDIX 2.1: DESCRIPTION OF A TYPICAL RED LUVisOL
(PROFILE 6b)

Location: Mlingano Agricultural Research Institute
Author: Mmari
Elevation: 180m (600 ft)
Physiographic position of the site: Convex upper slope
Landform of surrounding country: Rolling upland plain
Slope on which profile is situated: 10%
Vegetation or land use: Erosion experiments
Parent Material: Gneisses (usagaran rock) possibly with colluvial deposits
Moisture conditions: Moist throughout
Drainage: Well drained
Erosion: Sheet erosion
Presence of surface stones, rock outcrops: None

Ap 0-20cm Dark reddish brown (5YR 3/4d: 5YR 3/3m) clay; moderate subangular blocky structure, very hard when dry, friable when moist, sticky and slightly plastic when wet; common fine, medium roots; clear, smooth boundary.

B1t 20-70cm Dark red (2.5YR 3/6d and m) clay; strong subangular blocky structure, very hard when dry, friable when moist, sticky and plastic when wet; common fine, medium and coarse pores; common fine and few medium roots; patchy cutans, probably of clay and organic matter along channels, pores and insect burrows; gradual smooth boundary.

B2t 70-107/130cm Red (2.5YR 4/6d) and dark red (2.5YR 3/6m) clay; strong fine and medium subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; common fine and medium pores; few medium roots; broken cutans of clay on vertical and horizontal ped faces; abrupt wavy boundary.
Appendix 2.1 (continued)

Bc 107/130-140/162cm  Red (2.5YR 4/6d) and dark red (2.5YR 3/6m) very gravelly clay loam; massive; few fine roots; gravel composed mainly of quartz and weatherable rock.

CLASSIFICATION

USDA Soil Taxonomy : Oxic Rhodustalf
FAO Legend : Ferric Luvisol
## APPENDIX 2.2: -- ANALYTICAL DATA PROFILE 6b

<table>
<thead>
<tr>
<th>DEPTH cm</th>
<th>HORIZON</th>
<th>PARTICLE SIZE DISTRIBUTION per cent</th>
<th>BULK DENSITY g. cm(^{-3})</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td>SAND</td>
<td>SILT</td>
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<td></td>
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<td>50-20μ</td>
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<td>107/130-160</td>
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<th>DEPTH cm</th>
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<th>CEC (NH(_4)OAc) meq/100g</th>
<th>CEC CLAY meq/100g</th>
<th>BASE SAT %</th>
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<td>3.6</td>
<td>2.8</td>
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<tr>
<td>70-107/130</td>
<td>0.09</td>
<td>0.11</td>
<td>2.4</td>
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<tr>
<td>107/130-160</td>
<td>0.08</td>
<td>0.08</td>
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<td>2.2</td>
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APPENDIX 2.3: PHYSICAL DATA FOR PROFILE 6b

<table>
<thead>
<tr>
<th>SITE NO.</th>
<th>DEPTH cm</th>
<th>BULK DENSITY g cm$^{-3}$</th>
<th>GRAVIMETRIC MOISTURE PER CENT</th>
<th>AVAILABLE MOISTURE mm/m</th>
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<tr>
<td></td>
<td>0-20</td>
<td>1.15</td>
<td>25.23</td>
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<td>20-70</td>
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<tr>
<td>6B</td>
<td>70-107/1300</td>
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<td>25.16</td>
<td>17.03</td>
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<tr>
<td></td>
<td>107/130-140/160</td>
<td>1.17</td>
<td>23.96</td>
<td>16.51</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15 bar</td>
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</table>
APPENDIX 3.1: DESCRIPTION OF A TYPICAL RED CAMBISOL

Site Information

Location : 6 km north of Nyakaduha, Map 32/2;
            Coordinates 432,0-9706,2

Mapping Unit : HoPI-q/I

Soil unit : G2

Author(s) : Mugogo, Mari

Topography

Surrounding Landforms : Rolling hills with sloping pediment

Site : 2% slope; lower slope; elevation 1250m

Microtopography : Cultivation - ridges

Parent material : Medium textured regolith derived from monzonite rocks

Vegetation : Residual trees (Annona chrysophylla, Combretum spp.) and grasses

Land use : Cultivation: cassava, maize

Drainage : Well drained. Erosion/deposition: Nil

Profile Description

Ap 0-20 cm

Dark reddish brown (5YR 2.5/2m), sandy loam; weak fine and medium, subangular blocky; friable moist; non-sticky and non-plastic wet; many fine pores; many fine roots; clear smooth boundary; field pH 6.6

Au 20-43 cm

Dusky red (2.5YR 3/2m) sandy loam, weak fine and medium subangular blocky; friable moist, non-sticky and non-plastic wet; many fine pores; common fine roots; gradual smooth boundary; field pH 5.8.

Bu2 60-97 cm

Red (2.5YR 4/6m) sandy clay loam; moderate, fine and medium subangular blocky; friable moist, slightly sticky and slightly plastic wet; many fine pores; gradual smooth boundary; field pH 5.4
Appendix 3.1 (continued)

BW3 97-160 cm  Red (2.5YR 4/8) sandy clay loam; moderate fine and medium subangular blocky; friable moist; slightly sticky and slightly plastic wet; common fine pores; few roots; field pH 5.6

2c 160-200 cm  Yellowish brown (10YR 5/4m) very gravelly sandy loam; massive; about 70% angular and subangular gravels of weathering rock and quartz; field pH 5.8

CLASSIFICATION

USADA Soil Taxonomy:  Ustoxic Dystropept
FAO Legend:  Ferralic Cambisol

ANALYTICAL DATA

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<tr>
<th>DEPTH cm</th>
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<td>SILT</td>
<td>CLAY</td>
</tr>
<tr>
<td></td>
<td>50-20</td>
<td>20-2m</td>
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<td>0-20</td>
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<td>160-200</td>
<td>66.0</td>
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<table>
<thead>
<tr>
<th>0.0% Na</th>
<th>C/N</th>
<th>EXCHANGEABLE CATIONS (meq/100g soil)</th>
<th>SUM CEC OIL</th>
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<tr>
<td></td>
<td></td>
<td>Na</td>
<td>K</td>
<td>Ca</td>
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<td>0.07</td>
<td>0.18</td>
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<td>0.36</td>
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<td>0.27</td>
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<tr>
<td>0.18</td>
<td>0.02</td>
<td>9</td>
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<table>
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<tr>
<th>pH H₂O</th>
<th>SUM BASES</th>
<th>CEC CLAY</th>
<th>ESP</th>
<th>BASE SATURATION</th>
<th>P (ppm)</th>
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<tr>
<td>6.8</td>
<td>6.1</td>
<td>62.11</td>
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<td>98</td>
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<td>6.2</td>
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<td>97</td>
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<tr>
<td>6.1</td>
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<td>6.4</td>
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<td>28.1</td>
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<td>50.00</td>
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<td>98</td>
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APPENDIX 4.1: - DESCRIPTION OF A TYPICAL RED NITOSOL

Ap 0-30 Yellowish red (5YR 4/8d) sandy clay; moderate medium to coarse crumb structure; non-stricky nonplastic when wet, friable, slightly hard; common, very fine to fine inped pores; common, very fine to fine roots; gradual, smooth boundary.

Btz 30-90cm Red to dark red (2.5YR, 3.5/6d) sandy clay; weak, medium subangular blocky structure; non sticky non plastic when wet, very friable, soft, few to common very fine inped pores; few very fine roots; abrupt wavy boundary.

Bc 98-108cm Stoneline, mainly composed of gravel-size weakly weathered plagioclase and quartzite fragments. A dark red sandy clay (2.5YR 3/6d) was present in between the gravel pieces; clear, irregular boundary.

CB 100-130cm Red to dark red (2.5YR 3.5/6d); sandy clay loams; weak, medium, subangular blocky structure, non sticky, non plastic when wet, friable, soft; common very fine to fine inped pores; few very fine roots; clear broken boundary towards lithic contact.
## Analytical Data

<table>
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<tr>
<th>Depth</th>
<th>Particle Size Distribution</th>
<th>(\frac{1}{2} \text{ Water Between 1/3-15 Bars} )</th>
<th>CEC meq/100g</th>
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<tr>
<td></td>
<td>Sand 2-0.5</td>
<td>Silt 50-2</td>
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<td>30-90</td>
<td>45</td>
<td>6</td>
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<td>90-108</td>
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<td>108-130</td>
<td>51</td>
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<td>33</td>
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<table>
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<tr>
<th>pH</th>
<th>O.C %</th>
<th>P mg/kg</th>
<th>Exchangeable Cations (meq/100g)</th>
<th>CEC (SUM)</th>
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<td>K</td>
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<td>6.4</td>
<td>5.2</td>
<td>0.4</td>
<td>0.5</td>
<td>5.50</td>
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SOURCES OF INFORMATION NOT CITED IN TEXT


ANDERSON, G.D. 1967. Soils Map 1:3 000 000 in "Atlas of Tanzania".


MOBERG, J.P. 1981. (1) The Mineralogy of the clay, silt and sand fractions of soils from various parts of Tanzania and its relation to the soil forming factors.

(2) Pedological features of two soil associations in the Morogoro area, Tanzania, in relation to future land use. Department of Chem. Royal Vet. and Agricultural University, Copenhagen.


ABSTRACT

Red soils are common all over Zambia, including those of the Kalahari sand belt in the west of the country. Although locally they can occur over fairly large areas, their normal mode of occurrence is rather patchy, and they are not found over such extensive areas as some of the other major soils of Zambia. The formation of red soils in Zambia is basically governed by the type of parent material. Drainage plays an important role only in preserving red soils, as they characteristically occur in well drained positions. Most of the red soils have a fine clayey control section, but coarser textured red soils do occur. The influence of the parent material on the chemical characteristics of red soils is subordinate to the leaching effect of the rains, with the red soils in the north being considerably more strongly depleted of bases (strongly leached red clays) than those in the south (moderately leached red clays). This is also borne out in their classification, which ranges from acrustox and haplustox in the north to paleustult and paleustalf in the south. The red soils developed from limestone commonly have higher organic matter levels than the non-limestone soils, which accounts for the occurrence of red palustolls on the limestone plateau around Lusaka. The red soils of Zambia include some of the country's most productive soils, such that even among the strongly leached soils of the north, red soils are considered to be better than other acid soils. Some ideas are put forward to explain this.

INTRODUCTION

The red soil of Zambia were earlier described by Brammer (n.d.). Since then many more soil surveys at different levels of intensity have been carried out all over the country thus increasing knowledge of the distribution and properties of red soils considerably.
Red soils derive their importance not just from their striking colour, but also because they include the country's most productive soils. Even in the high rainfall zone, where virtually all the soils are strongly leached, red soils are considered, rightly or wrongly, as the better soils.

In this paper the red soils will be examined in the light of current knowledge and their importance vis-a-vis Zambia's agriculture will be reassessed.

AREAS OF OCCURRENCE AND MAIN TYPES

Red soils, defined as soils with Munsell colour hues or 5YR or redder, and commonly having high chromas (4 or more), are fairly widespread throughout Zambia. Generally, their mode of occurrence is rather patchy, in that they occupying relatively small areas in a matrix of soils with browner hues, or can be found over larger areas which, however, still do not cover such enormous tracts as is the case with some of Zambia's other major soils.

The 1:2,500,000 soil map of Zambia of 1969, on which red soils are distinguished separately, indicates that about 5% of the country is covered by red soils. Information obtained from soil surveys that have been carried out since then, has revealed that red soils are considerably more common. It has now been estimated, based on the extent given for red soil series in the Zambian Soil Classification (Veldkamp 1984), that red soils occupy approximately 15% of the country.

The main occurrence of red soils is in North-western Province (Solwezi, Kasempa, Mwinilunga and Chizera districts), Central and Lusaka Provinces (Kabwe south, Mumbwa and Lusaka districts), Southern Province from Mazabuka to Choma, Eastern
Province around Chipata and Petauke, Northern Province (northern part of Serenje district, from south of Mpika to Chinsali, Isoka and Nakonde, and discontinuous along the Tanzanian border between Mbala and Nakonde) and in Luapula Province (east and west of Kawambwa district in the Luena and Mbereshi districts). Isolated patches occur north of Ndola and Mufulira along the border with Zaire, and south of Kitwe and west of Luanshya, including the Mpongwe area, all in the Copperbelt Province. Scattered occurrences of red soils can also be found in the Kalahari sand belt, particularly around Livingstone, along the edge of the Zambezi valley between Senaga and Sesseke, near Mongu on high ridges adjoining the Zambezi valley and in Kabompo and Lukulu districts along the Kabompo river.

Nearly all of the red soils are situated in well drained upland positions on the gently undulating plateau. Red soils formed from limestone can also be found in Solwezi district in relatively large, well drained solution depressions.

The elevation of the plateau on which the red soils occur ranges from 1000 m to over 1500 m. Zambia's low areas, the Luangwa, Gwembe and Zambezi valleys, are almost devoid of red soils. Only small patches of red soils have been observed in the Zambezi valley between Chirundu and Luangwa, and near Mfuwe in the Luangwa valley.

The red soils of Zambia have been derived from a variety of parent materials, ranging from basic rocks, such as basalt and diorite, to acid materials like schists. They also occur on sedimentary parent material such as limestone, sandstone and quartz sands. Although the influence of the parent material is, to some extent, still recognizable in these soils particularly in the textural composition, the influence of climate as a soil forming factor has been more important. Soils in the high rainfall zone of the country (>1000 mm per year) are significantly more leached than the soils from the
low rainfall zone (<1000 mm per year).

Brammer (n.d.) identified four groups of red soils, which he differentiated on texture and on the degree of leaching as follows:

1. Red clays and red-brown loams
   1.1. moderately leached
   1.2. strongly leached

2. Barotse sands
   2.1. moderately leached
   2.2. strongly leached

This separation is still useful, although the notion that red clays occur over basic rock and red loams have formed from acid rocks has now been abandoned, since red clays apparently also develop over acid rocks like slates and phyllites.

SOIL CHARACTERISTICS

The texture of the control section of red clay and red-brown loamy soils is mostly fine clayey. Fine loamy red soils only occur as a red variant of otherwise dominatly yellower soils, as is the case with the Misamfu-red soil series (the Misamfu series s.s. is fine loamy), as colluvial deposits or in the transitional zone from Kalahari sands to residual soils. Apart from these examples, fine loamy red soils are rare. The red Kalahari sands (a name that is preferred to Barotse sands these days) are mostly sandy in the control section, but are occasionally also coarse loamy.

The division by Brammer into red clays and red-brown loams is based mainly on the texture of the topsoil. Red clays have a sandy clay loam to clay topsoil, while the topsoils of red-brown loams are sandy loam to sandy clay loam. Loamy sand topsoils are rare on red soils. They only occur in soils with a fine loamy control section, and in some of the soils of low rainfall zone.
The relatively fine texture of the majority of the red soils often makes them stand out from surrounding soils, which are either lighter throughout or have a lighter topsoil. Similarly, red clays and red-brown loams are usually considerably deeper than neighbouring soils. While many of Zambia's major upland soils are underlain by laterite or saprolite at a depth of 2 to 3 m, most of the red soils have their petroferric or (para) lithic contact at far greater depth. Red soils of less than 3 m depth, some of them less than 50 cm deep, are confined to transitional situations, such as at the foot of a hill or ridge, bordering a geological fault etc.

There is a wide variation in structure among the red soils. Whereas the sandy red soils are invariably weakly coherent, porous, massive to single grain, the structure of the heavier red soils ranges from moderately subangular blocky to porous massive, moderately coherent. Generally, the soils of the high rainfall zone have a very weak subangular to massive structure, regardless of their parent material, but some of the red soils in Northern Province, developed over diorite and possibly basalt, exhibit moderate subangular blocky structure. The structure of the red clays in the low rainfall zone is dominantly moderate, occasionally strong, subangular blocky.

In particular, the high rainfall clayey soils possess a strong to very strong microaggregation. This microaggregation, consisting of extremely fine (less than 1 mm in diameter) granules, is due to the binding effect of iron oxy-hydrates on fine particles like clay and silt. Although macrostructure may be absent, the microstructure renders these soils generally more permeable and thereby less susceptible to erosion, even under prolonged rainfall and in the absence of plant cover. In the low rainfall zone the microstructure is less conspicuous, and in spite of having a better developed macrostructure, the overall structural stability of these soils is less than that of their high rainfall counterparts. Coupled with a more prominent development of an argillic horizon, i.e. a less
homogeneous profile, the red soils below the 1000mm isohyet are more prone to erosion. The red soils with high micro-aggregation are particularly friable and very friable when moist, and non to slightly sticky when wet. In the low rainfall zone, the soils are less friable, but more sticky. These soils easily slake when wet, thus reducing trafficability in the rainy season.

The chemical properties of the Zambian red soils vary according to the amount of rainfall the soils receive and, to a lesser extent, according to the parent material. The red clays of North-western Province and the Copperbelt have been deeply weathered and highly leached. Even though some of these soils are underlain by rock types similar to other red soils elsewhere in the country, the leaching effect of the high rainfall distinguishes them.

These highly leached red clays are strongly to very strongly acid in reaction, with pH (CaCl$_2$) ranging from 3.9 to 4.6 throughout the profile. The influence of the parent material is recognizable in a pH that lies at the upper end of the acid range (4.4 to 4.6) for limestone soils, while the other soils have a pH of less than 4.3. Both the CEC and the base saturation are also very low, the former being mostly below 10 meq/100g clay, while the latter less than 10% in most of the red clays. Consequently, alumunium saturation reaches a high level of 70% in the limestone soils and 90% in the red soils derived from acidic rock (see Table 1, Chafukuma and Meheba series).

The red soils in the low rainfall zone show more variety in their chemical characteristics, but again it is meaningful to distinguish between soils developed over limestone and soils derived from more acidic material. Limestone soils, of which the Makeni series is a good example (see Table 1), have a pH(CaCl$_2$) of between 5.0 and 6.0, CEC of 20 meq /100g clay or more, and a base saturation in excess of 50%.
The soils over acid metamorphics and related rocks possess less favourable characteristics: a pH (CaCl₂) of 4.5 to 5.0, a CEC of 10 to 15 meq/100g clay and a base saturation of 30% or more. These soils have an aluminium saturation around 20%, while the limestone soils have no exchangeable aluminium. The red clays of Eastern Province are in a special category, since they are much younger. Although their pH(CaCl₂) lies around 5.0, their CEC goes up to 50 meq/100 grams clay with a concomitant high base saturation (more than 50%). The Mtirizi series (Table 1) is an example of such a red soil.

A number of red soils of the high rainfall zone can be considered as being transitional between the strongly leached and the moderately leached red clays. These soils, like the Mpongwe series in the Copperbelt and the Malashi series in Northern Province (Table 1), as well as the high lying (1600 m and more) red clays of the Nakonde area, are characterised by a pH (CaCl₂) of 4.5 to 5.5, a CEC around 10 meq/100 grams clay and a base saturation of 20 to 50%. Compared to the other red clays in the north of the country these figures are sufficiently high to be associated with an aluminium saturation of less than 50%. All these soils have moderate to weak, but not massive, structures, so that, at least in the high rainfall zone, there is a clear link between the presence of macrostructure and soil fertility. Analogous to the trends in the heavier textured soils, the Kalahari sand soils display an increase in saturation of the exchange complex from north to south (base saturation increasing from less than 5% to over 30%), with an attendant decrease in acidity pH(CaCl₂) increasing from 4.0 to 4.5). This is exemplified by the Chinsali and Kabuyu series (Table 1).

The organic carbon content of the red soils is not significantly different from that of the other upland soils in Zambia. The level is obviously related to type of land use - burning practices and type of vegetation - but generally there is a decrease in organic matter in the soil from north to south which is consistent with the decrease in rainfall from north to South.
<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Pit Number and Location</th>
<th>Classification and Characteristics</th>
<th>Parent Material</th>
<th>Colour</th>
<th>Texture</th>
<th>pH (CaCl₂)</th>
<th>Organic Carbon (0-20 cm)</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Ca per 100g</th>
<th>Mg per 100g</th>
<th>K per 100g</th>
<th>Al saturation</th>
<th>Fe saturation</th>
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<td>Aeric ferrosol haplic acrustox</td>
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<td>WNP/9/02, Subwski State Farm, North-western Province</td>
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<td>70*</td>
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</tr>
<tr>
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<td>WNP/9/04, Kapeka area, North-western Province</td>
<td>Ferric acrisol oxic paleustox</td>
<td>Mixture of Kalahari sand and silstone residuum</td>
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<td>55</td>
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<td>0.2</td>
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<td>49</td>
<td>0</td>
<td>12.9</td>
<td></td>
</tr>
<tr>
<td>Mongwe</td>
<td>BM-9, Mongwe Wheat scheme, Copperbelt</td>
<td>Distrist nubial oxic paleustox</td>
<td>Limestone</td>
<td>2.5YR 3/6</td>
<td>Fine clayey</td>
<td>5.2</td>
<td>2.3</td>
<td>1.4</td>
<td>1.4</td>
<td>0.1</td>
<td>10</td>
<td>39</td>
<td>10*</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>Chinsali</td>
<td>(Kalahari phase)</td>
<td>Aeric ferrosol oxic paleustox</td>
<td>Kalahari sand</td>
<td>2.5YR 4/6</td>
<td>Coarse loamy</td>
<td>4.2</td>
<td>0.6</td>
<td>0.1</td>
<td>tr</td>
<td>tr</td>
<td>13</td>
<td>6</td>
<td>90*</td>
<td>n.d.</td>
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</tr>
<tr>
<td>Nakweya</td>
<td>NK/1/00, York farm, Luapula Province</td>
<td>Luvic phosphoritic oxic paleustox</td>
<td>Gabbro or limestone</td>
<td>5YR 3/6</td>
<td>Fine clayey</td>
<td>5.6</td>
<td>1.4</td>
<td>5.5</td>
<td>8.4</td>
<td>0.45</td>
<td>33</td>
<td>66</td>
<td>0*</td>
<td>7.7</td>
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</tr>
<tr>
<td>Mazambika</td>
<td>NZ, Nakambala Sugar Estate, Southern Province</td>
<td>Luvic phosphoritic oxic paleustox</td>
<td>Calc-silicate schist</td>
<td>2.5YR 3/5</td>
<td>Fine clayey</td>
<td>5.0</td>
<td>0.75</td>
<td>2.7</td>
<td>2.5</td>
<td>0.4</td>
<td>26</td>
<td>50</td>
<td>0*</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Mitirizi</td>
<td>EMP/1/00, Mitirizi State Farm, Eastern Province</td>
<td>Aeric ferrosol Rhodic paleustox</td>
<td>Dolomitic marble</td>
<td>2.5YR 3/4</td>
<td>Fine clayey</td>
<td>5.5</td>
<td>2.6</td>
<td>9.0</td>
<td>8.2</td>
<td>0.2</td>
<td>33</td>
<td>55</td>
<td>0*</td>
<td>n.d.</td>
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</table>

cont/.......
<table>
<thead>
<tr>
<th>soil series</th>
<th>pit number and location</th>
<th>classification</th>
<th>parent material</th>
<th>colour</th>
<th>texture</th>
<th>pH</th>
<th>organic carbon (GdCl₂)</th>
<th>exch. Ca (req/100g)</th>
<th>exch. Mg (req/100g)</th>
<th>exch. K (req/100g)</th>
<th>OEC (req/100g)</th>
<th>base A</th>
<th>Fe/Ox</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chipangali</td>
<td>EP/7/84, Chibombo area, Eastern Prov.</td>
<td>ferric acrisol humic paleustalf</td>
<td>unknown</td>
<td>2.5YR 4/6</td>
<td>fine clayey</td>
<td>4.9</td>
<td>1.3</td>
<td>6.9</td>
<td>1.8</td>
<td>0.25</td>
<td>25*</td>
<td>50*</td>
<td>0*</td>
</tr>
<tr>
<td>Watopa</td>
<td>EP/5/85, S. Luangwa National Park Northern Province</td>
<td>chromosol udic ustochrept</td>
<td>terrace material derived from Karroo sandstone</td>
<td>5YR 4/6</td>
<td>loamy skeletal</td>
<td>5.1</td>
<td>n.d.</td>
<td>1.5</td>
<td>1.1</td>
<td>0.2</td>
<td>33*</td>
<td>50*</td>
<td>0*</td>
</tr>
<tr>
<td>Kabuyu</td>
<td>BM-17, Livingstone district, Southern Province</td>
<td>ferralic arrosoil typic ustipsamm</td>
<td>Kalabahi sand</td>
<td>2.5YR 4/6</td>
<td>sandy</td>
<td>4.7</td>
<td>0.8</td>
<td>0.4</td>
<td>0.3</td>
<td>0.1</td>
<td>11</td>
<td>80</td>
<td>0</td>
</tr>
</tbody>
</table>

* values estimated from other sources
TABLE 2: AVERAGE ORGANIC CARBON CONTENT (0-20 cm) UNDER NEGATIVE VEGETATION

<table>
<thead>
<tr>
<th></th>
<th>basic parent material</th>
<th>acidic parent material</th>
</tr>
</thead>
<tbody>
<tr>
<td>High rainfall zone</td>
<td>more than 2%</td>
<td>1 - 1.5%</td>
</tr>
<tr>
<td>Low rainfall zone</td>
<td>more than 1%</td>
<td>0.7%</td>
</tr>
</tbody>
</table>

Table 2 shows that the organic carbon levels in the soils of the high rainfall zone are about 50% higher than those of the low rainfall zone. Soils developed from basic rock have an organic carbon content approximately twice as much as those derived from acidic parent material. The organic carbon status of the Eastern Province red clays is more akin to that of the high rainfall soils. The high organic carbon content of the lime-stone soils sometimes extends into their subsoil. For instance, the Makeni series contains more than 1% organic carbon over the first 50 cm.

The clay fraction of the upland soils in Zambia is dominated by kaolinite. Actual contents, as determined by DTA, range from 30 to 60%. Goethite occurs as an accessory mineral occurring in small amounts and present in nearly all upland soils. Traces of micas, vermiculite and sometimes gibbsite can be found in the soils of the high rainfall zone. The soils of the low rainfall zone contain slightly less kaolinite, while amounts of micas are somewhat higher (small to moderate on a qualitative scale). The mineralogy of red clays differs from this general picture in that in the soils with a high iron content, hematite is sometimes present in the clay fraction. The non-clay fraction is almost completely dominated by quartz. This applies to the Kalahari sands as well.
**FERTILITY STATUS**

The fertility status of Zambian soils is generally low. Only a few soils have a cation exchange capacity of more than 24 meq/100 g clay. Soils with a base saturation of more than 50% are mostly limited to the southern part of the country, as indicated above. The two major soil series that exceed these levels (Makeni and Mazabuka series) are both moderately leached red clays, although the latter is a transitional soil as it includes many profiles with 7.5YR colours. With calcium plus magnesium in excess of 5, and often more than 10 meq and potassium dominantly between 0.2 and 1.0 meq, these soils contain sufficient reserves of bases to support a wide range of crops.

The Ca content of the other, less fertile red soils, is 1 to 2 meq/100g soil for the soils over basic parent material and those in the low rainfall zone, while the range for those in the high rainfall zone is from trace to 1 meq. The Mg content depends very much on the composition of the parent material, with some soils containing more exchangeable Mg than exchangeable Ca, but generally the values also lie between trace and 1 meq/100g soil. As a rule, these soils have low potassium reserves with very few containing more than 0.2 meq/100g soil. The strongly leached red clays in North-western Province are almost completely depleted of bases, with less than 1 meq of bases/100g soil. These soils are absolutely deficient in Ca, Mg and K.

The capacity of the red clays to fix phosphate varies. Although there is a correlation with the iron content of the soil, which in itself varies considerably even among red soils (See Table 1), the best correlation is found with percent clay followed by amorphous aluminium plus amorphous iron content (L. Hodgins, personal communication).

The few data available indicate that, with regard to micronutrients, red soils contain sufficient Cu and Mo, although the latter may become deficient after several years of intensive
cultivation. B and S are usually in short supply, while Zn levels are variable, but probably too low in most of the high rainfall soils. In a study of four ferralsols (oxisols) from North-western Province (Ting-Tiang, Magai and Kalyango, 1984) available Mn was found to be sufficient for normal plant growth but actual content became higher with increasing redness of the soil, so that in 2.5YR soils, Mn reached toxic proportions.

The physical properties of most red soils are satisfactory. Since the red clays have a good macrostructure or microstructure, their available water holding capacity is for most soils reasonable in comparision with other tropical soils (15 to 20% in the subsoil). In the topsoil, in particular it is significantly higher than in the so-called "sandveld" soils, which form one of Zambia's major soil groups. Red clays have no natural physical impediments to root penetration, but on heavily mechanized farms, frequent ripping may become necessary to counter the formation of a hardpan. Most red soils are relatively less susceptible to erosion under optimum management.

CLASSIFICATION

The red soils of Zambia, being spread over a wide area with varying climatic conditions and having developed from a variety of parent materials can be classified under a number of different taxonomic units. This certainly holds true for Soil Taxonomy, despite the fact that Zambia shows little differentiation in soil moisture regime and soil temperature regimes. Most of the country falls within the ustic soil moisture regime and has an isohyperthermic soil temperature regime.

The leaching effect of the rains has resulted in oxic horizons in the high rainfall zone, particularly in the North-western Province. Some of these soils are leached to the extent that they contain less than 1.5 meq of bases plus aluminium per
100g clay, and thus have acric properties. But lacking a positive charge within 1.25m, they are placed in the haplic subgroup of the acrustox. This is comparable to the acric ferralsol in the FAO legend (Meheba series, Table 1).

Around Solwezi the soil temperature regime is marginally isothermic. And since some of the red soils formed over limestone contain enough organic matter to meet the requirements for a humox, the occurrence of typic acrohumox in that area might be a possibility. For the time being they remain classified as typic haplustox (Chafukuma series, Table 1), until more climatic data become available. This classification is in line with the other soils with an oxic horizon, the only exception being some of the strongly leached clays over basalt and related rocks, which possess enough structure, as well as often being relatively shallow, to be classified as tropeptic haplustox. All these soils are rhodic ferralsol in the FAO legend.

More prevalent than the oxisols are the ultisols. Large areas of the Copperbelt, North-western, Northern, Luapula, Central and Southern Provinces are covered by these soils. Many red soils display a substantial increase in clay content with depth which is sufficient to be described as an argillic horizon. The occurrence of clay cutans in the soils of the high rainfall zone has often been the subject of fierce debate among soil scientists in Zambia. It is now accepted, however, that although often not very conspicuous, cutans are nevertheless common in the red soils of the high rainfall zone. The few micromorphological data available corroborate this view. Such cutans can be best recognized in certain parts of the profile, for example along zones of vertical water transport and in the lower part of the argillic horizon. Cutans in the moderately leached red clays are usually much better developed than in the other red soils.
Another feature of the deeply weathered red clays is the gradual downward decrease in clay content from the horizons of maximum accumulation. Thus the "pale" concept is particularly applicable to these soils. Soils that can be described as paleustults, and palehumults, that is soils that have a high organic matter content in the upper part of the profile, as is the case with the limestone soils (Mpongwe series, Table 1), are by far the most common red soils in the high rainfall zone. Their affinity with the oxisols is expressed by the oxic subgroup to which nearly all of them belong. Some of the moderately leached red clays of the high rainfall zone contain sufficient bases to drop out of the ultisol order as is the case with the Malashi series (oxic paleustalf, Table 1).

For field surveyors it is often not easy to distinguish between oxisol and ultisol in the high rainfall zone of Zambia. The introduction of more quantitative and less genetic orientated criteria, as would be the case with the "kandic" horizon, would solve this problem, to some extent.

In the low rainfall zone the moderately leached clays largely fall into the alfisol order on account of their relatively high base status. Depending on the nature of their clay profile they belong to either the paleustalf or the rhodustalf great groups. They deviate from the typic concept in not having accumulations of lime in their profile, and are accommodated in the udic subgroup of the paleustalf and rhodustalf great groups. From the African viewpoint it seems that such soils are more "typic" than the ones containing lime, and that a "calcic" subgroup should be created to accommodate the latter. This would also do away with the "udic" modifier, which conveys an idea of relatively high moisture that is out of place when set against the typic paleustult and haplustox of the high rainfall zone.

Not all of the soils of the low rainfall zone can be classified as luvisols in the FAO legend. In Soil Taxonomy the distinction between alfisol and ultisol is made on the basis of % base saturation at a depth of >1 m whereas the FAO legend
stipulates that a low base saturation in at least some part of the B horizon is sufficient to place a soil in the acrisol group. Consequently, some of the soils that qualify as alfisols in U.S. Taxonomy are acrisols rather than luvisols in the FAO legend (e.g. Chipangali series, Table 1), implying a lower base status than is true for such soils.

In an environment like that of Central Africa, where all soils are kaolinitic or at least have a high kaolinite component, as well as containing very little weatherable minerals, the balance of bases is easily altered by cultivation. Alfisols that under a native vegetation, classified as luvisols in the FAO legend can thus, within a short period, change into acrisols. This is not very satisfactory, taking into account that soil maps are usually long-term documents. The proposed splitting of lixisols from the luvisols and alisols from the acrisols (FAO, 1985) does little to change this. An improvement could be made by stipulating that a base saturation of more, or less, than 50% should apply to the major part of the argillic B horizon, for which it will be necessary to indicate what depth of the B horizon should be taken into consideration.

The decrease in leaching from the north to the south is less pronounced in the case of the red Kalahari sands as these soils are too sandy in most cases to have developed oxic or argillic horizons. The soils are mostly quartzipsamments with ustipsamments mainly in the south Kabuyu series, Table 1). The main difference that can be made is at subgroup level, where the more strongly weathered soils become ustoxic rather than typic for the moderately leached sands. In the north, where the sands have a course loamy control section they are differentiated into paleustult (Chinsali series, Table 1) in contrast to paleustalf in the south. There is no differentiation at all according to the FAO legend, which places all the red sands in the ferralic arenosols unit.
LAND USE

Red soils have long been favourites with farmers in Zambia. Trapnell and Clothier (1957) noted that even subsistence farmers in the high rainfall zone tended to prefer red soils.

In the case of the moderately leached red clays this preference is understandable. A relatively high inherent fertility and low aluminium saturation, combined with a clayey subsoil and a good structure, make these some of the best agricultural soils of Zambia. The red clays of the low rainfall zone were among the first to be opened up for commercial farming. They are still being farmed intensively today together with the moderately leached red clays, like the limestone soils of the Mpongwe series, that were only recently brought into cultivation. The large but often deep groundwater reserves of the limestone plateaus have been tapped to provide water for irrigation.

An irrigated wheat - rainfed soyabean rotation is very common on the moderately leached red clays. In areas with lower rainfall sunflower and cotton may substitute for soyabean, while in the high rainfall zone maize is often the principal rainfed crop. Many farms have part of their red clays kept under pasture. Standard amounts of fertilizer are usually applied, and although liming is normally not practised, commercial farmers now tend to lime after a number of years to counter the acidifying effects of ammonium fertilizers.

There is less commercial farming in the high rainfall zone than in the central and southern parts of the country, even on moderately leached red clays. Tea and coffee are grown on the red soils of the high rainfall zone as well, by emergent farmers and tea on a commercial scale only.

The preference for red soils by the small scale farmer in the high rainfall zone is not very well understood. In places where sandveld soils occur side by side with red clays the better waterholding capacity of the latter will probably result
in higher yields, in particular when dry spells are being experienced.

CONCLUSION

The moderately leached red clays are Zambia's prime agricultural soils. Their total extent is not exactly known, but could very well reach 500,000 ha. If fully utilized they could contribute substantially to the agricultural output of the country. Although they are locally being cultivated intensively, there are other areas where they are definitely being under-utilized. Even near Lusaka there are fields of land that have not been cultivated for many years. It should be a high priority for the policy-makers to ensure that the fullest possible use is made of this valuable natural resource in order to boost Zambia's food production.

The strongly leached red clays are problem soils, like most of the other soils in the high rainfall zone. It appears, however, that they possess some marginal advantages over the non-red strongly leached soils, like a more clayey texture, particularly in the upper part of the profile, greater depth and a higher available water holding capacity. Some of them might also be better on account of having a somewhat lower aluminium saturation and/or containing less soluble aluminium. Thus, in developing a management package that would make Zambia's strongly acid upland soils productive on a sustained basis and in an economically justified manner, special attention should be paid to the red clays as their constraints are probably less severe than those of other soils of the high rainfall zone.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Broekhuis and Drs. Spaargaren and Veldkamp, all of the Soil Survey Unit, as well as Mr. Hodgins of the ZAMCAN Wheat Project, for their critical comments and suggestions. They are also grateful to the Director of Agriculture for his permission to publish this paper.
REFERENCES


EXTENT, DISTRIBUTION AND PROPERTIES OF THE RED SOILS OF ZIMBABWE

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SUMMARY

The importance of red* soils in Zimbabwe is described and explained. The approximate extent of the soils is shown by reference to the distribution of the major parent materials responsible for the formation of red soils in Zimbabwe. Important relationships between the distribution of red soils and physical factors such as climate and topography are discussed. Information is also presented to give and illustrate the broad range of characteristics of these soils. The paper concludes by pointing out areas that need to be researched in order to shed more light on the properties and behaviour of the soils.

*The definition of the colour "red" is contained in an appendix to this Proceedings.
Fig. 1
Major mafic geological formations of Zimbabwe.

Legend

- **BASEMENT COMPLEX**
  (Shamvaian, Bulawayan & Sebakwian)
- **LIMPOPO MOBILE BELT**
- **PIRIWIRI, DEWERAS, LOMAGUNDI GROUPS**
- **UMKONDO and GAIREZI FRONTIER GROUPS**
INTRODUCTION

For a long time and even today, for the layman in Zimbabwe, a red soil is synonymous with a fertile soil. This may seem strange to the soil scientist who is familiar with the problems of tropical laterites and problems of managing oxisols in tropical regions. However, in the Zimbabwean context, there was much justification to this belief because the early agricultural settlements and many of the important commercial farming areas of today were located on relatively fertile red clays and clay loams, derived from mafic rocks associated with the geological formations in which the country's main gold-bearing ores are found. This formation is therefore often referred to locally as the "gold-belt series". This largely consists of the geological formations shown in Table 1.

TABLE 1. - COMPONENTS OF MAJOR MAFIC FORMATIONS.

<table>
<thead>
<tr>
<th>FORMATION</th>
<th>GEOLOGICAL COMPONENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement complex</td>
<td>greenstones, greywackes &quot;Magnesian schists&quot;, greenstones, amphibolities, granulites, dolerite dykes, paragneiss (mafic gneisses)</td>
</tr>
<tr>
<td>(Early to Mid Precambrian)</td>
<td></td>
</tr>
<tr>
<td>Limpopo Mobile Belt</td>
<td></td>
</tr>
<tr>
<td>(Various ages)</td>
<td></td>
</tr>
<tr>
<td>Piriwiri, Deweras and Lomagundi groups</td>
<td>greywackes, granodiorites, paragneiss, mica schists, amygdaloidal lavas, dolerite dykes, greenschist.</td>
</tr>
<tr>
<td>(Mid Precambrian)</td>
<td></td>
</tr>
<tr>
<td>Umkondo and Gaerezi groups</td>
<td>dolerites, muscovite schists, basic andesites</td>
</tr>
<tr>
<td>(Mid Precambrian)</td>
<td></td>
</tr>
</tbody>
</table>
On the basis of existing soil survey data, it is difficult to estimate the actual areal extent of the red soils of Zimbabwe, but they form some of the country's most productive farm land, on which practically all of Zimbabwe's commercial maize areas are located. A significant portion of the country's winter wheat is also grown on these soils under irrigation. The development and growth of the now important settlements of Triangle and Chiredzi in the south-eastern part of the country, was largely a result of the successful irrigation of sugar cane on the extensive red soils there. Today more than 30,000 ha of these soils are under irrigated sugar.

The Kalahari sands, some of which have bright red 2.5YR colours, will not be included in this discussion since they are viewed as a special category of soils with problems that are peculiar only to themselves. These soils are also of relatively little agricultural value at present.

For the purpose of this discussion, red soils are those that have a hue redder than 5YR in the major part of the profile.

Although a considerable amount of semi-detailed and detailed soils surveys have been carried out in Zimbabwe, by far the greatest amount of information available on Zimbabwean soils is based on mapping done at the reconnaissance level, at a scale of 1:1 000 000, which shows the dominant upland members of the country's soil families. At that scale, it is not possible to separate out the red soils from the other soils. It is therefore difficult to estimate the areal extent of the red soils. However, because in Zimbabwe, red soils are derived almost exclusively from mafic rocks, a relatively accurate estimate of their areal extent can be made from examining the extent of mafic rocks as shown on the country's synoptic 1:1 000 000 geological map. Such an estimate would suggest that red soils cover something more than 10% of the country.
The approximate extent, distribution and range of characteristics of these soils will be described below in some detail.

**OCCURRENCE AND DISTRIBUTION**

**Influence of parent material**

The major factor which determines the occurrence of red soils in Zimbabwe is parent material. Except for the highly weathered paraferrallitic and orthoferrallitic soils (approximately ultisols and oxisols) of the high rainfall areas along the eastern border of the country, some of which are derived from granites, red soils are derived almost exclusively from mafic and ultramafic rocks. There are also minor occurrences associated with metasediments and metavolcanics such as phyllite and even banded ironstone.

Fig. 1 shows the distribution of the major mafic formations of Zimbabwe which can be considered to coincide with main areas of red soils. Table 1 shows the major rock types associated with each of these formations.

On the basis of Fig. 1 it is clear that these soils occupy a significant portion of the country. It should be noted, however, that Fig. 1 excludes the Great Dyke, an ultramafic complex which is also associated with some red soils. In addition, at that scale of mapping, it is not possible to show the numerous intrusions and small dykes of dolerite and granodiorites which occur widely throughout the country giving rise to isolated but significant patches of red soils.

**Influence of topography**

The bright red colours of the red soils are the result of the presence of iron oxides in a high oxidation state. Thus red soils are only found in well drained upland positions on steep to gently sloping lands.
Influence of rainfall

Generally, rainfall increases from the south-west to the north-east and east of Zimbabwe. As a result, the red soils in the arid and semi-arid south-west and west of the country are relatively unleached and show minimum profile development. They are mainly siallitic soils, equivalent to inceptisols and aridisols and some alfisols. The soils become progressively leached as the rainfall increases, so that the red soils of the eastern and north-eastern parts of the country are the deep and highly leached paraferrallitic and orthoferrallitic soils which are equivalent to ultisols, oxisols and ultic subgroups of alfisols. Fig. 2 shows the broad relationship between rainfall and the occurrence of various soil types.

Approximate rainfall (mm)

<table>
<thead>
<tr>
<th>400-600</th>
<th>750-900</th>
<th>900-1200+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (m)</td>
<td>800-1500</td>
<td>1500</td>
</tr>
<tr>
<td>V.approx. 300-800</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mainly siallitic (inceptisols alfisols aridisols)

S/C > 31
B.S. > 85

Mainly fersiallitic predominantly alfisols some ultisols

S/C 6-30
B.S.usu. > 80

Paraferallitic & orthoferrallitic mainly ultisols some oxisols

S/C > 5 < 6

Figure 2: Schematic representation of relationship between rainfall and soils
PROPERTIES AND CLASSIFICATION

The soils included in this discussion are characterised by their bright red hues, which in all cases are redder than 5YR. Excluding the Kalahari sands, to which reference has been made in a foregoing section, these soils have a moderate to relatively high clay content, ranging between about 35 and 70 per cent.

An important effect of the rainfall gradient referred to earlier is that it has a marked influence on the clay mineral assemblages to be found in these soils. The red soils of the lower rainfall areas are rich in 2:1 minerals while those of the higher rainfall areas are dominated by 1:1 clay minerals and sesquioxides. It is important, however, to note that kaolinite is always present regardless of the rainfall regime in which the soils are found. Occurrences of a pyrophyllite-talc type mineral have been reported in some of the soils derived from metavolcanics and those associated with the ultramafic complex of the Great Dyke (Nyamapfene and Yin, 1985). Equally interesting is the discovery that, in some fersiallitics, halloysite rather than mica, as traditionally thought, is responsible for the charge in these clays (Nyamapfene 1985).

The broad range of chemical criteria used to categorise the main soil groups in which major red soil families are included is given in Table 2 in which the group names are indicated following the nomenclature of the Zimbabwean classification system of Thompson and Purves (1980).

TABLE 2 - CLASS LIMITS FOR THE MAJOR SOIL GROUPS

<table>
<thead>
<tr>
<th>Group</th>
<th>Exch. Cap. meq/100g clay</th>
<th>TEB meq/100 clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIALLITIC</td>
<td>not less than 35</td>
<td>&gt;31</td>
</tr>
<tr>
<td>FERSIALLITIC</td>
<td>12 - 35</td>
<td>6 - 30</td>
</tr>
<tr>
<td>PARAFERRALLITIC</td>
<td>&lt;12</td>
<td>&lt;6</td>
</tr>
<tr>
<td>ORTHOFERRALLITIC</td>
<td>&lt;11</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>

1. Referred to as E/C value in Zimbabwean literature.
2. Referred to as S/C value in Zimbabwean literature.
The siallitic and fersiallitic groups form by far the most important agricultural soils with the fersiallitics being the most extensive in the country and occurring largely in the moderate to high rainfall areas of the central watershed, which receives 700 - 900 mm of rain per annum.

Table 3 shows selected data for some typical examples of red soils from what could be considered as benchmark sites.

**TABLE 3A - SITE DATA FOR SOME TYPICAL RED SOILS**

<table>
<thead>
<tr>
<th>Site</th>
<th>Rainfall (mm)</th>
<th>Zimb. name</th>
<th>U.S. Tax1</th>
<th>Parent Material</th>
<th>Sub Soil2 Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harare</td>
<td>840</td>
<td>fersiallitic</td>
<td>rhodustalf</td>
<td>gabbro</td>
<td>2,5YR 3/6</td>
</tr>
<tr>
<td>Chinhoi</td>
<td>800</td>
<td>fersiallitic</td>
<td>ustropept</td>
<td>actinolite schist</td>
<td>2,5YR 3/6</td>
</tr>
<tr>
<td>Banket</td>
<td>823</td>
<td>fersiallitic</td>
<td>paleustalf</td>
<td>dolerite</td>
<td>2,5YR 3/4</td>
</tr>
<tr>
<td>Triangle</td>
<td>600</td>
<td>siallitic</td>
<td>haplargid</td>
<td>paragneiss</td>
<td>2,5YR 3/4</td>
</tr>
<tr>
<td>Chipinga</td>
<td>1580</td>
<td>orthoferrallitic</td>
<td>orthox</td>
<td>dolerite</td>
<td>2,5YR 4/6</td>
</tr>
</tbody>
</table>

**TABLE 3B - SELECTED ANALYTICAL DATA FOR SOME TYPICAL RED SOILS**

<table>
<thead>
<tr>
<th>Site</th>
<th>Subsoil Clay %</th>
<th>Fe2O3%</th>
<th>pH (CaCl2)</th>
<th>C.E.C.3 meq%</th>
<th>T.E.B. meq%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harare</td>
<td>60 - 73</td>
<td>11</td>
<td>5,7</td>
<td>12</td>
<td>9,9</td>
</tr>
<tr>
<td>Chinhoi</td>
<td>39 - 42</td>
<td>5</td>
<td>5,3</td>
<td>9</td>
<td>9,0</td>
</tr>
<tr>
<td>Banket</td>
<td>62 - 76</td>
<td>8</td>
<td>4,8</td>
<td>15</td>
<td>15,0</td>
</tr>
<tr>
<td>Triangle</td>
<td>35 - 38</td>
<td>3</td>
<td>6,3</td>
<td>22</td>
<td>22,0</td>
</tr>
<tr>
<td>Chipinga</td>
<td>69 - 76</td>
<td>17</td>
<td>4,4</td>
<td>2,4</td>
<td>0,7</td>
</tr>
</tbody>
</table>

1. U.S. Taxonomy name is only approximate
2. moist colour reading
3. CEC. M NH4OAc see Russell (1973) and Thompson and Purves (1980).
Much work still needs to be done to assess interactions of these soils with nutrients, particularly phosphate. Work done by Campbell (1976) and Sibanda and Le Mare (1984) suggests that even in those soils containing as much as 15% citrate dithionite extractable iron, P sorption in most of these soils does not appear to be a major problem. It is only in a few of the para- and ortho- ferrallitic groups and some fersiallitics that are strongly influenced by ironstone that P sorption problems manifest themselves to any significant extent.

For purposes of comparison with international classification systems, the majority of these soils fall within the alfisol order of U.S. taxonomy (USDA, 1975). However, the paraferrallitic and orthoferralsitic groups which are generally equivalent to the ultisol and oxisol orders, create problems. Not all the paraferrallitics are ultisols and not all the orthoferralsitics are oxisols. In fact some of the orthoferralsitics fall into oxic and ultic subgroups of alfisols.

This may be an indication of inherent weaknesses in either of the two classifications being compared. A detailed analysis of this problem was carried out by Asumadu and Weil (1986).

CONCLUSIONS

The red soils of Zimbabwe cover a significant portion of the country's surface area. They are therefore important for that reason and also because of the central role they play in the country's agriculture, since by far the greatest amount of commercial farming activities are located on these soils. Much work needs to be done to understand the properties and behaviour of these soils. In particular, little work has been done on the mineralogy, especially the nature of the oxide systems. An understanding of these systems could also lead to a better understanding of the dynamics of nutrients.
REFERENCES


NUTRITIONAL ASPECTS OF PLANT PRODUCTION ON RED SOILS

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SUMMARY

To improve the plant yield on red soils, two possible strategies amongst others can be followed from the view of plant nutrition, either by adapting the plant to the given conditions or by adjusting the soil properties to meet the needs of the plants. The first approach considers the selection of plant species or genotypes that are either tolerant to the prevailing conditions of red soils, i.e. low pH, Al/Mn-toxicity, and/or which are efficient in coping with P-fixation and the competition in cation uptake. Adjusting the soil to the requirements of the plants comprises mostly the increase of the soil pH by liming, which results in changes of the chemical properties, e.g. degree of Al-saturation, sorption characteristics, nutrient availabilities, towards more favourable conditions for plant development. Consequently the application of fertilizer has to be adapted accordingly in order to support and extend the positive effect of liming, as well as to supply the nutrients necessary according to the higher requirement after improving the soil conditions.
INTRODUCTION

It is a common observation that soon after putting acidic tropical soils under cultivation the yield level drops drastically if either soil amendments and fertilizer application are inadequate or poorly adapted plant species/genotypes are used.

The effect of lime and fertilizer application on the maintenance of soil fertility was impressively documented by Sanchez, Bandy, Villachica and Nicholaides, (1982) on an oxisol in the Peruvian Amazon Basin. While with appropriate doses of lime and fertilizers the initial high yield could be maintained even after more than 8 years of intensive production, yields were already dropping after the 4th crop to nearly zero in those plots which had received no fertilizer. The yields of maize, soyabean and peanuts for instance were reduced to 7, 10, and 20% of the level of the intensively managed plots, respectively. A similar observation was made by Moorman and Greenland (1980) in Nigeria, or by Chan (1980) with cassava.

The early loss in productivity can be related inter alia to the nutrient uptake as affected by the environmental conditions. In this context the development of the root system in general and the distribution pattern and uptake efficiency, in particular, are of specific importance. It is obvious that a sparse root system can exploit the soil only partially. This affects the uptake especially of those nutrients which are supplied mainly by diffusion such as potassium or phosphorus. The supply of these nutrients is moreover restricted in soils containing predominantly kaolinitic clay minerals or soils with strong P-fixation. In kaolinitic soils the low buffer capacity and CEC leads to an early local depletion of potassium and in P fixing soils the slow release of phosphorus cannot cope with demand.

The efficiency of the root system can be considered from two different aspects, (i) the absorption intensity, i.e. the absorption of nutrients per time unit, and (ii) the uptake
selectivity, i.e. the uptake even in the presence of high concentrations of competing ions.

In these pages the influence of some of the characteristics of an acidic tropical soil, namely low pH, high Al saturation, marked variation in water content and high temperatures will be discussed with respect to root development and nutrient uptake and conclusions are drawn for the management of these soils.

DISCUSSION

Effect of Aluminium on Root Growth

Exposing roots of Al sensitive plants to the presence of this element results in growth inhibition. The roots are often curled, extensively branched, stained and show discoloured tips. The change in root morphology is caused by blocked cell division as observed for example in cassava (Munn and McCollum, 1976). With disintegration of the tip, the root loses the gravity sensing mechanism (Juniper, Groves, Landan-Schachar and Audus, 1966) and starts curling. The simultaneous loss in apical dominance enhances the development of lateral roots e.g. in soybean (Foy, Fleming and Armiger, 1969), or of adventitious roots in maize (Clark, 1977).

The stunted root habit in the presence of Al can also be related to the influence of Al on certain metabolic processes such as the inhibited P assimilation into organic compounds like hexosephosphate (Rorison, 1965), the reduced DNA synthesis hydrates into cellwall material in cotton roots (Huck, 1972).

The root tips are known to be an important source of phytohormones, e.g cytokinins, gibberellins or abscisic acid (Phillips and Jones, 1964). Disintegration of root tips will undoubtably affect the phytohormone biosynthesis and hence the hormonally controlled growth processes and yield formation.
Effect of Aluminium on Nutrient Uptake

Numerous studies show that Al inhibits uptake of Ca, for instance in wheat (Mugwira, Elgawhary and Patel, 1976) maize (Clark, 1977), soybean (Foy et al., 1969) or in potatoes (Table 1). According to Clarkson and Sanderson (1971) Al blocks the uptake sites in the root tissue and hence Ca supply of the shoot. With respect to Ca uptake and its translocation, the integrity of the apical root zone is of particular importance. As shown for barley and marrow plants Ca uptake of the root, decreases with increasing distance from the root tip (Harrison-Murray and Clarkson, 1973; Russell and Clarkson, 1976). Consequently, Ca uptake efficiency of the root system decreases when the root apices are damaged.

A similar interaction between Al and nutrient uptake was found for Mg, e.g. in potatoes (Table 1), barley and soybean (Grimme, 1981; 1984). This author related the yield reduction of Al treated plants to the reduced Mg content of leaves. Increased supply of Mg, however, could counterbalance the inhibitory effect of Al on Mg uptake.

A rather indirect effect of Al on nutrient uptake is the binding of phosphate by Al hydroxides within the root tissue, although the binding seems to be relatively unstable (Kinzel, 1982). In this context the strong P-fixation in acidic soils is of course of major concern for P uptake. This applies also to molybdenum.

Low pH soils are also characterised by excessive concentrations of manganese. Reduced Mg contents in plant shoots as found by Grimme (personal communication) at high Mn concentrations can be related to unspecific competition for uptake sites in the root. A different regulatory mechanism is involved in the interaction between Mn and Ca uptake. Excess of Mn in the tissue stimulates the activity of IAA oxidase which subsequently leads
**TABLE 1:** EFFECT OF ALUMINIUM ON GROWTH AND CATION CONTENT IN THE SHOOT OF POTATO cv DTO 28 AT HIGH ROOT TEMPERATURES (Al CONCENTRATION 8 ppm, pH 4.0, ROOT TEMPERATURE 30°C, DURATION 14 DAYS) (KRAUSS AND MARSCHNER, UNPUBLISHED)

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>+Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>shoot g Fwt</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>roots g Fwt</td>
<td>4.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Ca mg/g DM</td>
<td>5.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Mg mg/g DM</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>K  mg/g DM</td>
<td>68.0</td>
<td>66.1</td>
</tr>
</tbody>
</table>
to auxin deficiency (Morgan, Hahn and Amin, 1966). Since cell wall expansion and formation of new negatively charged exchange sites in the tissue is controlled by auxins (Horst and Marschner, 1978), auxin deficiency at enhanced IAA oxidase activity restricts indirectly the Ca movement into the apex of the shoot.

Apart from Al and Mn the high H⁺ concentration in acidic soils also has a direct impact on nutrient uptake, e.g. uptake of potassium (Olsen, 1953). High H⁺ concentration increases membrane permeability, so that the "leaky" membrane cannot withhold K and hence the net uptake of K decreases (Jacobson, Overstreet, King and Handley, 1950). Ca supply counteracts the H⁺ effect by reducing membrane permeability (Rains, Schmid and Epstein, 1964).

Effect of Soil Water Content on Nutrient Uptake

Nutrients are translocated to the roots either by mass flow (e.g. NO₃ or Ca) or - as already mentioned - by diffusion. The driving force for massflow is transpiration. Intensive transpiration may lead to accumulation of mobile ions around the root surface when the uptake rate is lower than the supply through mass flow. Ions accumulated on the root surface will suppress uptake of less available nutrients.

Diffusion becomes effective when the nutrient supply by mass flow cannot cope with the absorption intensity of the root. When nutrients are removed from the soil solution, a concentration gradient will build up which forces the nutrients to move towards the absorbing root. The diffusive flux in soils is determined by the diffusion coefficient, the concentration of the mobile species, the distance, the soil water content as well as by
an impedance factor. With respect to soil water content this means that the lower soil water content is, the lower will be the diffusive flux and vice versa. This is consistent with findings by v. Braunschweig and Grimme (1973) that K availability was reduced between 35 and 50% after decreasing the soil water content from 30 to 20%. The reduced uptake of potassium (Danielson and Russell, 1957) or nitrogen (DeDatta, Faye and Mallick, 1974) at low water contents is also in accordance with the above cited function. However, yield reduction due to restricted uptake of potassium at low water content could be compensated by increasing the K status from 17 to 46 mg exchangeable K/100g soil (Mengel and v. Braunschweig, 1972). These findings are supported by the positive yield response of maize and soybeans to K application in dry years (Barber, 1963; 1971) or the yield response to fertilizer application on upper slopes of toposequences (ICRISAT, 1983).

The dependence of nutrient supply on soil water content implies furthermore that the nutrient uptake is highly irregular in soils with strongly varying water contents as commonly observed in red soils even between two rain showers. The detrimental effect of short term interruption in nutrient supply on the cation content and on yield is well demonstrated by results reported by Forster and Mengel (1969) in barley. Interruption of K for 8 days reduced grain yield by approximately 20%.

Leaching is another factor interfering with the nutrient uptake. This becomes particularly relevant in soils with a high percentage of transmission pores and in soils with less favourable absorption characteristics (e.g. kaolinitic clay minerals). The higher selectivity of ultisols for Al than for Ca (Pleysier and Juo, 1981) is certainly one of the factors responsible for the high Ca leaching losses as observed on Nigerian ultisols (Friesen, Juo and Miller, 1982).
Effect of Root Temperature on Nutrient Uptake

Increase in root temperature affects nutrient uptake and translocation differently. Lal (1979) showed that increasing the root zone temperature from 27 to 37°C reduced the Ca content in the shoot of soybean, pigeonpea and cowpea by 21, 29 and 49%, respectively. In potato plants the decrease in Ca content after raising root temperature from 15 to 30°C was more pronounced in the apical than basal part of the shoot (Table 2). A similar effect was found by Porter and Moraghan (1975) in maize. The simultaneous accumulation of Ca in the roots (Table 2) indicates that high temperatures interfere with Ca translocation within the plant.

High root temperatures also affect the Mg content (Table 2). However, in contrast to Ca the Mg content is more affected in the basal than the apical part of the plant. This reflects the relatively high phloem mobility of Mg compared to Ca. Interruption of Mg translocation from the roots can therefore be compensated for at least in part by retranslocating Mg from older into younger parts of the shoot.

K uptake and translocation obviously tolerate higher root temperatures than Ca and Mg. In potatoes the K content differed only insignificantly. In sorghum, soybean and pigeonpea the K content increased even up to 32, 31 and 34°C, respectively and declined only at higher temperatures (Beber and Caldwell, 1964; Lal, 1979).

Interactions between higher root temperature and decreased nutrient contents were also shown for P and Zn (Lal, 1979).

From the results in Table 2 it is also interesting to note that increasing root temperatures reduced root growth of potato plants while stimulating shoot growth at the same time. Simultaneous restriction of apical Ca translocation
TABLE 2: EFFECT OF INCREASE IN ROOT TEMPERATURE FROM 15 TO 30°C ON GROWTH AND ON THE CONTENT OF K, Ca AND Mg IN DIFFERENT PARTS OF POTATO cv MARIVA (RELATIVE VALUES, 15°C = 100) (KRAUSS AND MARSCHNER, UNPUBLISHED)

<table>
<thead>
<tr>
<th>Freshweight</th>
<th>Content of Ca</th>
<th>Mg</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>apical bud</td>
<td>52</td>
<td>82</td>
<td>88</td>
</tr>
<tr>
<td>apical leaves</td>
<td>42</td>
<td>69</td>
<td>95</td>
</tr>
<tr>
<td>apical stem</td>
<td>53</td>
<td>68</td>
<td>100</td>
</tr>
<tr>
<td>basal leaves</td>
<td>57</td>
<td>59</td>
<td>124</td>
</tr>
<tr>
<td>basal stem</td>
<td>83</td>
<td>59</td>
<td>109</td>
</tr>
<tr>
<td>total shoot</td>
<td>146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>roots</td>
<td>48</td>
<td></td>
<td>154</td>
</tr>
</tbody>
</table>
and promotion of shoot growth impairs the Ca supply of the shoot apices ("dilution effect"). However, the meristematic tissue of the shoot apex is considered to be one of the production sites for phytohormones such as auxin. Ca deficiency of the shoot apex causes disintegration of the meristematic tissue hence inhibiting auxin synthesis. With decreasing auxin production the plant is gradually released from the control mechanism exerted by apical dominance. Under these circumstances the diageotrophically growing stolons in potato develop into erect leafy shoots (Fig 1). The same effect was obtained by Kumar and Wareing (1972) after decapitating potato cuttings. It is conceivable that turning potato stolons into leafy shoots reduces the yield potential of these plants drastically.

Genotypical Differences in Tolerance to Mineral Stress As Related to Acidic Soils

The use of adapted genotypes can be considered as one of the tools for improving productivity of acidic tropical soils. Genotypical differences with the respective tolerance have been described for a wide range of different plant species.

In Al tolerance 2 groups of mechanisms can be distinguished, (i) tolerance in view of detoxicating Al, and (ii) tolerance associated with a high absorption efficiency of the root system.

The complex binding of Al within the plant is known in tea (Jayman and Sivasubramaniam, 1975), the precipitation of Al in the cell wall (Matsumoto, Hirasawa, Morimura and Takahashi, 1977) or the selective absorption of Al in the mucilage of cowpea root tips as found by Horst et al (1983) belong to the first group of tolerance mechanisms. The same holds true for those plant species/genotypes which detoxicate Al by changing the pH either within the free space of the root tissue (Nair and Prenzel, 1978) or in the rhizospheric soil (Mugwira et al., 1976)
FIG 1: CONTROL OF THE APICAL DOMINANCE IN POTATO PLANTS
BY Ca SUPPLY THROUGH THE ROOTS AND ITS EFFECT
ON STOLON GROWTH (SCHEMATIC VIEW)
Genotypical differences associated with the efficiency to absorb phosphate also under mineral stress were found in tomato (Foy et al., 1973), maize (Clark and Brown, 1974) or beans (Gerloff, 1977). Tolerance associated with Ca efficiency occurred in cowpea (Horst, 1985) or soybean (Foy et al., 1969), and associated with Mg efficiency was shown in potato (Lee, 1971) and maize (Clark, 1977).

A specific tolerance mechanism to detoxicate excessive Mn is obviously in operation in cowpea. Susceptible genotypes show a highly irregular distribution of Mn in the leaf tissue (MnO$_2$ agglomerates) in contrast to tolerant genotypes with a fairly uniform Mn distribution pattern (Horst, 1983).

**Screening of Genetic resources for Tolerance to Acidic Soils**

Attempts have been made to correlate a certain morphological expression with the degree of tolerance. Black coated beans (Spain et al., 1975), 6 row barley (Stlen, 1965) and hexaploid wheat (Slootmaker 1974) are found to be more tolerant to acidic soils than the non-black coated beans, 2 row barley, and di- and tetraploid wheat, respectively. Regarding wheat, however, 56% of the Al tolerant genotypes selected from Ethiopian wheat germplasm are tetraploid and 44% hexaploid (Krauss and Mahteme, 1985).

Although morphological expressions are only rough criteria to trace tolerance they can assist in initial classifications. The sensitivity of the root system to the presence of Al, however, seems to be more suitable for screening purposes. Several methods have been developed using either water culture or soil. A range of different methods are described in the "Proceedings of a Workshop on Plant Adaptation to Mineral Stress in Problem Soils" (1976, Beltsville/Maryland). From one of these (Campbell and LaFever, 1976) a simplified method has been adapted by the Plant Genetic Resources Center of Ethiopia to screen indigenous wheat germplasm for Al tolerance.
The ratio of the root length of plants after growing them for 7 days in an ultisol pH \(_{KCl} 3.8 - 4.0\) and in a "standard" soil (ph 4.8 - 5.2), respectively was used as a selection criterion. The higher the relative root length value (RRL) the higher is the tolerance to Al and vice versa. Wheat varieties with a known tolerance were included to control the accuracy of the test. A typical frequency distribution is shown in Figure 2. Out of 654 genetically uniform lines nearly 9% of the germplasm can be considered as being tolerant.

In Fig. 3 the root lengths of 3 tolerant and 3 sensitive wheat genotypes are plotted against different soil pH values. The soil pH was adjusted by adding different quantities of CaCO\(_3\) and AlCl\(_3\), respectively. The pH of the untreated soil was 3.97 (0.1 N KCl). On decreasing pH the root length of the tolerant genotypes remained much longer on the same initial level than that of the sensitive types. Therefore, the tolerant genotypes show a considerably higher degree of flexibility to cope with changing soil reactions than the sensitive types.

**Effect of Fertilizer Application and Nutrient Uptake on Soil pH**

Another tool to improve productivity of acidic soils is the application of fertilizers. However, depending on the kind of fertilizer used the resulting effect can even aggravate the situation.

The favourable effect of lime which increases soil pH and thus reduces toxic levels of Al (and Mn) is well documented. It has also been discussed whether the quantity of lime should be adjusted to reach a pH level high enough to eliminate soluble Al or to "merely" reduce Al saturation below a critical limit. In favour of the latter is the finding of Friesen et al., (1982) that 90% of maximum yield is achieved even at 35% Al saturation in maize, and even up to 55% saturation in cowpea. Similarly, maximum yield in Sudangrass was obtained with only
FIG 2 : FREQUENCY DISTRIBUTION OF RELATIVE ROOT LENGTH (RRL) OF INDIGENOUS ETHIOPIAN WHEAT GERMPLASM (n = 654 lines; mean RRL = 0.44; $s_d = \pm 0.15$) (KRAUSS AND MAHTEME, 1985)
FIG 3: ROOT LENGTH OF WHEAT GERMPLASM DIFFERING IN ACIDITY TOLERANCE AS AFFECTED BY SOIL pH (FULL SYMBOLS AND SOLID LINE = 3 DIFFERENT SENSITIVE ACCESSIONS AND MEAN, RESPECTIVELY; OPEN SYMBOLS AND DOTTED LINES = TOLERANT ACCESSIONS)
1/6 of the amount of lime necessary to increase the soil pH to 6.5 (Reeve and Sumner, 1970).

The placement is as important as the quantity of lime to be applied. In order to increase the rooting zone Ca has to reach the subsoil layers as well. In this respect impressive results of deep lime placement have been obtained by Gonzales-Enrico, Kamprath, Naderman and Soares (1979). Apart from the fact that deep placement improved the water balance of the soil the yield of maize correlated very closely with the content of soluble Al in the 15 - 30cm soil layer (Fig 4).

The movement of Ca within the soil profile is determined by the accompanying anion. Ca applied as CaCO$_3$ remains accumulated in the toplayer due to exchange reactions with H$^+$. The latter reacts with the carbonate. Ca from sulfate reaches medium depth in the profile whereas Ca applied as chloride is leached very quickly below the rooting zone (Ritchey, Souza, Lobato and Correa, 1980). As mentioned earlier a similar leaching pattern was found for potassium. In constrast to the positive effect of lime, application of KCl to unlimed soils can increase the Al content of the solution through exchange, especially in soils with high K selectivity. Thus yield of sweet corn is reduced unless lime is applied as well (Ragland and Coleman, 1959).

Special attention has to be paid to the effect of nutrient uptake on the pH of the rhizosphere. The most prominent nutrient affecting the pH of the rhizospheric soil measurably is NH$_4^+$ Uptake of ammonium is accompanied by extrusion of equivalent amounts of protons (H$^+$) to the solution (Smiley, 1974). Romheld, Muller and Marschner (1984) measured H$^+$ extrusion rates for sunflowers in the range of 3.6 M H$^+$ g$^{-1}$ Fwt h$^{-1}$ after application of ammonium sulfate. The acidifying effect of ammonium uptake can explain, at least in part, the strong pH decrease in soils which had received high doses of ammonium sulfate over a long
period of time as reported from Puerto Rico (Abruna, Plarson and Perez-Escolar, 1974) or from Nigeria (Aduayi, 1984).

Due to conversion into ammonium, urea has in principle the same acidifying effect as pure ammonium fertilizer.

In contrast nitrate uptake results in a pH increase as long as the nitrate uptake exceeds the cation uptake. The pH increase after nitrate application is more pronounced in monocots than in dicots. In general, preferential uptake of cations results in decreasing pH of the rhizosphere. Dicots with a relatively high CEC of the root tissue and \( \text{N}_2 \) fixing plants are known for their preferential cation uptake and thus their aptitude to decrease pH in the rhizosphere. In leguminous plants pH reduction occurs also in the presence of nitrate as shown by Romheld (1983) in beans, peas and peanuts. The difference between leguminous and non-leguminous crops in reducing the rhizospheric pH in the presence of nitrate also exists when both species are intercropped: the pH in the rhizosphere decreased in chick-pea and increased in maize respectively (Marschner and Romheld, 1983).

As shown by the same authors the change in rhizospheric pH is more pronounced in less buffered soils. Furthermore, the change in pH on the root surface increases with decreasing water content of the soil but intensive mass flow compresses the zone of pH change (Nye, 1981).

CONCLUSION

Considering plant production on acidic tropical soils from the aspect of nutrient uptake sustained productivity is doubtlessly linked with appropriate management of the
root system. It is self explanatory that, with increasing rooting depth, those nutrients, which had once been leached out of the toplayer are at least partly recovered. Utilization of subsoil layers becomes relevant in particular after depletion of the topsoil (Gass, Peterren, Hauck and Olson, 1971). Furthermore, increased utilization of soil and fertilizer nutrients with increasing root densities may be expected.

Apart from physical exploitation of the soil the efficiency of nutrient absorption in the presence of toxic or highly competitive ions is another factor determining yield potential.

A wide genetic variability is known to exist in the response of rooting pattern and nutrient uptake to the conditions of acidic soils. Therefore, the exploitation of the genetic potential, i.e. screening of existing genepools, could be one of the measures to ensure productivity. However, care should be taken during screening to avoid accidental inclusion of agronomically less desirable characteristics such as susceptibility to disease.

Secondly, lime application controls the solubility of Al and hence root growth and efficiency of nutrient uptake. Disintegration of root tips affects not only proliferation but also metabolism of phyto-hormones and Ca uptake in particular. The intensity of root proliferation determines the intensity of physical soil exploitation. Phytohormones control the sink activity and therefore the yield potential. Increasing sink activity attracts more nutrients and consequently indirectly improves the utilization of fertilizers.

Presence of Ca in the solution of the top soil layer is also essential for the growth of underground storage organs which depend on exogenous supply of Ca from the surrounding media.
A third measure would be the avoidance of acidifying fertilizers. The interaction between NH$_4^+$ uptake and H$^+$ extrusion on the one hand and between H$^+$ concentration and K$^+$ net uptake on the other militates against the use of NH$_4$ fertilizer or urea. However, high leaching losses, high costs and restricted availability are some limitations of using nitrate fertilizers. Therefore application of ammonium fertilizer should be linked with close control of the Al status.

Measures which conserve soil water assist nutrient uptake as well. This is relevant not only for compensating the adverse effect of irregular rainfall pattern during the vegetative period but also to extend nutrient availability after the rainy season. The yield increase on tied ridges especially in years with extreme rainfall distribution (Honisch, 1974), the positive effect of potholing as well as the marked yield reduction at late planting can also be related to the impact of water shortage on nutrient uptake. Improvement of the nutrient status of the soil can counterbalance, at least in part, the inhibiting effect of water stress on nutrient uptake. The application of less leachable fertilizers e.g. potassium sulphate instead of muriate and split application - also recommended for potassium (Uehara and Keng, 1975) are other measures to extend the nutrient availability and therefore, to adjust the nutrient supply to the actual requirement of the plant.

Finally, mulching considerably reduces the amplitude of the temperature profile especially in the top layer. Controlling the root zone temperature improves the Ca status of the plant and consequently yield potential. In addition to the indirect effect on Ca uptake mulch also contributes to the nutrient supply of plants as shown by Lal (1979) and restricts nutrient losses through erosion.
ACKNOWLEDGEMENT

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INTRODUCTION

Physiographic position, physical and chemical properties determine the soil management practices required for optimal crop production. In the lowlands of the Kingdom of Lesotho there are three major geomorphic units, viz. plateaus, pediments, and river terraces. Associated with each type of geomorphic unit are characteristic soils. Red coloured soils can be found on pediments, but the central concept for red soils can be found on pediments but the central concept for red soils in the lowlands is the Leribe Soil Series of the plateau areas which are sandy loams and loams with a consistent 5YR hue. The Leribe series is often described as one of the best agricultural soils in Lesotho. In this paper, the soils of the lowlands valley of Ha Tsilo will be presented and discussed in terms of management requirements for crop production and implications for government agricultural development policy.

HA TSILO VALLEY: LOCATION, GEOLOGY AND GEOMORPHOLOGY

The valley of ha Tsilo is located between Maseru and Matsieng in the central lowlands of the Kingdom of Lesotho, southern Africa. The valley is defined by the sandstone escarpment which separates the lowlands from the Foothills and mountains of Lesotho.

The valley floor and walls are composed of different formations of the Stormberg Series of rock which are of Triassic to Rhaetic age (Stockley, 1947). The valley floor consists of materials from the Red Beds formation and
alluvial sediments which have been transported into the valley. The upper valley walls consist of rocks from the Cave Sandstone formation.

HA Tsilo valley contains 3 geomorphic surfaces: escarpment pediments, descending from the valley walls, river terraces, and a residual plateau. Each geomorphic unit has a sequence of soils with different physical and chemical properties. A study area approximately 3 km sq. was selected near the mouth of the valley. Two escarpment pediment slopes, 2 large areas of river terraces and a small residual plateau were included in the research area.

The two pediment slopes, referred to as the Valley Wall pediment and the Side Slope pediment differed in size, aspect, slope shape and the nature of the escarpment from which they were derived. The valley Wall pediment was approximately 1.3 km wide and 0.2 km long. A dyke which intruded into the northern end of the pediment formed the boundary of the research area. The upper slope shapes of the pediment tended to be convex and steep (15-18% slope), and the midslopes and lower slopes were straight with 5-7% slope. The smaller Side Slopes pediment was approximately 0.3 km wide and 0.3 km long. The upper portion of this escarpment tended to be concave in shape, with 9-16% slope, while the mid and lower sections of the pediment were straight with 5-7% slope.

Both pediment slopes have shapes which would be characterized as water-distributing rather than water-collecting. A distinctive feature of the pediments was the presence of deep erosion gullies which cut to bedrock in most places. Springs occur at the nick points on both concave and convex slopes.

The river terraces, referred to as Alluvial Areas, were characterized by flat areas with 0-4% slope. Alluvial deposits were also found on the lower parts of some areas of the Valley Wall pediment. Where the slope was 3-4%, broad (0.5-1 metre) erosion rills were cutting into the farmer's fields.
The residual plateau was formed on an outcrop of sandstone from the valley floor and thus is elevated above the river terraces which border on the east and north and the ephemeral stream bed on the west. The plateau faces north and has a small convex upper region with a 6% slope, a straight-shaped midsection with a 5% slope and a relatively large, level lower area. Neither erosion channels nor springs were found on the plateau. In this study, the area is referred to as Upland Plateau.

METHODS

Survey and characterisation of soils

A map of the area was made by distinguishing soil boundaries. Surface soil samples were taken for analysis, and holes were made with an auger to a depth of 1 metre to characterize soil colour, texture, and pH changes with depth. The soil properties thus observed were used to relate the soils of the research area to those described by Soil Conservation Service (1979).

Soil samples taken from the plough layer of fields in the research area were sent to the Cornell University soil test laboratory for analysis using standard methods (Greweling and Peech, 1965). The number of fields sampled on each geomorphic unit permitted statistical analysis by non-parametric methods for small sample sizes. The Kruskal-Wallis one-way analysis of variance was used to determine whether samples of each geomorphic unit represented samples from one population, and thus could be grouped for analysis. The Mann-Whitney test was employed to determine whether there were significant differences between sampled populations, and the Jonckheere-Terpstra test for ordered alternatives was used in determining a ranking order among several different populations (Daniel, 1978).

Soil pH was determined in the field with colour dye kits and in the laboratory in 1:1 soil: water extract.
Al, Mn, Fe, P, Ca, K, Mg were determined from sodium acetate-acetic acid buffer (pH 4.8) extracts of soil (1:5 soil:solution). Na was determined from 1M ammonium chloride extracts of soil.

**RESULTS AND DISCUSSION**

A summary of the soil units mapped is presented in Table 1, relating the soils of the geomorphic units of the research area to the 1967 CCTA/CSA classification and Soil Taxonomy, (Soil Survey Staff, 1975). Some of the soils described in "The Soils of Lesotho" were not identified in the earlier classification system. Similarly, some of the upper pediment soils of ha Tsilo were not described in Soil Taxonomy. These soils are noted as "unclassified" in the Table.

**TABLE 1 - CORRELATIONS OF HA TSILO WITH OTHER CLASSIFICATIONS**

<table>
<thead>
<tr>
<th>Research Area Name</th>
<th>CCTA/CSA system</th>
<th>Lesotho Soil Series</th>
<th>Soil Taxonomy Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland Plateau</td>
<td>Persiallitic</td>
<td>Berea</td>
<td>Plinthaquic Dystrochrept</td>
</tr>
<tr>
<td></td>
<td>Persiallitic</td>
<td>Leribe</td>
<td>Typic Hapludoll</td>
</tr>
<tr>
<td>Side Slope</td>
<td>Clay Pan Soil of Maseru Set</td>
<td>Maseru</td>
<td>Typic Albaqualf</td>
</tr>
<tr>
<td></td>
<td>Unclassified</td>
<td>Rama</td>
<td>Aquic Argiudoll (Aquic Hapludalf)</td>
</tr>
<tr>
<td>Valley Wall</td>
<td>Clay Pan Soil Sephul</td>
<td>Sephul</td>
<td>Aeric Albaqualf (Albaquic Hapludalf)</td>
</tr>
<tr>
<td></td>
<td>Clay Pan Soil Tsiki of Maseru Set</td>
<td>Tsiki</td>
<td>Typic Albaqualf</td>
</tr>
<tr>
<td></td>
<td>Clay Pan Soil Maseru</td>
<td>Maseru</td>
<td>Typic Albaqualf (Aquic Hapludalf)</td>
</tr>
<tr>
<td></td>
<td>Almost: Vert-sol of Topo-graphic Depressions</td>
<td>Maseru, dark variant</td>
<td>Aquic Argiudoll (Aquic Hapludalf)</td>
</tr>
<tr>
<td></td>
<td>Unclassified</td>
<td>Rama</td>
<td></td>
</tr>
<tr>
<td>Alluvial Area</td>
<td>Vertisols of Pogographic Depressions</td>
<td>Khabos</td>
<td>Pachic Argiudoll</td>
</tr>
<tr>
<td></td>
<td>Unclassified</td>
<td>Unclassified</td>
<td></td>
</tr>
</tbody>
</table>
Difficulty was experienced in using the 1979 'Soils of Lesotho' because, although the soils of ha Tsilo matched descriptions of soil series, they did not have the properties required for the stated moisture regimes, temperature regimes, and diagnostic horizons. In particular, criteria could not be met for the mollic epipedon. Other users of Soil Taxonomy have had difficulties with the 'Soils of Lesotho'. As a result, after the USAID mission which produced the book left the country, staff of the Ministry of Agriculture had to resample, recharacterise, and reclassify the soils of Lesotho. The results of this work should be available in late 1986. It is understood that most of the "mollisols" have now been classified as alfisols. Until the new publication is available, the most accurate classification is the CCTA/CSA work of 1967.

Despite the technical problems of classification systems, Table 1 does show that, at the highest level of classification, the soils of each geomorphic unit are the same and largely different from those of other geomorphic units. The Upland Plateau features fersiallitic soils, the pediment clay pan soils, and the alluvial areas vertisols.

SOIL PROPERTIES: ERODIBILITY, MOISTURE, AND NUTRITIONAL STATUS

The soil properties of concern to farmers are erodibility, moisture supplying capacity, and nutrient status. The soils of each geomorphic unit had distinct and different properties which affected these concerns.

General statements have already been made about the presence of observable erosion features on each geomorphic unit: the absence of gully or rill erosion on the red soils of the Upland Plateau, rills on the gently sloping alluvial soils, and deep gullies on the pediment soils. Sheet erosion was also least severe on the red Upland Plateau soils. It
has been reported elsewhere (Showers, 1982) that the development of erosion gullies in the pediments was the result of improperly designed conservation works designed by colonial engineers during the late 1930's. The different physical properties of the soils of the Alluvial Areas and Upland Plateau together with the difference in physiography, prevented gully formation on these surfaces.

As noted in the previous section, both pediments had areas of wet spots and springs at the nick point in the slope and evidence of saturated throughflow downhill within the pediments. The Alluvial Areas, which did not have springs had increased subsoil moisture associated with changes in soil texture at depth. In sharp contrast, the red soils of the Upland Plateau had neither springs nor perched water tables and were, therefore, drier at depth than the soils of other geomorphic units.

The range of soil chemical characteristics associated with each geomorphic unit are presented in Tables 2 and 3, along with notations of statistical relationships. The statistical analysis supported the validity of the assumption that the soils of each geomorphic unit represented samples of a single, larger population and that comparisons could be made among geomorphic units. Of particular interest here is the observation that the soils of the Upland Plateau - both the red Leribe Series and the associated yellowish-red Berea Series - form a single sampling population which is distinctly different from all of the other soils of the research area. The upland Plateau Soils are more acidic, higher in aluminium and manganese, and lower in phosphorus, sodium, potassium, magnesium, and calcium than soils of the other geomorphic units. The sum of the bases, was distinctly lower than for soils of other geomorphic units as was % base saturation and calcium as per cent of CEC (vide table 2).
INTERPRETATION OF CHEMICAL PROPERTIES FOR CROP PRODUCTION

Correlation data for maize grown on the acid soils of northern New York State, USA; Kumasi, Ghana; and Brazilia, Brazil using the Cornell Soil Test Laboratory procedures which were available were used as the basis for management interpretation.

**TABLE 2: RANGE OF CHEMICAL PROPERTIES OF SURFACE SOILS, HATSILO LESOTHO**

<table>
<thead>
<tr>
<th>Property</th>
<th>Upland Plateau</th>
<th>Statistical Signif.</th>
<th>Side Slope</th>
<th>Valley Wall</th>
<th>Alluvial Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.8-5.2</td>
<td>= .01 KW</td>
<td>5.0-5.7</td>
<td>5.0-0.6</td>
<td>5.2-5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.01 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsoil</td>
<td>5.2-5.4</td>
<td>= .01 KW</td>
<td>5.6-6.6</td>
<td>5.4-6.6</td>
<td>5.6-5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.01 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exch H+</td>
<td>5-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>me/100g</td>
<td>0.4-1.3</td>
<td>= 0.1 KW</td>
<td>0.1-0.2</td>
<td>0.1-0.8</td>
<td>0.1-0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0.1 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.10-0.46</td>
<td>= 0.1 KW</td>
<td>0.9-0.14</td>
<td>0.05-0.17</td>
<td>0.10-0.18</td>
</tr>
<tr>
<td>me/100g</td>
<td></td>
<td>= 0.1 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>1-2</td>
<td>= 0.1 aJT</td>
<td>1-3</td>
<td>1-2</td>
<td>4-7</td>
</tr>
<tr>
<td>Iron</td>
<td>1-3</td>
<td>1-2</td>
<td>4-7</td>
<td>12-22</td>
<td></td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.0-0.0</td>
<td>= 0.1 aJT</td>
<td>0.0-0.1</td>
<td>0.0-0.1</td>
<td>0.0-0.0</td>
</tr>
<tr>
<td>1b/Acre</td>
<td></td>
<td>= 0.1 aJT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>0.1-0.3</td>
<td>= 0.1 aJT</td>
<td>0.1-0.3</td>
<td>0.1-0.3</td>
<td>0.2-0.4</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.1-0.5</td>
<td>= 0.1 aJT</td>
<td>0.6-0.8</td>
<td>0.5-1.9</td>
<td>3.6-5.4</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.3-0.8</td>
<td></td>
<td>2.5-0.0</td>
<td>1.5-8.5</td>
<td>7.8-13.0</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.4-1.5</td>
<td></td>
<td>2.9-5.9</td>
<td>2.2-10.6</td>
<td>11.6-18.8</td>
</tr>
<tr>
<td>Sum of Bases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Notes on statistics:
=.01 KW - Kruskal-Wall; one-way analysis of variance showed no difference at =.01 between the median of the populations of values from the Side Slope, Valley Wall, and Alluvial Area, indicating samples represent the same large population.

=0.1 MW - Mann-Whitney test showed significant difference between the population of values from the Upland Plateau and those of the other locations.

=.01 aJT - Jonckheere-Terpstra test for ordered alternatives showed a significant ranking of populations, with the LOWEST values associated with Upland Plateau.

=0.1 bJT - Jonkheere-Terpstra test for ordered alternatives showed a significant ranking of populations, with the HIGHEST values associated with Upland Plateau.
TABLE 3 - RANGE OF PERCENT ORGANIC MATTER, NITROGEN AND C/N RATIOS FOR SURFACE SOILS, HA TSILIO, LESOTHO

<table>
<thead>
<tr>
<th>Property</th>
<th>Upland Plateau</th>
<th>Side Slope</th>
<th>Valley Wall</th>
<th>Alluvial Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Organic(^1)</td>
<td>0.7-1.5</td>
<td>1.1-1.9</td>
<td>1.2-3.1</td>
<td>3.6-4.2</td>
</tr>
<tr>
<td>% Nitrogen</td>
<td>0.3-0.8</td>
<td>0.7-0.10</td>
<td>0.6-0.10</td>
<td>0.2-0.4</td>
</tr>
<tr>
<td>C/N Ratio(^2)</td>
<td>10-17</td>
<td>12-12</td>
<td>9-15</td>
<td>7-12</td>
</tr>
</tbody>
</table>

\(^1\)OM determined by "loss on ignition" method
\(^2\)C calculated from organic matter using factor of 1.72

Table 4 presents the numerical ranges derived for optimal levels of some elements and indicates the number of fields on each geomorphic surface having optimal or sub-optimal levels for plant production. Combining the information from Tables 2 and 4, it is clear that the Upland Plateau soils have toxic levels of aluminium and manganese and insufficient levels of phosphorus and bases. A survey of the literature on plant requirements for calcium suggests that the calcium levels in the Upland Plateau could induce deficiency symptoms in plants (Pierre and Allaway, 1941; Birch, 1952; Howard and Adams, 1965).

Plant growth would obviously be most inhibited on the Upland Plateau soils where toxic levels of aluminium and manganese and deficient levels of calcium would inhibit root growth, decreasing the plants' ability to utilize the limited quantities of moisture and nutrients in the soil. Crops grown on the higher moisture and base status pediment soils would be limited, by the availability of phosphorus, potassium, and nitrogen. The most favourable conditions for plants would be found on the alluvial soils, where nitrogen might be the only limiting production.

The Red Leribe Soil Series could justifiably be called one of the best soils in the valley in terms of observable evidence of low susceptibility to soil erodibility. However, in terms
of water relations and soil chemical properties, these soils are the most inadequate in the valley for crop production. Farmers operating at a subsistence or sub-subsistence level of production would obviously value the alluvial soils most, over the red and yellowish red Upland Plateau soils, despite the problems associated with gullies in the pediment soils.

TABLE 4 - NUMBER OF FIELDS IN OPTIMAL OR SUB-OPTIMAL RANGE OF SOIL CHEMICAL CHARACTERISTICS, HA TSILO, LESOTHO

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.5-6.5</td>
<td>0</td>
<td>6</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Topsoil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsoil</td>
<td></td>
<td>0</td>
<td>6</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>aluminium</td>
<td>1-99 lb/A</td>
<td>0</td>
<td>6</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Manganese</td>
<td>1-99 lb/A</td>
<td>2</td>
<td>5</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Range, lb/A</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>v. Low &lt;1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low 1-3</td>
<td></td>
<td>4</td>
<td>14</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Med 4-8</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>High 9-39</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>v. high&gt;39</td>
<td></td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Range, lb/A</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>v. Low &lt;20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low 20-65</td>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Me 66-100</td>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>0</td>
<td>18</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
The cost of purchasing adequate amounts of fertilizers, the difficulty of transporting them to a valley which is not served by a vehicular transport system and the techniques associated with the proper application of fertilizers will be well beyond the capacity of a subsistence farmer. The red Leribe soils which are considered to be among the best in the country may not be the best for poor farmers.

**POLICY IMPLICATIONS**

All of the farmers in the ha Tsilo Valley and most of the farmers in Lesotho operate at a subsistence level. Despite their poverty, they do invest in agriculture and livestock production. Cash from migrant labourers is used to purchase implements, seed, pest control measures, and cattle for ploughing. Human energy and time are spent repairing equipment, selecting and storing seed, providing food to field workers, and such production activities as land preparation, cultivation, and weeding.

Increased crop yields will depend firstly on creating optimum soil chemical environments and secondly on supplying optimum levels of water to the growing crops. On all but alluvial soils, this will require a large financial investment. The level of investment is beyond the means of any of the farmers in the valley. If the national goal is for food self-sufficiency, then government priority - and creativity - must be centred on designing mechanisms to make essential soil amendments available to subsistence farmers at rates which they can afford, coupled with a farm-gate delivery system and technical advisors to ensure the most efficient application of fertilizers to the land.

**CONCLUSION**

It has been shown that, in the Valley of ha Tsilo, red soils exist on residual plateaus and, to a lesser extent, on the upper portions of pediment slopes. The physical and chemical properties of the red Leribe soil series and the associated yellowish red Berea soil series were distinctly
different from those of other soils in the valley.

Although considered one of the best soils in Lesotho from the point of view of resistance to soil erosion, the red Leribe soils are the poorest in providing a suitable soil chemical and moisture environment for plant growth. The subsistence farmers of the valley could not afford to purchase the soil amendments needed to correct the many nutrient deficiencies. This has implications for government policy. If the nation wants to achieve a state of self-sufficiency in food production and food security, mechanisms must be created to assist the majority of subsistence farmers to obtain and use the required soil amendments.

ACKNOWLEDGEMENTS

The author was guided in field work by Mr Randy Davis, a Peace Corps Volunteer who had mapped substantial areas of the lowlands and foothills of Lesotho for the Ministry of Agriculture. His assistance is gratefully acknowledged.

REFERENCES


SOME RED SOILS OF THE MIOMBO WOODLAND AND
THE POTENTIAL OF AGROFORESTRY

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INTRODUCTION

The decision to look at the soils of such a large area in one paper was because this whole area falls under the same Agro-ecological zone. Consequently, they are found to possess similar problems and the interventions intended to solve these problems are bound to be similar to a great extent.

What is 'The miombo zone'

The term 'miombo' is adopted from the FAO/UNESCO vegetation classification for savanna woodland. Miombo is a common 'Bantu' name used to describe vegetation dominated by tree genera like the Brachystegia, Julbernadia and Isoberlinia. The trees in this ecological zone are small to medium size (5 to 20 m), with a single canopy, well adapted to water stress and fire, and frequently deciduous. Other features of these genera are that they are slow-growing and have poor coppicing properties. A significant feature of this vegetation type is that most of the species that are encountered in this ecozone are leguminous. Some of them are symbiotic with nitrogen-fixing bacteria whilst others are known to benefit from a symbiotic association with ectomycorrhizal fungi. Other important genera of this ecozone are the Acacias, Albizias and Terminaliae. The distribution of these vegetation types is governed by climate, soil factors and altitude.

In order to assess the extent of miombo woodland in Central and Southern Africa, various data on climate and altitude were examined.
Various criteria were then used to delineate miombo areas, namely; that the FAO-defined 'growing period' should lie between 90 and 270 days; the altitude should lie between 300 and 1800 m; the rainfall pattern should be unimodal and annual rainfall be between 550 mm and 1600 mm. From this exercise, it was established that in Tanzania, Malawi, Zambia and Zimbabwe, over 60% of the total areas could fall into miombo type woodland.

Soils under the Miombo Woodland

In order to compare the soils in all four countries in this ecozone, the FAO/UNESCO soil legend was used (FAO/UNESCO, 1974). When looking at the soils under the miombo vegetation, it is observed that there are only four different units in all four countries. There are Ferralsols, found mainly in Zambia and Malawi as well as in the Eastern Highlands of Zimbabwe and parts of the Ruvuma, Morogoro and Lindi regions in Tanzania. These are the red, highly weathered soils of the tropics, representing the final stage of ferralitic weathering. They have virtually no 2:1 lattice clay minerals and have a low CEC. These soils mainly cover the wetter parts of the miombo zone. The most dominant of these are the orthic Ferralsols which are fairly low in fertility except under forest where the more efficient cycling of nutrients gives them a temporary high fertility status. The rhodic Ferralsols are found in the Northern Provinces of Zambia and the Eastern Highlands of Zimbabwe. They have a slightly higher fertility status than the other Ferralsols. Other properties and details are given in Table 1.

The second most dominant soil unit in the ecozone is the Acrisols, found mainly in the Central and Southern parts of Tanzania. These are relatively unweathered, red, tropical soils, but more strongly leached than Luvisols and have a base saturation <50%. They are found in areas that have slightly lower rainfall than the Ferralsols. Such soils are found in the drier Zambezian miombo woodland in Tanzania. The only Acrisols found in this ecozone are the ferric Acrisols which are fairly poor in plant nutrients.
<table>
<thead>
<tr>
<th>Soil Class</th>
<th>Associated Soils</th>
<th>Texture</th>
<th>Drainage</th>
<th>Topography</th>
<th>Fertility Status</th>
<th>Soil Suitability</th>
<th>Country</th>
<th>Province/ Locality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferric plinthic Acrisols,</td>
<td>rhodic, Ferralsols, Arenosols</td>
<td>COARSE</td>
<td>Moderate to</td>
<td>Undulating</td>
<td>Low to Medium</td>
<td>For Cassava, G/nuts,</td>
<td>TANZANIA</td>
<td>RUUVUMA,</td>
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<tr>
<td>ACRISOLS</td>
<td></td>
<td>MEDIUM</td>
<td>well drained</td>
<td>&amp; Rolling in</td>
<td></td>
<td>beans and livestock</td>
<td></td>
<td>MOROGORO,</td>
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<td>Ruvuma</td>
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<td>production</td>
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<td>MBEYA,</td>
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<tr>
<td>Orthic plinthic Acrisols,</td>
<td>ferralic Arenosols</td>
<td>MEDIUM</td>
<td>Moderate to</td>
<td>Undulating</td>
<td>Low to Medium</td>
<td>For cassava, G/nuts,</td>
<td>TANZANIA</td>
<td>MBeya,</td>
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<td>well drained</td>
<td>to Rolling</td>
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<td>beans and livestock</td>
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<td>MRONGORO,</td>
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<td>IRINGA.</td>
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<td>Ferric lithosols</td>
<td></td>
<td>COARSE</td>
<td>Well drained</td>
<td>Undulating</td>
<td>Moderate to Low</td>
<td>G/nuts, tobacco, cotton</td>
<td>TANZANIA</td>
<td>KIGOMA, W.</td>
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<tr>
<td>Ferric Chromic luvisols</td>
<td></td>
<td>MEDIUM</td>
<td>to Low</td>
<td>Moderate to Low</td>
<td></td>
<td>Livestock</td>
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<td>TABORA,</td>
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<td>FINE</td>
<td>Well drained</td>
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<td>BLANTYRE,</td>
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<td>LILONGWE,</td>
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<td>LASUNGU DISTR.</td>
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<tr>
<td>Ferric ferralic Arenosols</td>
<td>eutric Nitosols</td>
<td>COARSE</td>
<td>Well drained</td>
<td>Undulating</td>
<td>Moderate to Low</td>
<td>G/nuts, tobacco, cotton</td>
<td>ZIMBABWE</td>
<td>MATABELELAND-ND,</td>
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<td></td>
<td></td>
<td>MEDIUM</td>
<td></td>
<td></td>
<td></td>
<td>Livestock</td>
<td></td>
<td>E.C.W. MIDLANDS,</td>
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<td>MASHONALAND,</td>
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<td>MANICALAND.</td>
</tr>
<tr>
<td>Orthic Solonetz</td>
<td></td>
<td>COARSE</td>
<td>Well drained</td>
<td>Undulating</td>
<td>Moderate</td>
<td>Tobacco, maize, ranching</td>
<td>ZIMBABWE</td>
<td>MASHONALAND-ND,</td>
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<td>MATABELELAND S.</td>
</tr>
<tr>
<td>Soil Type</td>
<td>Texture</td>
<td>Drainage</td>
<td>Topography</td>
<td>Land Use</td>
<td>Country</td>
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<tr>
<td>Chromic Orthic Solonetz</td>
<td>Coarse &amp; Medium</td>
<td>Well Drained</td>
<td>Undulating</td>
<td>Moderate Sorghum, cassava</td>
<td>Zimbabwe</td>
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<tr>
<td>Chromic Orthic Solonetz</td>
<td>Medium &amp; Fine</td>
<td>Well Drained</td>
<td>Undulating</td>
<td>Moderate Sorghum, cassava</td>
<td>Zambia</td>
<td></td>
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</tr>
<tr>
<td>Orthic Xanthic Ferralsols</td>
<td>Medium &amp; Fine</td>
<td>Well Drained</td>
<td>Undulating</td>
<td>Low Cocoa, Coffee, oil palm, intensive Agriculture not advisable</td>
<td>Zambia, N. Western Pr. Central Pr., Northern Pr., Luapula Pr., Southern Pr.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthic Xanthic Ferralsols</td>
<td>Medium &amp; Fine</td>
<td>Well Drained</td>
<td>Rolling to hilly</td>
<td>Low Extensive ranching</td>
<td>Malawi, Karonga, Mzuzu, Kasungu, Lilongwe, ADDS.</td>
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<td>Ferralsols</td>
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<td></td>
</tr>
<tr>
<td>Xanthic Orthic &amp; ferralic Arenosols</td>
<td>Coarse &amp; Medium</td>
<td>Well Drained to Rolling</td>
<td>Undulating Low to Rolling</td>
<td>Low Rubber, Cocoa, Coffee, oil palm and grazing</td>
<td>Zambia, West of Central Pr., West. Pr., N. West.</td>
<td></td>
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</tr>
<tr>
<td>Rhodic Orthic Ferralsols</td>
<td>Fine</td>
<td>Well Drained</td>
<td>Undulating</td>
<td>Low to Moderate</td>
<td>Cassava, banana, coffee, tea, maize</td>
<td>Zambia, N. Western Pr., Copper-Belt Pr.</td>
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</tbody>
</table>
The third most dominant soil unit in the ecozone is the Luvisols which cover most of Zimbabwe, southern Malawi, northwestern Tanzania and southern Zambia. These are red to yellowish red soils with a base saturation >50% and only partially weathered due to the fact that they experience a long dry season. The Luvisols have some 2:1 lattice clay minerals and a moderate to low CEC (ca. 10 meq/100 g). The most dominant of these are the ferric Luvisols found under the drier Zambezian miombo woodland, the undifferentiated miombo woodland in Zimbabwe and the wetter Zambezian woodland in Tanzania. Chromic Luvisols are also found in the drier part of miombo, or along the river basins in both Zimbabwe and Zambia.

**PROBLEMS EXPERIENCED ON RED SOILS OF MIOMBO WOODLAND**

Since a major problem in these environments is soil erosion which is largely due to the fact that the erosive power of tropical rain may be about 16 times greater than temperate rain (Hudson, 1971). One of the characteristics of these soils which needs to be examined is their erodibility. Erodibility is directly influenced by the particle size distribution of the soil especially the ratio of sand + silt/clay. As the ratio becomes larger or the texture become sandier, erodibility increases (Bouyoucos, 1935). It can be observed from Table 1 that, with the exception of the rhodic Ferralsols in Zambia and some of the ferric Luvisols in Malawi and the orthic Ferralsols in Malawi, the texture of most of the soils is medium to coarse. It can therefore be recognized that a combination of highly erosive rainfall and highly erodible soils gives a potentially dangerous situation.

The topography with respect to soil erosion also needs close examination. The steepness of the slope directly influences soil erosion. The slope length is also directly linked to the amount of damage the surface runoff can cause. From Table 1 it can be observed that most of the land in this ecozone is undulating (slope of up to 8%). The topography of the Ruvuma
and Mbeya regions in Tanzania, most of Malawi and eastern Zimbabwe (Manicaland) is termed as rolling to hilly (8 to 30% slope). It can be seen that a combination of these slopes, the erosive rainfall and the highly erodible soils could be a recipe for disaster.

The soil can also be degraded with respect to fertility. Therefore considerable attention needs to be focused on potential problems linked to soil fertility. Inherently, the soils of this ecozone are not fertile as shown in Table 1. As these soils are formed in an ecozone of high rainfall and temperature, the rate of decomposition of both soil minerals from the parent rock and the organic matter of the soils is high. As a result, nutrients released by weathering are rapidly leached out especially as these soils have high infiltration rates and low water holding capacities. Similarly organic matter decomposes rapidly resulting in very little or no organic matter accumulation in these soils. Therefore, since these soils are highly weathered and leached and have no nutrient reserves, they are usually considered to be of medium to low fertility status. They also tend to have acidic pHs of between 4 and 4.5 for Ferralsols, 5 and 6 for Luvisols and 4.5 and 5.5 for Acrisols.

Lastly, the social aspects that could potentially lead to deterioration of these fragile soils should be examined. The human population pressure cannot be divorced from the fertility aspects of the soils. As population increases, people of this ecozone, who are still largely traditional shifting cultivators, will be forced to crop continuously on the same piece of land. Also, the type of crops that they produce, mainly maize, tobacco, cotton, sorghum and millet, have a high demand for nutrients and do not return much to the soil. This will aggravate an already bad situation. These crops will deplete the soil nutrients very rapidly. These crops also do not provide good ground cover at early stages of growth to prevent the intensive tropical rains from dislodging the loose top soil.
In broad terms, Agroforestry could be defined as multiple land-use systems and practices in which woody components are deliberately grown on the same land management unit as crops and/or animals, either on some form of spatial arrangement or in a time sequence and the system should permit a significant economic and ecological interaction between the woody and non-woody components.

Agroforestry practices have been carried out by small holders in the American, African and Asian tropics for many years without being acknowledged as beneficial systems or practices. Therefore very little is known scientifically about these practices and very little research has been done on them. These are systems like the "taungya system" in Asia where landless people or farmers are allowed to produce crops in the early years of a forest plantation. The crops benefit from the falling litter of the trees. Another example, from the miombo woodland itself, is the deliberate leaving of the "miracle tree" i.e. Acacia albida in Malawi within the cropland to provide fertility to the growing crops. Agroforestry can be divided into four different systems as follows:

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>COMBINATION SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees</td>
<td>Silvicultural</td>
</tr>
<tr>
<td>Crops</td>
<td>Silvipastoral</td>
</tr>
<tr>
<td>Livestock</td>
<td>Agrisilvicultural</td>
</tr>
<tr>
<td></td>
<td>Agrisilvipastoral</td>
</tr>
</tbody>
</table>

What should be clear from the beginning is that agro-forestry is not the system that will solve all the problems of this ecozone. It is just one system that might be considered when one tries to solve these problems. There is definitely a lot that can be done to improve soil fertility or provide good fodder
for animals but the advantage of agroforestry is that it has a land use system focus. Before one can jump to any conclusions about what agroforestry practice will suit a particular situation, one would have to analyse the production system as a whole to know all its weak and strong points.

In work done by ICRAF, in this ecozone, two outstanding problems have emerged namely soil erosion, mainly by water, and soil fertility decline. Where both erosion and fertility decline occur in this ecozone it is due to both human population pressure and livestock population pressure which have led to deforestation and overgrazing as well as continuous cropping without allowing the soils to go into fallow to rejuvenate or add any nutrients back to the soil. An agroforestry approach that can address these problems would have to look at increasing livestock fodder, maintaining ground cover, reducing deforestation or encouraging reafforestation as well as reducing the speed of surface runoff on grazing lands.

Since trees have deeper rooting systems than grasses, they are able to utilize groundwater for growth from great depths when the water table has receded beyond the level of the rooting system of grasses. Trees may therefore provide better alternative fodder for livestock during the dry season when the water table is low. Tree species which can provide fodder for animals and play a soil conservation role by maintaining good ground cover at the beginning of the rainy season, may be most desirable. As well as conserving the soil, such trees also provide poles, timber and fuelwood. Therefore the selection of Multi-Purpose-Trees (MPT's) that can at least provide the two basic requirements will be very important, since the land is scarce. Also, a few more of the trees could be planted in the "waste" lands around the homestead or as hedgerows. A few examples of the kind of trees that can be planted for this purpose and will grow well in this ecozone are Sesbania bispinosa, Gloricidia sepium, Parkia biglobosa, Albizia schimperiana.
Considering the soil fertility aspects of this ecozone, it has been observed that, due to pressure on land, permanent or continuous cultivation on the same piece of land has replaced shifting cultivation. The land users have realized the importance of trees in maintenance of soil fertility. Therefore, they should be encouraged to grow trees on grass strips or among crops in a particular pattern so that nutrient cycling is maintained by leaf fall. The trees can also be grown on the edges of cropland or in small woodlots, then branches of these trees can be lopped and carried to mulch fields, temporarily providing a conservation measure but later releasing nutrients back to the soil as they decompose. The trees are also capable of bringing back the leached nutrients to the surface by reabsorbing them by their deep rooting system and recycling them by leaf fall instead of losing them through leaching which is active/intense in this ecozone. The choice of the kind of trees which serve the purpose most efficiently is important. They must be fast-growing and easy to manage in order to prevent shading of crops. A few examples of such trees are *Prosopis juliflora*, *Prosopis africana*, *Leucaena leucocephala*, *Tamarindus indica*, *Psidium guajava*, *Acacia nilotica* and *Acacia albida*. Some of these trees are leguminous nitrogen-fixers while others are non-leguminous nitrogen-fixers. As observed in Malawi and many other countries, *Acacia albida* is unique; it sheds its leaves during the rainy season when crops are growing and new leaves only grow during the dry season. Like the other MPT's, *Acacia albida* can be utilized as fodder, timber and fuelwood which are useful bonuses in this region where the miombo woodland is rapidly disappearing specifically because of these various uses to which the trees are being put.

There are other important facts to consider when looking at the agroforestry potential of this ecozone. Local miombo tree species that are potential agroforestry species like the *Acacia*, *Albizia*, *Ziziphus*, *Ficus* and *Uapaca kirkiana* most of which are leguminous nitrogen-fixing species also produce food, fodder
and timber. It should therefore be emphasized that these agroforestry species are just as good as the exotic species and they are already well adapted to this ecozone. They can meet most of the requirements of the desired systems in the ecozone.

CONCLUSION

Appropriate agroforestry systems could therefore provide fuel, food, fibre, fodder, improve the fertility of the relatively infertile red soils of the miombo woodland and go a long way in promoting the conservation of the fragile miombo woodland soils.

Maybe, for the miombo woodland, agroforestry might be the technology the people can afford and be able to manage with the available resources. It might be the technology that will bring about sustainability in the production systems of the ecozone. This is a technology worth thinking about as "a technology of production with sustainability".

REFERENCES


LAND SUITABILITY EVALUATION OF RED SOILS IN THE KILIFI-KWALE COASTAL AREA, KENYA

BY

GATAHI, M.M* and D'COSTA, V.**

ABSTRACT

Red Soils - Arenosols, Ferralsols, Nitosols, Acrisols, Luvisols and Cambisols cover approximately 150,000 hectares in Kwale-Kilifi coastal area, Kenya. They occur on footslopes, coastal uplands and plains and lie in Kenya's agro-climatic zones II, III, IV and V where they cover 8,000, 86,000, 41,000 and 15,000 hectares respectively (Fig. 1).

Due to their extent and suitable physical characteristics the red soils are used extensively for production coconuts, cashewnuts and maize. A land suitability evaluation of the soils was made for coconuts, cashewnuts and maize based on the important land qualities, availability of moisture, nutrients and oxygen, susceptibility to soil erosion, availability of foothold for plants and the possibility of mechanisation. Each land quality was studied, quantified and rated. Subsequently, the suitability of each unit was obtained by matching the land qualities with the crop requirements through conversion tables.

For coconuts, Nitosols and chromic Luvisols are moderately suitable, Ferralsols, Acrisols and ferric Luvisols, are suitable but Cambisols and Arenosols are not suitable.

For cashewnuts, all soil units are moderately to marginally suitable except for Cambisols which are not suitable.

In Agroclimatic zones II, III and IV soil units are at least marginally suitable for maize except Arenosols which are not suitable in all Agroclimatic zones.

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RED SOILS OF KILIFI–KWALE COASTAL AREA, KENYA

LEGEND
- Excessively drained, very deep, red to yellowish red, sand to sandy loam. (terrific ARENOSOLS)
- well drained, very deep, yellowish red, sandy clay loam (terrific FERRALSOL)
- well drained, moderately deep, red to dusky red, sandy clay loam to sandy clay (mesic FERRALSOL)
- well drained, very deep, dark red clay (ferric NITOSOL)
- well drained, deep to very deep, yellowish red, sandy clay to clay (ferric ACRISOL)
- well drained, deep to very deep, yellowish red to dark red, sand to sandy loam underlyng 20–40 cm sandy loam (terrific LUVISOL)
- well drained, shallow to deep, yellowish red to dark red, sandy clay loam to clay (ceramic LUVISOL)

SAND 1:500,000

Drawing No. 85032
The most limiting land qualities are availability of moisture and foothold for coconuts and cashewnuts but, for maize, the availability of nutrients, moisture and susceptibility to soil erosion are most limiting.

INTRODUCTION

Red soils cover extensive areas in a 15 to 25 kilometre wide coastal strip of Kenya (Sombroek et al. 1982). Due to their favourable physical characteristics, these soils are used extensively for producing coconuts, cashews, citrus and the annual crops maize, cassava and some sugar cane.

Although of moderate agricultural potential, the coastal strip of Kenya has not been fully utilized since the present production is based on a low to medium level of technology. In future, the level of production has to be increased in order to meet the demand of its rapidly growing population. Increased production may be achieved through intensified land use based on a sound physical evaluation of the land (soil) resources in the area. The present land suitability classification evaluates the suitability of the red soils in the area for coconuts, cashewnuts and maize - the most important crops in the area.

The evaluation is confined to the red soils in the Kilifi-Kwale coastal area which have been characterised, classified and mapped at a scale of 1:100,000 (Michieka, et al. 1978; TPIP, 1983).

The productivity of red soils is constrained by several factors including availability of moisture, nutrients, susceptibility to soil erosion, foothold for plants, and possibilities for use of agricultural implements. These land qualities were therefore used as the diagnostic criteria in the evaluation.

THE STUDY AREA

The area stretches from the Kenya - Tanzania border to 3°30'S in the North and extends 25 kilometres inland from
the coast (Fig. 1). The study area has a hot humid to semi-arid climate and lies in Agroclimatic zones II to V. The rainfall pattern is bi-modal with a main peak in April-June and a minor one in September-November. The amount of annual rainfall decreases northwards along the coast and inland from the coast.

Red soils - with hues of 5YR and redder and chromas of 4 or more, occur extensively on the higher parts of the catenas in the coastal plain, uplands and footslopes in the area.

On the coastal plain, the well drained, red sandy loams to sandy clay loams developed from lagoonal (Kilindini) sands occur on flat to gently undulating landscapes with slopes of 0-5%. Along the coastline are shallow to moderately deep soils developed from coral limestones.

On the coastal uplands are well drained, extremely deep, sandy loams to sandy clay developed from unconsolidated red sands, fine to coarse grained sandstones and intermediate igneous rocks. The relief in the uplands is gently undulating to rolling with slopes ranging from 0 to over 25%.

On the Footslopes are well drained, very deep sandy clays to clays, developed from intermediate igneous rocks with an undulating to rolling relief.

The present land use is dominated by cultivation of the perennial crops coconut, cashew and the staple food maize.

METHODS

LAND EVALUATION METHOD

This physical land evaluation was based on the principles and concepts in the Framework for Land Evaluation, (FAO, 1976) and carried out following the guidelines "Land

Soil resources maps of the Kwale area at a scale of 1:100,000 (Michieka et al. 1978) and Kilifi area (T.P.I.P, 1983) provided the physical data on which the evaluation was based. After delineation of the red soils, their land characteristics (L.C.) were studied. The land quality (L.Q) concept of Beek and Bennema (1972) was used to select the diagnostic criteria for the evaluation. The LQ's selected were studies, quantified, rated and subsequently used to specify the suitability classes for the crops using conversion tables.

The suitability of each red soil was obtained by matching its rated LQs with the crop requirements of each LQ using the conversion tables.

The schemes for rating the LQ's were adapted from Gatahi (1983) and van de Weg and Braun (1977) as outlined below.

a) Availability of moisture

This LQ was assessed through the moisture deficits experienced by i) coconuts 24 months before harvest and,

ii) cashewnuts, August - December during the year of harvest.

For each crop a water balance calculation taking into the account the available moisture storage capacity (pF 2.0 - pF 4.2), the rooting depth, monthly evapotranspiration, monthly rainfall and infiltration rates was used to determine the deficits. This LQ was rated as shown in table 1. The availability of moisture for maize was assessed through the available moisture storage capacity.
Table 1. Rating for availability of moisture

<table>
<thead>
<tr>
<th>Rating Class</th>
<th>24-month deficits for coconuts (mm)</th>
<th>August-December deficits for cashew (mm)</th>
<th>Available storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-570</td>
<td>160</td>
<td>II+III IV V</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>150 250 -</td>
</tr>
<tr>
<td>2</td>
<td>571-1140</td>
<td>161-320</td>
<td>80-150 150-250 250</td>
</tr>
<tr>
<td>3</td>
<td>1141-1700</td>
<td>321-470</td>
<td>40-80 80-150 150-250</td>
</tr>
<tr>
<td>4</td>
<td>1701-2200</td>
<td>471-625</td>
<td>40 80 150</td>
</tr>
<tr>
<td>5</td>
<td>2200</td>
<td>625</td>
<td>- - -</td>
</tr>
</tbody>
</table>

b) Availability of nutrients

This LQ was assessed using the cation exchange capacity (subrating r1), the base saturation (subrating r2), sum of available elements viz., available cations, percentage carbon, phosphorus (subrating r3). The final rating of availability of nutrients was obtained by summing up the subratings r1, r2, and r3 according to the scheme in table 2.

Table 2. Rating of availability of nutrients

<table>
<thead>
<tr>
<th>Rating Class</th>
<th>CEC me/100g</th>
<th>Base sat. %</th>
<th>Available elements - r3</th>
<th>%C</th>
<th>P-ppm</th>
<th>r3 Final rating r1,r2,r3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>75</td>
<td>Ca++ Mg++ K+ 1.2</td>
<td>35</td>
<td>80</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>10-16</td>
<td>50-75</td>
<td>10-15 1-3 0.6-1.2 2.0-5.0</td>
<td>40-80</td>
<td>8-12</td>
<td>5-7</td>
</tr>
<tr>
<td>3</td>
<td>5-10</td>
<td>35-50</td>
<td>5-10 0.5-1.0 0.2-0.6 1.0-2.0</td>
<td>20-40</td>
<td>13-17</td>
<td>8-9</td>
</tr>
<tr>
<td>4</td>
<td>2-5</td>
<td>35</td>
<td>2-5 0.2-0.5 0.1-0.2 0.5-1.0</td>
<td>10-20</td>
<td>18-22</td>
<td>10-12</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>-</td>
<td>2 0.2 0.1 0.5 10</td>
<td>22</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

Ca++, Mg++, K+ in me/100g soil
c) **Susceptibility to soil erosion**

Susceptibility to soil erosion was assessed through slope angle (substrating R2), rainfall erosivity (substrating R3) and soil erodibility (substrating R4). Slope length and angle were measured in the field and the soil erodibility was assessed from the laboratory determinations of percentage carbon \( (r_1) \), flocculation index (ratio of natural clay to dispersed clay) \( (r_2) \) and the silt to clay ratio \( (r_3) \). The sum of subratings \( r_1, r_2 \) and \( r_3 \) gave the final rating of soil erodibility \( (R_4) \).

Rainfall erosivity was calculated from mean annual rainfall \( (x \text{ mm}) \) and the kinetic energy \( (KE) \) using the equation of Moore (1979) for coastal stations.

\[
K.E. = 22.82 x - 15795
\]

\[
R = 0.029 \text{ KE}^{-0.26.0} \text{ where } R = \text{ erosivity factor in tonnes/ha/year.}
\]

The final rating of susceptibility to erosion was obtained as the product of the subratings \( R_1, R_2, R_3 \) and \( R_4 \). The rating schemes for susceptibility to erosion are presented in table 3.

d) **Availability of oxygen**

Availability of oxygen, though important for crop production, was not limiting for red soils since all the soils are well drained.
TABLE 3. THE SUBRATINGS AND RATING OF SUSCEPTIBILITY TO EROSION

<table>
<thead>
<tr>
<th>Rating Class</th>
<th>Slope length R₁ (m)</th>
<th>Slope angle R₂ (%)</th>
<th>Erosivity factor R₃</th>
<th>%C R₁</th>
<th>F.1 (%) R₂</th>
<th>Silt/Clay R₃</th>
<th>Final Soil erodibility r₁, r₂, r₃</th>
<th>Susceptibility to erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>5</td>
<td>100</td>
<td>2</td>
<td>70</td>
<td>0.02</td>
<td>3-4</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>51-100</td>
<td>6-8</td>
<td>101-200</td>
<td>1-2</td>
<td>50-70</td>
<td>0.2-0.4</td>
<td>5</td>
<td>9-40</td>
</tr>
<tr>
<td>3</td>
<td>101-200</td>
<td>9-16</td>
<td>201-300</td>
<td>1</td>
<td>50</td>
<td>0.4</td>
<td>6</td>
<td>41-170</td>
</tr>
<tr>
<td>4</td>
<td>201-300</td>
<td>17-30</td>
<td>301-400</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>171-320</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>30</td>
<td>400</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8-9</td>
<td>320</td>
</tr>
</tbody>
</table>

Adapted from Gachene and Barber, (1982) and Gatahi (1983).

e) Availability of foothold for plants

Foothold for plants is an important LQ especially here where anchorage of tree crops is under consideration. This LQ considers compactness as it hinders root penetration together with the effective soil depth but in this area only the latter was important and was rated according to table 4.

TABLE 4. RATING OF FOOTHOLD FOR PLANTS

<table>
<thead>
<tr>
<th>Rating</th>
<th>Depth to limiting layer (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
</tr>
<tr>
<td>2</td>
<td>150-250</td>
</tr>
<tr>
<td>3</td>
<td>80-150</td>
</tr>
<tr>
<td>4</td>
<td>30-80</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
</tr>
</tbody>
</table>

TABLE 5. RATING FOR POSSIBILITY OF MECHANISATION

<table>
<thead>
<tr>
<th>Rating Class</th>
<th>Slope Range (%)</th>
<th>Depth to Bedrock (cm)</th>
<th>Distance between rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-9</td>
<td>50</td>
<td>100m</td>
</tr>
<tr>
<td>2</td>
<td>10-18</td>
<td>25-50</td>
<td>100-35m</td>
</tr>
<tr>
<td>3</td>
<td>19-27</td>
<td>15-25</td>
<td>35-10m</td>
</tr>
<tr>
<td>4</td>
<td>28-36</td>
<td>15</td>
<td>10.35m</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>-</td>
<td>3.5</td>
</tr>
</tbody>
</table>

f) Possibilities for mechanisation

This LQ which is important where farm machinery is used was assessed from the characteristics slope, depth/bedrock or ironstone and the distance between the rocks/to on the surface. The rating scheme is presented in table 5 where the lowest rating determines the final LQ rating.
RESULTS AND DISCUSSION

According to the FAO-UNESCO legend (1974) the soils classify into the subgroups ferralic Arenosols, orthic and rhodic Ferralsols, dystric and eutric Nitosols, ferral-chromic and, orthic Acrisols, ferric and chromic Luvisols and ferral-dystric Cambisols. The distribution and a brief description of each sub-group are given on the attached soil map of the Kilifi-Kwale coastal area.

These soils are developed on quartz and iron rich sandstones, grits, unconsolidated sands and limestones. Due to their parent materials these soils are sandy with very sandy topsoils. They are mainly acidic and have low organic matter content and are low to moderate in soil fertility. They are deficient in most major plant nutrients and have low to medium moisture storage capacity. The soils developed from intermediate igneous rocks and limestones are, however, higher in soil fertility and have a moderate to high moisture storage capacity.

These soils clay mineralogy is dominated by the I:1 clay kaolinite of varying degree of crystallization and some variable amounts of illite.

Ferralic Arenosols, covering about 6,000 ha are excessively drained extremely deep sands to sandy loams developed from sandstones and coral limestones. They occur on coastal uplands and plains on slopes of 5-16% and 0-2% respectively. They are of low fertility and low moisture storage capacities.

Ferralsols comprise well drained, very deep, sandy loams to sand clay with sandy loam to loamy sand topsoils. Orthic and rhodic subgroups cover 14,000 ha and 40,000 ha respectively in both the coastal upland and plains. In the coastal plains and uplands they are on slopes of 2-5% and 5-16% respectively and are developed on sandstones, unconsolidated sands and coral limestones. Both subgroups are acidic, and of low to moderate soil fertility with moderate soil moisture storage capacity.
Nitrosols, covering about 12,000 ha are well drained, very sandy clay to clay in the coastal uplands on slopes of 2-8%. The eutric Nitrosols are developed from a richer parent material—intermediate igneous rock, while the dystric ones are developed from limestones. Nitrosols are slightly acid and of moderate soil fertility with high soil moisture storage capacity.

Acrisols which cover about 17,500 ha are well drained, very deep sandy clay loams to sandy clay with sandy loam topsoil. The acrisols are developed from medium to coarse-grained sandstones in the coastal upland with slopes of 5-16%. The Acrisols are acidic and have low soil fertility and low moisture storage capacity. The ferral-chromic acrisols have lower CEC and base saturations.

Luvisols, covering about 32,000 ha comprise well drained, very deep sandy clay loam to sandy clay with loam topsoil. The luvisols are developed from sandstones in the uplands with slopes of 2-8%. In the coastal plain, the Luvisols are smaller in extent and are characterised by a layer of ferric nodules in the deeper subsoil. Luvisols are slightly to moderately acid, low in soil fertility and have a low to high moisture storage capacity.

Cambisols which cover about 28,000 ha along the coastal plain, comprises well drained, shallow to moderately deep, fairly rocky sandy clay loams to sandy clays. They are already developed from coral limestones. The cambisols are slightly acidic and of low to moderate soil fertility. The soil surface is on average, 20% rocky but may be 50% rocky in some places. The slopes are 0-2%.

Important physical and chemical characteristics of the red soils of the study area are presented in table 6.

The rating of each LQ for each soil unit is presented in table 7. The LQ availability of moisture is rated very low.
(5) to low (4) for coconuts but for cashews, which have a lower moisture requirement, it was rated low (4) in cambisols with other soils being moderate to high.

In agroclimatic zones II and III all the soils have low to moderate availability of moisture for maize except eutric Nitosols which have a high availability of moisture. In agroclimatic zones IV and V the availability of moisture for maize is low to very low for maize except for eutric Nitosols. In the assessment of available moisture for maize an effective soil depth of about 150cm was used, consequently the AMSC of the soils was lowered for maize.
### TABLE 6. SOME PHYSICAL–CHEMICAL CHARACTERISTICS OF THE RED SOILS

<table>
<thead>
<tr>
<th>SOIL UNIT</th>
<th>TEXTURE</th>
<th>ORGANIC MATTER (%)</th>
<th>pH</th>
<th>CEC (me/100g)</th>
<th>Base Saturation</th>
<th>EFFECTIVE SOIL DEPTH (cm)</th>
<th>A.M.S.C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOP SOIL</td>
<td>SUB SOIL</td>
<td>TOP SOIL</td>
<td>SUB SOIL</td>
<td>TOP SOIL</td>
<td>SUB SOIL</td>
<td>TOP SOIL</td>
</tr>
<tr>
<td>Qf/AD</td>
<td>S-SL</td>
<td>S-SL</td>
<td>0.3</td>
<td>0.07</td>
<td>5.4</td>
<td>5.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Fo/C</td>
<td>SL-</td>
<td>SCL-SC</td>
<td>0.7</td>
<td>0.2</td>
<td>6.7</td>
<td>6.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Fr/A-E</td>
<td>SL-SCL</td>
<td>SCL-SC</td>
<td>1.4</td>
<td>0.23</td>
<td>6.4</td>
<td>5.5</td>
<td>5.0-11</td>
</tr>
<tr>
<td>Nd/AB</td>
<td>SC</td>
<td>SC-C</td>
<td>0.9</td>
<td>0.35</td>
<td>5.9</td>
<td>6.2</td>
<td>9.4</td>
</tr>
<tr>
<td>Ne-BC</td>
<td>C</td>
<td>C</td>
<td>4.0</td>
<td>0.3</td>
<td>6.4</td>
<td>5.5</td>
<td>24</td>
</tr>
<tr>
<td>Afc/C</td>
<td>SL-LS</td>
<td>SCL-C</td>
<td>0.7</td>
<td>0.23</td>
<td>5.8</td>
<td>5.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Ao/AB</td>
<td>SL</td>
<td>SL-SCL</td>
<td>1.0</td>
<td>0.2</td>
<td>6.2</td>
<td>5.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Lf/AB</td>
<td>LS</td>
<td>SCL</td>
<td>1.2</td>
<td>0.3</td>
<td>5.9</td>
<td>6.2</td>
<td>9.6</td>
</tr>
<tr>
<td>Lc/AB</td>
<td>SCL-SC</td>
<td>SC-CL</td>
<td>0.74</td>
<td>0.26</td>
<td>6.2</td>
<td>6.0</td>
<td>10.8</td>
</tr>
<tr>
<td>Bdf/A</td>
<td>SL-SCL</td>
<td>SCL-SC</td>
<td>0.8</td>
<td>0.3</td>
<td>5.8</td>
<td>4.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

S = Sand    SL = Sandy Loam LS = Loamy sand, SCL = Sandy clay loam
SC = Sandy clay C = Clay
TABLE 7. RATED LAND QUALITIES FOR EACH SOIL UNIT.

<table>
<thead>
<tr>
<th>LAND QUALITY</th>
<th>Qf/AD</th>
<th>Po/C</th>
<th>Fr/A-E</th>
<th>Nd/AB</th>
<th>Ne/BC</th>
<th>Afc/C</th>
<th>Ao/AB</th>
<th>Lf/ABLc/ABBdf/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability of moisture a</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4-5*</td>
<td>4-5*</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>2-3*</td>
<td>2</td>
<td>1-2*</td>
<td>1-2*</td>
<td>2-1</td>
<td>2-3*</td>
<td>2-3*</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>3-4*</td>
<td>2-3*</td>
<td>2-3*</td>
<td>1-2*</td>
<td>2-3*</td>
<td>3-4*</td>
<td>2-3*</td>
</tr>
<tr>
<td>Availability of nutrients</td>
<td>5</td>
<td>3</td>
<td>2-3</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Susceptibility to erosion</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Availability oxygen</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Foothold for Plants</td>
<td>1</td>
<td>1</td>
<td>1-2</td>
<td>1-2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Possibility Mechanisation</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2-3</td>
<td>2-3</td>
<td>1</td>
</tr>
</tbody>
</table>

a = availability of moisture for coconuts  
b = availability of moisture for cashews  
c = availability of moisture for maize  
* = availability of moisture in Agroclimatic zones IV and V

Given the sandy nature of the topsoil, the natural soil fertility is dependent on the organic matter content, consequently Arenosols, ferral-chromic Acrisols and ferral-dystric Cambisols which are both sandy and low in organic matter have a low (rating 4) to very low (rating 5) soil fertility. Other soils are of moderate fertility except Nitosols have high to very high soil fertility.

The susceptibility to soil erosion is low (rating 2) to moderate (rating 3). Long slopes, high erosivity and low organic matter contents are the major causes of these susceptibility ratings. All the soils have a high availability of oxygen. The rootability is rated high for all soils except for the Cambisols which are only moderately deep but these too, satisfy the anchorage requirement for maize.
Surface rockiness and stoniness is the main limitation to mechanisation especially for the dystric Nitosols (rating 4) and Cambisols (rating 5). Soil depth also contributes against mechanisation for Cambisols. Rhodic Ferralsols, eutric Nitosols, Acrisols and chromic Luvisols show slight to moderate limitations to mechanisation due to their slopes. All the remaining soils do not have any significant limitations to mechanisation.

Suitability classification

The specifications of the diagnostic criteria viz. the 'conversion tables' used for assessing the suitability of each soil unit for coconuts and cashew is presented in table 8 and that for maize in table 9. It must be emphasised that there is a general lack of specific data on the requirements for both tree crops while for maize the necessary data is meagre.

TABLE 8 CONVERSION TABLES FOR COCOMUTS (a) CASHEWNUTS (b)

<table>
<thead>
<tr>
<th>LAND QUALITY</th>
<th>SUITABILITY CLASS</th>
<th>Availability of moisture</th>
<th>Availability of nutrients</th>
<th>Susceptibility to soil erosion</th>
<th>Availability of oxygen</th>
<th>Foothold for plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGHLY SUITABLE (S1)</td>
<td>(a) 1</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>(b) 1</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td>MODERATELY SUITABLE (S2)</td>
<td>(a) 2-3</td>
<td>3</td>
<td>3-4</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>(b) 2-3</td>
<td>3</td>
<td>3-4</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td>MARGINALLY SUITABLE (S3)</td>
<td>(a) 4</td>
<td>4-5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) 4</td>
<td>4-5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>NOT-SUITABLE NS</td>
<td>(a) 5</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4-5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) 5</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4-5</td>
<td></td>
</tr>
</tbody>
</table>
The suitability of each soil unit for each of the three crops is presented (table 10) for each agroclimatic zone. Table 10 clearly shows that the red soils are marginally suitable for coconuts except for Nitosols, Cambisols and Arenosols.

Nitosols are moderately suitable for coconuts while the Cambisols and Arenosols are not suitable for the crop due to very low availability of moisture and/or shallow depth. In agroclimatic zones IV and V, orthic Acrisols and ferric Luvisols are not suitable for the crop due to low availability of moisture.

All soils are moderately to marginally suitable for cashew but the Nitosols are highly suitable in potential zones II and III, but Cambisols are not suitable due to limited depth.

**TABLE 9. CONVERSION TABLES FOR MAIZE**

<table>
<thead>
<tr>
<th>Suitability Class</th>
<th>Land Quality</th>
<th>Agroclimatic Zone and AMSC(mm)</th>
<th>Availability of Nutrients</th>
<th>Susceptibility to erosion</th>
<th>Availability of oxygen</th>
<th>Foothold for plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly Suitable (S1)</td>
<td>III &amp; II 150</td>
<td>1-2 1-2 1-2 1-2 1-2 1-2</td>
<td>1-2 1-2 1-2 1-2 1-2 1-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV 250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately Suitable (S2)</td>
<td>III &amp; II 80-150</td>
<td>3 3 3 3 3 3</td>
<td>3 3 3 3 3 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV 150-250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V 250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marginally Suitable (S3)</td>
<td>II &amp; III 40-80</td>
<td>4 4 4 4 4 4</td>
<td>4 4 4 4 4 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV 80-150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V 150-250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not-suitable (NS)</td>
<td>II &amp; III 40</td>
<td>5 5 5 5 5 5</td>
<td>5 5 5 5 5 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV 80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V 150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 10. LAND SUITABILITY CLASSIFICATION FOR COCONUTS, CASHEW AND MAIZE

<table>
<thead>
<tr>
<th>CROP</th>
<th>SOIL UNIT</th>
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<th>Ne/BC</th>
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</table>

* Suitability refers to agroclimatic zone II and III
** Suitability refers to agroclimatic zone IV
*** This crop is not found in this zone

**CONCLUSION**

The production of coconuts, cashewnuts and maize on the red soils of coastal Kenya is limited mostly by the availability of moisture and foothold for plants in the case of perennial crops. For maize availability of nutrients and moisture are the biggest limitations to production.

The magnitude of limitation caused by availability of nutrients on the productivity of red soils for the perennial crops is not very clear due to lack of data and there/possibilities that the constraints so caused are more limiting than has been/are assumed in this evaluation.

**ACKNOWLEDGEMENTS:**

This paper was sent for publication with the kind permission of the Director of Agriculture. The attached map was kindly drawn by the Cartographic Section of Kenya Soil Survey, Nairobi, Kenya.
REFERENCES


THE EFFECT OF CULTIVATION ON ORGANIC CARBON, NITROGEN AND PHOSPHORUS OF SOME KENYAN RED SOILS

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SUMMARY

In a comparative study using cultivated and uncultivated adjacent soils, changes in carbon, nitrogen and phosphorus were examined. 3 soil profiles (0 - 100 cm) were sampled at increments of 10 cm and analysed. The 3 sample profiles represented a Chromic Luvisol and 2 Nitosols, these being the soils used most intensively for cultivation in Kenya.

Carbon and Nitrogen showed a declining trend in the plough layer of the 3 cultivated soils. Changes ranged between 3.1% and 14.8% for carbon, and 3.7% and 15.2% for nitrogen. For phosphorus, the cultivated soils had slightly higher amounts within the plough layer than the uncultivated soils. At lower depths, there was virtually no marked difference between the cultivated and uncultivated soils. The magnitude of change in the cultivated soils is attributed to the length of land use and the soil management practices.

INTRODUCTION

Intensive and continuous cultivation of soils leads to deterioration, especially the decline of organic carbon. This has far reaching effects on both physical and chemical properties of soils.

In traditional agriculture, it was possible to restore soil fertility through shifting cultivation. This practice, however, is not possible these days because of land pressure. The rapid increase of population in most tropical countries has considerably reduced the cultivable land and thus led to continuous use of available agricultural land. This continuous cropping of land
has led to a decline in fertility. Nye and Greenland (1960) reported steady decline in yields on land cropped continuously for a wide range of different crops on different soils. Similar observations have been reported by other workers (Lal, 1976; Juo and Lal, 1977; Aina, 1979 and Okigbo and Lal, 1979). The decline in yields as a result of loss of plant nutrients and deterioration of soil physical condition due to cultivation is a well established fact (Baver, 1972). The loss of plant nutrients from soil is ascribed to removal by crops, erosion and leaching (Widdowson and Penny, 1978).

Various observations suggest that most tropical soils decline in productivity even when supplied with fertilizer (Allen, 1965; Le Mare, 1972 and Stephens, 1969). Continuous cultivation appears to affect tropical soils more than temperate soils. The aim of this paper, therefore, is to highlight some of the results of preliminary studies on the effect of cultivation on organic carbon, nitrogen and phosphorus of some intensively used soils of Kenya. The soils were chosen from three different agro-ecological zones. For comparison, soils under cultivation and the adjacent uncultivated soils (fallow, range or virgin) were sampled and used for this study.

**MATERIALS AND METHODS**

**Soils**

Two groups of soils were sampled namely humic nitosols and chromic luvisols (FAO/UNESCO, 1974). The humic nitosol samples were taken from 6 cultivated and 3 uncultivated sites in the Kisii Highlands of South-Western Kenya, (NITOSOL A) an area of high rainfall. Another set of samples was obtained from 4 cultivated and 4 uncultivated lands at the University of Nairobi farm (NITOSOL B), a moderate rainfall area. The Kisii soils are derived from basic igneous rocks and the Nairobi soils are derived from Tertiary trachytic lava and are also known as Kikuyu friable clays.
The second group of soils were ferral chromic luvisols made up of 4 profiles from cultivated sites and 3 uncultivated. The profiles were located at Katumani Dryland Experimental Station, a semi-arid area. The soils are derived from quartzo-magnesian gneisses of the pre-Cambrian basement complex.

Analytical methods

All determinations were carried out on air-dried soils ground to pass a 2 mm sieve. Organic carbon was according to the method described by Woesthoff (1959). Total N was by a modified Kjeldhal method (Fliege et al. 1971) and P was by a Kjeldhal type digestion followed by colorimetric determination as phospho-vanadate (Passbender, 1973).

RESULTS AND DISCUSSION

Organic carbon

For Nitosol A, the uncultivated soils generally had more accumulation of carbon (mean) in the surface horizon (0 - 10 cm - 3.85% C)* than its adjacent cultivated soils (mean, 3.28% C), a difference of 14.8%. In the lower depths, however, the means of the land use systems, seem to overlap, an indication of less change with cultivation. Carbon content decreased with depth. The top soils with 3.56% C (mean values of cultivated and range soils) dropped steeply to 1.02% C in the 80 - 100 cm layer.

Carbon content in Nitosol B was as high as that of Nitosol A, i.e. above 3.0% C but, unlike Nitosol A, the changes due to tillage affected the whole plough layer (i.e. 0 - 40 cm depth).

In the Chromic Luvisol, change also took place in the top 0 - 10 cm layer. There was a reduction in carbon of about 8.3% in the cultivated soils as compared to the uncultivated.

* The editors have left out the tables of figures as the data sets were incomplete.
Unlike the two NITOSOLS, the carbon content in the Luvisol was almost 50% less.

Mean values of cultivated and uncultivated soils lie between 1.25% at the surface and .58% in the 80-100cm.

Cultivation accelerated the reduction of Carbon in the top soil of the three soils, leaving the lower depths more or less unchanged. However, the effect was not uniform for the three soils. The effect for NITOSOL A and the chromic luvisol was only up to 10 cm from the surface whereas for NITOSOL B it was up to 40 cm depth.

Reduction of organic carbon due to cultivation has also been reported by others (Ryan et al., 1984; Lal, 1976; Aduayi, 1980; Adepetu et al., 1979 and Obigbesan and Amalu, 1985). Aduayi (1980) observed a relative reduction of 24% C from an Alfisol in Western Nigeria after 5 years of continuous cultivation while Adepetu et al. (1979) reported a relative reduction of 58% C after 7 years of continuous cultivation on an Alfisol.

The results for nitrogen (N) in both the cultivated and uncultivated soils showed that, in the top soil of the cultivated soils, the relative changes were -15.2% and -4.8% for the NITOSOLS A and B, respectively, and -3.7% for the Chromic LUVISOL. The N changes therefore correspond to C changes but with low magnitudes except for NITOSOL A, where N changes were as high as C changes (cf. 14.8% to 15.2%). N changes respond to C changes because N is an integral part of organic carbon. These changes of N in soils have been either under fallow or cultivation. The longer and continuous the cultivation or fallowing, the greater the N changes. Similar cases have been reported by others (Fleige and Baeumer, 1974; Kahnt, 1971).

Unlike C and N, changes in phosphorus (P) due to cultivation did not show a clear trend. The cultivated soils of NITOSOL A and the Luvisol, exhibited higher P values in the top soil than the adjacent uncultivated soils whereas uncultivated soils had higher P values for NITOSOL B than the adjacent soil. There was
accumulation of P at the surface of the cultivated soils which could be due to P fertilization. However, for NITOSOL B where uncultivated soils exhibited relatively higher P values than cultivated soils, this could be due to high demand for P by the previous crop i.e. an inter-cropping of maize and cowpeas. Leguminous plants have high demand for P. Similar accumulation of P in the top soil has also been observed by others (Aduayi, 1980 and Agboola and Corey, 1973). Aduayi (1980) observed over 200% relative increase of P in cultivated soils under maize.

CONCLUSION

These preliminary studies suggest that cultivation of soils will result in reduction of C and N in the top soil. Although the changes were not as high as those reported in other studies e.g. Aduayi, (1980), probably due to differences in soil management and the period in which the soils have been either under cultivation or fallow, there are good indications that continuous use of soils without adding organic matter to them, may lead to soil deterioration. This is of particular concern in utilization of soils of marginal areas (soils with low C content) where very little or none at all of the organic matter residues are returned to the soil.

The method of tillage also appears to have influence on C and N changes, especially in the plough layer. Conventional tillage tends to have a greater negative effect on C and N than ox-ploughing.

REFERENCES


SORPTION OF ORTHO – AND PYROPHOSPHATE BY
TWO HIGHLY WEATHERED TANZANIAN SOILS

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ABSTRACT

The sorption of orthophosphate (OP) and
pyrophosphate (PP) by samples of an Ultisol and
an Oxisol obtained at different depths was investi­
gated. The data obtained were fitted to the Langmuir
and Freundlich equations. Both OP and PP sorption
showed closer agreement with the Langmuir isotherm than
with the Freundlich isotherm.

The Langmuir adsorption maximum and bonding
constant data indicated that the more weathered Oxisol
retained more phosphorus, and with greater energy
than the Ultisol at all sampling depths. The sorption
of OP and PP as estimated by the Langmuir adsorption
maximum was significantly correlated with clay and
extractable Fe and Al contents, with OP sorption being
better correlated with these soil properties than PP
sorption. Both OP and PP retention increased with depth.
Samples of the two soils consistently retained more PP
and with greater energy than OP.
The possible use of polyphosphates as sources of phosphorus (P) for plants has been investigated by a number of workers (Carpenter, 1969; Glixelli and Boratynsk, 1933; and Hashimoto et al. 1969). Most have concluded that hydrolytic degradation to orthophosphate (OP) is a prerequisite for the effective utilisation of the condensed phosphates by plants. In many temperate soils, it appears that the hydrolysis rate is sufficiently high to make the condensed phosphates comparable to OPs as sources of phosphorus for plants. The same may not, however, apply to the highly weathered tropical soils which have a much greater capacity for P retention compared to temperate soils. Because of their greater capacity for P retention, tropical soils are likely to retain more polyphosphate resistant to hydrolysis than the less weathered temperate soils.

Since little information is available on polyphosphate behaviour in tropical soils, this study was undertaken to investigate the adsorption of pyrophosphate (PP) and OP in two highly weathered Tanzanian soils. Pyrophosphate was chosen since it is the main component of non-orthophosphates present in the superphosphoric acid used in the manufacture of polyphosphate fertilizers.

MATERIALS AND METHODS

Soils and Phosphorus sources

Soil samples were obtained from Mzumbe and Mkuyuni areas located on the west and south east of Morogoro town, respectively. A profile was opened at each location and four samples taken between 0 and 90 cm. The sampling depths and selected properties of the soils are shown in Table 1. The Mzumbe soil was classified as an Oxisol while the Mkuyuni soil was classified as an Ultisol according to Soil Taxonomy (Soil Survey Staff, 1975) (Mrema, J.P.* 1985, Personal Communication).

* Department of Soil Science, Sokoine University of Agriculture, Morogoro, Tanzania.
## Table 1. Some Properties of the Experimental Soils

<table>
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<tr>
<th>Soil</th>
<th>Sampling depth (cm)</th>
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<th>OC</th>
<th>Al</th>
<th>H</th>
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C = Clay; Sicl = silty clay loam; Sic = silty clay; OC = Walkley/Black organic carbon; Fe = Citrate Bicarbonate Dithionite extractable Fe.
The sources of phosphorus were reagent grade sodium dihydrogen phosphate (NaH$_2$PO$_4$) and tetrasodium pyrophosphate (Na$_4$P$_2$O$_7$·10H$_2$O).

**Chemical Analyses**

Soil samples were analysed for organic carbon by the chromic acid oxidation method of Walkley and Black (1934). pH was determined in 1:2.5 soil:water suspension using a pH meter. Exchangeable cations were extracted with N ammonium acetate solution. Exchangeable acidity was determined by the KCl method (Thomas, 1982). Cation exchange capacity (CEC) was estimated as the sum of exchangeable metallic cations and exchangeable acidity. The Fe content was determined by the Citrate - Bicarbonate-Dithionite (CBD) method (Anonymous, 1979). Particle size was by the Bouyoucos hydrometer method (Day, 1965) using sodium hexametaphosphate as a dispersant.

**Sorption Study**

Three-gram samples in 250 cm$^3$ plastic bottles were mixed with 30 cm$^3$ of P solutions ranging in concentration from 0 to 100 mg P L$^{-1}$ in a 0.03 M KCl solution. Three drops of toluene were added to each of the bottles to inhibit microbial activity. The bottles were then shaken on a mechanical shaker set at a speed of 160 r.p.m. for 12 hours at 25°C ± 3°C. The equilibrated samples were then filtered through Whatman No. 44 filter paper. Aliquots of the supernatant solutions obtained after filtration were hydrolyzed with 0.05 M H$_2$SO$_4$ at 90°C for 1 hour in a water bath. Phosphorus in the hydrolyzed samples was determined using the molybdate blue-ascorbic acid method (Anonymous, 1979). The amount of P sorbed was calculated as the difference between P added and P in the equilibrium supernatant solution.

**Treatment of data**

Adsorption parameters were estimated using the following linearized forms of the Langmuir and Freundlich equations:

(i) Langmuir equation

\[
\frac{C}{(x/m)} = \frac{1}{(ba)} + \frac{C}{a}
\]
(ii) Freundlich equation
\[
\log \left( \frac{x}{m} \right) = \log K + \left( \frac{\log C}{n} \right)
\]
were \( x/m = P \) adsorbed (mg P kg\(^{-1}\) soil); \( C = \) equilibrium P concentration (mg P. L\(^{-1}\)); \( b = a \) parameter related to the energy of adsorption; \( a = \) adsorption maximum (mg P kg\(^{-1}\) soil); and \( K \) and \( 1/n = \) Freundlich adsorption constants.

The least squares method was used to fit adsorbed P and equilibrium solution P concentration data for each treatment to the above equations. Relationships between sorption parameters and soil properties were obtained using simple correlation and regression analyses.

RESULTS AND DISCUSSION

Properties of the soils

Properties of the soils are given in Table 1. Clay content was higher in the Oxisol than in the Ultisol at all sampling depths. In both soils, subsoil samples had higher clay contents than the topsoil samples. Citrate bicarbonate dithionite (CBD) extractable Fe values were higher in Oxisol samples than in the Ultisol samples and tended to increase with depth in both soils.

Soil pH values ranged from 4.4 to 5.6 in Oxisol samples and from 5.5 to 6.2 in Ultisol samples. Thus Oxisol samples were more acidic than the Ultisol samples which explains the relatively higher exchangeable Al values observed in the Oxisol samples. Organic carbon content values were higher in the Ultisol than Oxisol samples and tended to decrease with depth for both soils.

Adsorption Isotherms

The amount of phosphate (OP and PP) adsorbed was plotted against the equilibrium phosphate concentration in solution to give the adsorption isotherms. Generally, isotherms for the different samples were similar in shape and resembled the one shown in Fig. 1, which was constructed from the Oxisol surface (0-10 cm) sample data.
Figure 1: Isotherms for P adsorption from Na₄P₂O₇·10H₂O (open circles) and NaH₂PO₄ (closed circles) solutions by the surface sample of an oxisol.
Examination of the isotherms shows that the two phosphate ions followed very different adsorption patterns. The PP isotherm rises very steeply and remains close to the Y-axis while the OP isotherm rises gradually and tends to flatten off at high equilibrium P concentrations. The isotherms were divided by inspection into distinct regions as follows:

Region I: Low equilibrium P concentrations (<8 mg P L⁻¹). In this region the isotherms rise steeply and remain close to the Y-axis.

Region II: Commences at approximately 8 mg P L⁻¹ when the isotherms become convex to the Y-axis.

Region III: Is the linear portion of the isotherm which for OP occurred at equilibrium P concentrations >25 mg P L⁻¹. The PP isotherms had no region III in the concentration range studied.

Muljadi et al (1966) obtained similar regions for OP sorption by kaolinite and gibbistie samples. They suggested that the regions are related to the affinity of phosphate for at least three energetically different reactive sites. The energy of bonding of phosphate to sites in the different regions was thought to be greatest in region I followed by regions II and III in that order. Adsorption sites for regions I and II were reported to be located on edge - Al (OH)₂ of the adsorbents while adsorption in region III resulted from physical penetration of phosphate ions into some amorphous regions of the crystal surfaces (Muljadi et al (1966); Ryden et al (1977)).

Nearly all the added PP was adsorbed by high energy sites in region I in contrast to OP which was adsorbed on to sites in all three regions of the isotherm (Fig. 1). These results indicate that, at equivalent rates of application, PP would tend to be held more strongly than OP. Furthermore, some high energy sites in the soils are only available for PP but not OP retention.
Adsorption Parameters

Both the Langmuir and Freundlich equations were fitted to the adsorption data. Both equations showed satisfactory fit to the P adsorption results with $r^2$ values for both equations on the surface soils ranging from 0.956 to 0.998 (Table 2). Similar values (not shown) were also obtained on the other samples. However, the Langmuir equation resulted in relatively higher $r^2$ values compared to values obtained with the Freundlich equation which indicated that the Langmuir equation fitted the data better. Consequently, the Langmuir equation was adopted for computing adsorption parameters.

Effect of P Source on OP and PP Sorption

More PP was retained by both Oxisol and Ultisol samples at all sampling depths than was OP (Table 3). These results are in agreement with the findings of Sutton and Larsen (1964); Hashimoto et al (1969); Savant and Tambe (1969) and Mnkeni and MacKenzie (1985), who, working with some temperate region soils, also observed higher maximum adsorption capacities for PP than OP. Thus it seems that the relative retention of PP and OP follows the same pattern in the highly weathered tropical soils as in the usually less weathered temperate soils.

Sutton and Larsen (1964) ascribed the greater retention of P as PP than as OP to the fact that each PP ion adsorbed from solution contains two P atoms compared to only one P atom for each OP ion adsorbed. This could be the explanation for the results of the present study as well. In addition Mnkeni and MacKenzie (1985) have suggested that greater PP than OP retention could also be related, at least partly, to the greater ability of polyphosphates compared to orthophosphates, to solubilize organic matter from soil minerals. This would have the effect of exposing P adsorption sites on soil minerals which would otherwise be blocked by organic matter. This explanation seems consistent with results of the present study in that the magnitude of the difference between PP and OP retention (Table 3) tended to decrease with decrease in organic carbon (Table 1).
TABLE 2. - COMPARISON OF GOODNESS OF FIT OF THE LANGMUIR AND
FREUNDLICH EQUATIONS TO THE ORTHOPHOSPHATE (OP) AND
PYROPHOSPHATE (PP) ADSORPTION DATA USING DATA FOR
THE SURFACE (0–10 CM) SOIL SAMPLES.

<table>
<thead>
<tr>
<th>Soil Sample</th>
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<td></td>
<td>PP</td>
<td>0.986</td>
</tr>
<tr>
<td>Ultisol</td>
<td>OP</td>
<td>0.986</td>
</tr>
<tr>
<td></td>
<td>PP</td>
<td>0.994</td>
</tr>
</tbody>
</table>

TABLE 3. - ORTHOPHOSPHATE (P) AND PYROPHOSPHATE (PP) LANGMUIR
ADSORPTION PARAMETERS FOR SAMPLES OF TWO SOILS TAKEN
AT DIFFERENT DEPTHS.

<table>
<thead>
<tr>
<th>Soil Sample</th>
<th>Sampling depth (cm)</th>
<th>Adsorption maxima (a) for indicated phosphate species</th>
<th>Bonding Constant (k) for indicated phosphate species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OP (mg Kg⁻¹)</td>
<td>PP (mg Kg⁻¹)</td>
</tr>
<tr>
<td>Oxisol</td>
<td>0–10</td>
<td>475</td>
<td>976</td>
</tr>
<tr>
<td></td>
<td>10–30</td>
<td>756</td>
<td>1001</td>
</tr>
<tr>
<td></td>
<td>30–50</td>
<td>866</td>
<td>978</td>
</tr>
<tr>
<td>Ultisol</td>
<td>0–10</td>
<td>432</td>
<td>907</td>
</tr>
<tr>
<td></td>
<td>10–30</td>
<td>537</td>
<td>917</td>
</tr>
<tr>
<td></td>
<td>30–50</td>
<td>541</td>
<td>917</td>
</tr>
<tr>
<td></td>
<td>50–90</td>
<td>550</td>
<td>953</td>
</tr>
</tbody>
</table>
The Langmuir bonding constant data (Table 3) indicate that, with few exceptions, PP was more strongly adsorbed by the soils than was OP. Similar deductions were made earlier by inspecting the OP and PP adsorption isotherms (Fig. 1). These results confirmed those of Hashimoto et al (1969) and Savant and Tambe (1979) who also reported higher bonding energies for PP than OP. However, they were at variance with those of Sutton and Larsen (1964) who observed lower bonding energy for PP than OP.

The observed differences in the strengths of binding of PP and OP ions to the soil colloids could be explained by the difference in the valencies of the dominant species of the ions from the two P sources. At pH values between 4 and 6.5, a range which includes the pH of all soil samples studied (Table 1), the OP ions exist in solution mainly as the monovalent $\text{H}_2\text{PO}_4^-$ species, while PP ions exist mainly as divalent $\text{H}_2\text{P}_2\text{O}_7^{2-}$ ions (Lindsay and Vlek, 1977). It is therefore possible that PP was retained more strongly than OP because of the higher charge of the dominant PP ions compared to that of the OP ions.

Based on the two Langmuir adsorption parameters discussed above, it is apparent that PP will be adsorbed to a greater extent and with greater energy than OP when applied at equivalent rates to the two soils. This could mean that PP added to the two soils may not readily hydrolyze to the OP form preferred by plants. It therefore seems likely that PP may not be as effective as OP as a source of P for plants in these soils.

Relationship between Adsorbed P and some soil properties

Clay content was significantly correlated with both adsorbed OP ($r = 0.93, p<0.01$) and adsorbed PP ($r = 0.83, p<0.01$) (Table 4), though a higher correlation coefficient was observed with OP than with PP retention.

High and significant correlations were also found between CBD extractable Fe and adsorbed OP ($r = 0.91, p<0.01$) and adsorbed PP ($r = 0.73, p<0.01$). The results indicate that adsorbed
P (OP or PP) was mostly associated with clay and CBD extractable Fe contents in the two soils. This explains why the Oxisol samples which had relatively high clay and extractable Fe contents retained more P than Ultisol samples.

**TABLE 4. - SIMPLE CORRELATIONS BETWEEN SOME SOIL PROPERTIES AND LANGMUIR ADSORPTION PARAMETERS FOR ORTHOPHOSPHATE (OP) AND PYROPHOSPHATE (PP).**

<table>
<thead>
<tr>
<th>Soil Properties</th>
<th>Adsorption maxima</th>
<th>Bonding Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OP</td>
<td>PP</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>0.93**</td>
<td>0.83**</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>-0.52</td>
<td>-0.39</td>
</tr>
<tr>
<td>CBD extractable Fe (%)</td>
<td>0.91**</td>
<td>0.73**</td>
</tr>
<tr>
<td>Exchangeable Al</td>
<td>0.73**</td>
<td>0.62*</td>
</tr>
<tr>
<td>pH</td>
<td>-0.75*</td>
<td>-0.65</td>
</tr>
</tbody>
</table>

* **- Significant at 95 and 99% levels, respectively

CBD- Citrate Bicarbonate Dithionite.

Soil pH was negatively correlated with adsorbed OP ($r = -0.75$, $P<0.01$) and adsorbed PP ($r = -0.65$, $P<0.05$) in agreement with results of Fox et al (1971) who also observed negative correlation coefficients, indicating the indirect influence of soil pH on phosphate retention in that, at low pH values, the solubility of Al and Fe species is increased resulting in increased P retention mostly by Al precipitation. This is consistent with observed positive correlation coefficients between exchangeable Al and adsorbed OP and PP (Table 4) which were more or less equal in magnitude to those observed with soil pH but with an opposite sign.
Nonsignificant relationships were found between adsorbed OP and PP and organic carbon content (Table 4). The lack of relationship indicated non dependence of P retention on soil organic matter per se in this study. Similar findings were reported by Larsen et al (1959).
REFERENCES


RESPONSE OF MAIZE TO TRIPLE SUPERPHOSPHATE:
RESULTS OF EXPERIMENTS ON A RED SOIL IN TANZANIA

B.J. KIWAMBO

National Soil Service, Mlingano, Tanga, Tanzania

SUMMARY

The paper reports the results of an experiment carried out at Mlingano Agricultural Research Institute at Tanga to investigate the response of maize to various applications of triple superphosphate. The soil on which the experiment was carried out is a Rhodic Ferralsol. Analytical data for a typical site are presented. Yield data to compare the effects of various treatments are also given.
<table>
<thead>
<tr>
<th>Site</th>
<th>S/No.</th>
<th>Depth in cm</th>
<th>pH</th>
<th>Walkey &amp; Kjeldahl N</th>
<th>ppm P</th>
<th>Exchangeable ions milliequivalents/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>H2O 1:2.5</td>
<td>CaCl2 1:2.5</td>
<td>Black O.C. %</td>
<td>B &amp; K II</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td>SITE I</td>
<td>1</td>
<td>0-30</td>
<td>6.6</td>
<td>5.8</td>
<td>1.95</td>
<td>0.200</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6.4</td>
<td>5.5</td>
<td>1.87</td>
<td>0.200</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6.4</td>
<td>5.5</td>
<td>2.11</td>
<td>0.190</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6.3</td>
<td>5.4</td>
<td>1.79</td>
<td>0.210</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.4</td>
<td>5.5</td>
<td>2.18</td>
<td>0.190</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>6.3</td>
<td>5.4</td>
<td>2.26</td>
<td>0.220</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6.2</td>
<td>5.5</td>
<td>2.18</td>
<td>0.230</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>6.4</td>
<td>5.7</td>
<td>1.87</td>
<td>0.200</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>6.5</td>
<td>5.7</td>
<td>2.26</td>
<td>0.230</td>
<td>2.8</td>
</tr>
<tr>
<td>SITE II</td>
<td>1</td>
<td>6.3</td>
<td>5.6</td>
<td>2.34</td>
<td>0.240</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6.1</td>
<td>5.2</td>
<td>1.87</td>
<td>0.230</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6.0</td>
<td>5.4</td>
<td>2.34</td>
<td>0.210</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6.1</td>
<td>5.1</td>
<td>1.87</td>
<td>0.200</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.1</td>
<td>5.3</td>
<td>1.95</td>
<td>0.210</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>6.4</td>
<td>5.5</td>
<td>2.26</td>
<td>0.230</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6.2</td>
<td>5.4</td>
<td>2.26</td>
<td>0.220</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>6.4</td>
<td>5.6</td>
<td>2.34</td>
<td>0.240</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>6.0</td>
<td>5.2</td>
<td>2.42</td>
<td>0.250</td>
<td>Tr.</td>
</tr>
</tbody>
</table>
### TABLE 2a. - MAIZE GRAIN YIELD (kg/ha) - SITE I

<table>
<thead>
<tr>
<th>TREATMENT P₂O₅ kg/ha</th>
<th>REPLICATION</th>
<th>TOTAL</th>
<th>MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>1.0 (control)</td>
<td>4811</td>
<td>3175</td>
<td>2937</td>
</tr>
<tr>
<td>2.80</td>
<td>4421</td>
<td>5032</td>
<td>4564</td>
</tr>
<tr>
<td>3.160</td>
<td>5992</td>
<td>5849</td>
<td>6111</td>
</tr>
<tr>
<td>4.240</td>
<td>5952</td>
<td>5397</td>
<td>6444</td>
</tr>
<tr>
<td>5.320</td>
<td>3413</td>
<td>3611</td>
<td>6270</td>
</tr>
<tr>
<td>6.400</td>
<td>3889</td>
<td>4206</td>
<td>6286</td>
</tr>
<tr>
<td>7.480</td>
<td>6032</td>
<td>6071</td>
<td>5857</td>
</tr>
<tr>
<td>8.560</td>
<td>5675</td>
<td>5675</td>
<td>6270</td>
</tr>
<tr>
<td>9.640</td>
<td>5857</td>
<td>5476</td>
<td>4000</td>
</tr>
<tr>
<td>Total</td>
<td>46072</td>
<td>44492</td>
<td>48739</td>
</tr>
</tbody>
</table>

NB : All plots received 60 kg N/ha.

### TABLE 2b. - MAIZE GRAIN YIELD (kg/ha) - SITE II

<table>
<thead>
<tr>
<th>TREATMENT P₂O₅ kg/ha</th>
<th>REPLICATION</th>
<th>TOTAL</th>
<th>MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>1.0 (control)</td>
<td>952</td>
<td>2897</td>
<td>2222</td>
</tr>
<tr>
<td>2.80</td>
<td>2302</td>
<td>3135</td>
<td>1389</td>
</tr>
<tr>
<td>3.160</td>
<td>4841</td>
<td>3016</td>
<td>4286</td>
</tr>
<tr>
<td>4.240</td>
<td>1349</td>
<td>3889</td>
<td>3730</td>
</tr>
<tr>
<td>5.320</td>
<td>3056</td>
<td>3611</td>
<td>5873</td>
</tr>
<tr>
<td>6.400</td>
<td>1587</td>
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<td>4762</td>
</tr>
<tr>
<td>7.480</td>
<td>5952</td>
<td>3095</td>
<td>4008</td>
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<tr>
<td>8.560</td>
<td>5437</td>
<td>2857</td>
<td>3254</td>
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<tr>
<td>9.640</td>
<td>4286</td>
<td>2897</td>
<td>1901</td>
</tr>
<tr>
<td>Total</td>
<td>29762</td>
<td>29841</td>
<td>31425</td>
</tr>
</tbody>
</table>

NB : All plots received 60 kg N/ha.
INTRODUCTION

The experience of Mlingano Agricultural Research Institute, Tanga, on responses to Triple Superphosphate (TSP) at high doses and various levels of NPK (N as (NH₄)₂S0₄) is presented in this paper. The soil type on which the experiments were carried out, is classified as a Rhodic Ferralsol, (FAO-UNESCO, 1974).

RESULTS AND DISCUSSION

Analytical data for the sites on which the experiments were carried out are shown in Table 1.

The data indicate that both sites are slightly acid, pH in water ranging from 6.0 to 6.5. These pH values are, however, within the favourable range for P availability and yet high P₂O₅ doses are required to obtain response, as indicated in Table 2, which shows the yields achieved at various levels of TSP.

The mean grain yield indicated that there was a significant increase with increasing rates of P, up to 480 kg/ha P₂O₅. However, further investigation in Tanzania is required to show whether or not this is an economic application rate for maize cropping.

REFERENCES

EFFECT OF TIME OF WEEDING ON SOIL MOISTURE AND PERFORMANCE OF MAIZE GROWN ON AN OXIC PALEUSTALF

R.B. SHARMA

Department of Soil Science, Sokoine University of Agriculture, Morogoro, Tanzania

SUMMARY

Influence of time of weed elimination on drought sustenance of rainfed maize (Zea Mays L. cv. Ilonga composit) was investigated during 1985 on an Oxic Paleustalf at the Sokoine University of Agriculture farm, Morogoro, Tanzania following a drought caused by a 23-day dry spell that occurred 13 days after planting. There were weeding treatments viz., weeding done 20, 27 and 34 days after planting.

The average soil moisture content, on the 35th day from planting (2 days before the end of dry spell) within the first 0 - 60 cm decreased from 16.2 to 14.1% (w/w) as the period of weed elimination was progressively increased from 20 to 34 days after planting. The leaf water potential also decreased with increase in time to weed elimination. On the 65th day from planting, the crop had received 210 mm of rainfall following the dry spell, but there were no differences in leaf water potential and the value ranged from -8.25 to -8.5 bars.

Leaf area, plant height, stem diameter and shoot dry weight decreased significantly (p= 0.0001) as weed elimination time increased from 20 to 34 days after planting. Leaf area per plant at 94th day from planting was 10653, 8883 and 5743 cm² respectively for the plots weeded at 20, 27 and 34 days after planting. Thus it was reduced by 16.6 and 46.1 per cent, respectively, for the plots weeded at 27 and 34 days compared with those at 20 days after planting. Plant height at 68th day from planting was 241.4 cm for the plots weeded at 20 days and was reduced, by 21.6 and 39.6 per cent respectively for those weeded at 27 and 34 days after planting.
There were significant differences in stem diameter, shoot dry weight per plant according to differences in weed elimination time. The grain yield decreased with the progressive increase in the period of weed elimination from 20 to 34 days after planting.

It is concluded that, in order to increase the drought sustenance of maize under rainfed conditions, weeds should be controlled during the first 30 to 35 days from planting.

INTRODUCTION

The effect of competition by weeds against crop plants for nutrients, light and soil moisture is well known. The competition for water is of major importance in the tropical and subtropical environments of Eastern and Southern Africa where the crop has to rely largely on precipitation. During dry spells in the rainy season weeds appear to compete most effectively for the limited soil moisture as reported by (Rao, 1983).

Maize (Zea Mays L.) is the major crop grown in the rainfed tropics of Eastern and Southern Africa. Due to unreliability and variability of rainfall in these areas, dry spells of short durations causing a drought situation occur very frequently (Gommes and Houssau, 1982; De Pauw, 1983 Sharma, 1985). Considerable work has been done on competition for water and nutrients by weeds against maize (Lozanovski et al., 1973; Cheasalin and Timafeeva, 1974; Rajan and Shankaran, 1974; Elakkad and Behrens, 1975; Atkinson, 1978; Elakkad and Behrens, 1978; Bhushan et al., 1979; Remison 1979; Roa, 1983; Croon et al., 1984). Critical periods of weed competition in maize were reported by (Bejarano and Ortiz, 1969; Chandra Singh et al., 1975; Blanco et al., 1976; Carson, 1979; Croon, et al., 1984). Grain yield reductions ranging from about 30 to 80 percent have been reported (Mani et al., 1968; Meggitt, 1970) rising at times to 100 percent (Bejarano and Ortiz 1969). However, little effort, if any has been made to investigate the influence of weed infestation
on plant: water relations and in turn the drought sustenance of maize under rainfed conditions. Therefore, the objective of the present investigation was to quantify the effect of time of weed elimination on the drought sustenance of rainfed maize in terms of leaf water potential, plant growth parameters and grain yield.

**MATERIALS AND METHODS**

To evaluate the influence of time of weed elimination on drought sustenance of rainfed maize, an on-farm trial was conducted during the long rains of 1985 on an Oxic Paleustalf at the Sokoine University of Agriculture farm, Morogoro, Tanzania.

The maize was planted on February 13, 1985 after the field had received 64.2 mm of rainfall within the previous 10 days. The crop was planted manually with a spacing of 75 cm between and 30 cm within rows. Phosphorus was applied at the rate of 25 kg P/ha as band placement at the time of sowing. Nitrogen at the rate of 26 kg/ha was applied at tasselling stage.

Three weeding treatments allowing weed elimination at different times viz., 29, 27 and 34 days after planting were done by hand. Each of the 15 x 60 cm strips weeded was divided into 5 equal parts representing 5 replications from which the sampling was done for various measurements.

Within 13 days from planting, the crop received another 94.5 mm of rainfall which was followed by a dry spell of 23 days causing a drought situation.

Soil moisture content was measured gravimetrically at 15 cm intervals down to a depth of 60 cm 2 days before the end of the dry spell (35th day from planting) and leaf water potential was measured 1 day before the end of the dry spell (36th day from planting). At the end of the dry spell (37th day from planting) measurements were also made for leaf area, stem diameter, plant height and shoot dry weight. Except stem
diameter, other plant growth parameters and leaf water potential were measured at a later growth stage also. Stem diameter was measured at the third internode from the ground using Vernier calipers. Leaf water potential of a fully grown and exposed third leaf from the top was measured at 1130 hr using a dye method (Shardakov, 1948). An electronic Planimeter (Model: Paton Electronic Planimeter Australia) was used for measuring the leaf area and shoot dry weight was taken after drying the samples in an oven at 70°C. Whereas stem diameter, leaf area, plant height and shoot dry weight were measured on the samples collected from all the five replications, leaf water potential was measured only on two plants from two different replications. Grain yield, however, was obtained only from one section measuring 10 x 10 m located in the centre of a 15 x 16 m strip.

RESULTS AND DISCUSSION

Selected properties of the soil are shown in Table 1

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Organic Carbon (%)</th>
<th>CEC me/100g</th>
<th>pH H2O 1:2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap1</td>
<td>0-23</td>
<td>65</td>
<td>5</td>
<td>30</td>
<td>1.42</td>
<td>18.0</td>
<td>6.2</td>
</tr>
<tr>
<td>A2</td>
<td>23-42</td>
<td>62</td>
<td>6</td>
<td>32</td>
<td>1.21</td>
<td>17.5</td>
<td>5.9</td>
</tr>
<tr>
<td>B21t</td>
<td>42-73</td>
<td>45</td>
<td>5</td>
<td>50</td>
<td>1.21</td>
<td>16.5</td>
<td>5.9</td>
</tr>
<tr>
<td>B22t</td>
<td>73-123</td>
<td>40</td>
<td>5</td>
<td>55</td>
<td>1.04</td>
<td>16.4</td>
<td>5.9</td>
</tr>
<tr>
<td>B23t</td>
<td>123-150</td>
<td>42</td>
<td>6</td>
<td>52</td>
<td>0.93</td>
<td>16.0</td>
<td>6.1</td>
</tr>
</tbody>
</table>

The data on soil moisture content of various layers down to a depth of 60 cm at 35 days from planting (2 days before the end of dry spell) are presented in Table 2.
TABLE 2. SOIL MOISTURE CONTENT, % (w/w) IN DIFFERENT LAYERS AS INFLUENCED BY TIME OF WEED ELIMINATION

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Time of weed elimination</th>
<th>20</th>
<th>27</th>
<th>34</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>12.8 ± 0.28</td>
<td>11.2 ± 0.28</td>
<td>9.9 ± 0.35</td>
<td></td>
</tr>
<tr>
<td>15-30</td>
<td>16.1 ± 0.28</td>
<td>15.6 ± 0.14</td>
<td>14.8 ± 0.21</td>
<td></td>
</tr>
<tr>
<td>30-45</td>
<td>17.4 ± 0.14</td>
<td>16.9 ± 0.28</td>
<td>15.8 ± 0.42</td>
<td></td>
</tr>
<tr>
<td>45-60</td>
<td>18.4 ± 0.14</td>
<td>17.1 ± 0.28</td>
<td>15.9 ± 0.42</td>
<td></td>
</tr>
<tr>
<td>Average+</td>
<td>16.17</td>
<td>15.20</td>
<td>14.10</td>
<td></td>
</tr>
</tbody>
</table>

+ Average values over 2 replications

It is evident from the data that the soil moisture content of all the layers decreased proportionately as the time of weed elimination increased from 20 to 34 days after planting. The average soil moisture content within 0-60cm depth for the plots weeded at 20, 27 and 34 days after planting was 16.2, 15.2 and 14.1 per cent respectively. Thus greater loss of water occurred from the plots where weeds were allowed to grow for longer periods of time. Reduced soil moisture content resulting from extended periods of weed infestation were also reported by Lozanovski et al. (1973).

The data on leaf water potential of maize on the 36th day from planting (one day before the end of the dry spell) and 65 days from planting (when the crop received 210mm of rainfall after the dry spell) are presented in Table 3.
As time to weed elimination increased from 20 to 27 days after planting, the leaf water potential decreased from -17.75 to -20.5 bars. A further increase in weed elimination time to 34 days after planting resulted in reduction of leaf water potential to -23.75 bars. The values of leaf water potential under different treatments look all the more logical when soil moisture content data (Table 2) under different weeding treatments are taken into account. The leaf water potential was highest when the weeds were eliminated at 20 days after planting showing greater availability of water to the crop. On the other hand, the plots which were weeded at 34 days after planting showed the lowest values of both the soil moisture content and leaf water potential, indicating lower availability of water to the crop. Increased water uptake from the soil profile by weeds under drought conditions resulting in less available water for crops has been reported earlier (Rao, 1983; Elakkad, 1984). It is thus obvious that, when a dry spell occurs causing a drought situation the drought sustenance of maize decreases due to lower plant water potential resulting from availability of water. Leaf water potential at 65th day from planting, when the crop had received 210mm of rainfall after the end of the dry spell did not differ significantly under different weeding treatments and ranged from -8.25 to 08.5 bars showing full compensation after sufficient water was added by rainfall.
Leaf area per plant for maize at various stages of growth viz., 37th, 63rd and 94th day from planting is given in Table 4.

**TABLE 4. LEAF AREA (CM/PLANT) OF MAIZE AT DIFFERENT STAGES OF GROWTH AS INFLUENCED BY TIME OF WEED ELIMINATION**

<table>
<thead>
<tr>
<th>Time of weed elimination (days after planting)</th>
<th>Crop growth stage (Days from Planting)</th>
<th>% reduction compared with weeding @ 20DAP</th>
<th>% reduction compared with weeding @ 20DAP</th>
<th>% reduction compared with weeding @ 20DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>37</td>
<td>68</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>2137.8</td>
<td>6590.2</td>
<td>10653.0</td>
<td>-</td>
</tr>
<tr>
<td>27</td>
<td>886.2</td>
<td>4463.0</td>
<td>8882.8</td>
<td>16.6</td>
</tr>
<tr>
<td>34</td>
<td>416.6</td>
<td>2310.8</td>
<td>5743.0</td>
<td>46.1</td>
</tr>
<tr>
<td>LSD (0.01)</td>
<td>886.1</td>
<td>790.7</td>
<td>648.3</td>
<td></td>
</tr>
</tbody>
</table>

+ DAP = Days after planting

Except on the 37th day from planting when there were no significant differences for plots weeded at 27 and 34 days after planting, leaf area at all the stages of growth decreased significantly (p = 0.01) as the time to eliminate weeds increased progressively from 20 to 34 days. At the end of the dry spell (37th day from planting), compared to the plots weeded at 20 days after planting, leaf area per plant was reduced by 58.5 and 80.5 per cent, for the plots weeded at 27 and 34 days respectively. However, the difference narrowed down with the advancing crop growth stage. For example, by the 94th day from planting per cent reduction in leaf area per plant, when compared with plots weeded at 20 days after planting, was only 16.6 and 46.1 for plots weeded at 27 and 34 days after planting respectively.

The recovery in leaf at a later stage could be attributed to better supply of water both as a result of rainfall and elimination of weeds. Significant reductions in leaf area with increasing weed infestation time were also reported by Lozanovski et al. (1973).
Stem diameter, plant height, shoot dry weight and grain yield all varied significantly ($p = 0.01$) as the time to eliminate weeds increased progressively from 20 to 34 days after planting (Table 5, 6, 7).

**TABLE 5. STEM DIAMETER OF MAIZE AT 37TH DAY FROM PLANTING AS INFLUENCED BY TIME OF WEED ELIMINATION**

<table>
<thead>
<tr>
<th>Time of weed elimination (Days after planting)</th>
<th>Stem diameter (mm)</th>
<th>% reduction compared with weeding at 20 DAP+</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>23.2</td>
<td>-</td>
</tr>
<tr>
<td>27</td>
<td>16.6</td>
<td>28.4</td>
</tr>
<tr>
<td>34</td>
<td>12.3</td>
<td>46.9</td>
</tr>
<tr>
<td>LSD (0.01)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+ DAP = Days after planting

Compared with the plots which were weeded at 20 days after planting, stem diameter was reduced by 29.4 and 46.9 per cent, respectively, for those weeded at 27 and 34 days after planting.

**TABLE 6. PLANT HEIGHT (CM) OF MAIZE AT DIFFERENT STAGES AS INFLUENCED BY TIME OF WEED ELIMINATION**

<table>
<thead>
<tr>
<th>Time of weed elimination</th>
<th>crop growth stage (Days from planting)</th>
<th>% reduction compared with weeding at 20 DAP+</th>
<th>% reduction compared with weeding at 20 DAP+</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>37</td>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>20</td>
<td>76.1</td>
<td>-</td>
<td>241.4</td>
</tr>
<tr>
<td>26</td>
<td>56.6</td>
<td>25.6</td>
<td>189.2</td>
</tr>
<tr>
<td>34</td>
<td>43.4</td>
<td>42.9</td>
<td>145.8</td>
</tr>
<tr>
<td>LSD (0.01)</td>
<td>7.9</td>
<td>-</td>
<td>18.3</td>
</tr>
</tbody>
</table>

+DAP = Days after planting
Plant height was reduced by 25.6 and 42.9 per cent, for the plots weeded at 27 and 34 days respectively, compared to those weeded at 20 days after planting. The trend continued even at a later growth stage (68th day from planting) when the reductions in plant height were 21.6 and 39.6 per cent, respectively, for plots weeded at 27 and 34 days after planting. A reduction of 36 per cent in plant height due to weed competition was also reported by Blanco et al. (1976). Shoot dry weight for the plots weeded at 27 and 34 days after planting was reduced by 53.1 and 79.9 per cent respectively. At a later stage (94th day from planting) per cent reductions in shoot dry weight for plots weeded at 27 and 34 days after planting were 32.3 and 60.9 respectively compared with those weeded at 20 days after planting. Similar effects were also reported by Krishnamurthy et al. (1979).

TABLE 7. SHOOT DRY WEIGHT (g/PLANT) OF MAIZE AT DIFFERENT GROWTH STAGES AS INFLUENCED BY TIME OF WEED ELIMINATION

<table>
<thead>
<tr>
<th>Time of weed elimination (days after planting)</th>
<th>Crop growth stage (Days from planting)</th>
<th>% reduction compared with weeding at 20 DAP</th>
<th>% reduction compared with weeding at 20 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>37</td>
<td>20.7</td>
<td>583.0</td>
</tr>
<tr>
<td>27</td>
<td>9.7</td>
<td>53.1</td>
<td>394.5</td>
</tr>
<tr>
<td>34</td>
<td>4.3</td>
<td>79.2</td>
<td>227.5</td>
</tr>
<tr>
<td>LSD (0.0)</td>
<td>1.7</td>
<td>77.9</td>
<td></td>
</tr>
</tbody>
</table>

+ DAP = Days after Planting

Grain yield decreased as the time of weed elimination progressively increased and was found to be 48, 30 and 18quintals/ha for the plots weeded after 20, 27 and 34 days respectively. Compared with the plots weeded after 20 days the yield reductions were 37.5 and 62.5 per cent respectively, for those weeded after 27 and 34 days. Yield reductions up to 50 per cent have been reported when weeds were allowed to remain for the first 30 days of the life of a maize crop (Romero et al., 1970). However, if the weeds were allowed to compete up to 60 days, the yield was
reduced by 83 per cent (Blanco et al., 1973).

The results presented above show that plants maintained a higher leaf water potential and growth rate where weeds were eliminated at 20 days compared with those where weeds were allowed to compete for longer periods of 27 and 34 days after planting. It is thus obvious that, if the weeds are eliminated earlier, the plants are able to sustain drought better and yield more by maintaining higher leaf water potential. Significant reductions ($p = 0.1$) in all plant growth parameters and in turn the grain yield for the plots weeded at 27 and 34 days after planting compared with those weeded at 20 days show that weed competition is very critical during the first 30 to 35 from planting. During the first 2 - 3 weeks after emergence weeds undergo 15 - 18 per cent of their total growth (Meggit, 1970) (Nieto et al., 1968; Cruz et al., 1969; Romero et al., 1970; Singh, 1973; Chandra Singh and Rao, 1975; Vengris, 1978; Carson, 1979) have reported that, for maize, in the first 30 days from planting or 2 to 3 weeks after emergence weed competition is very critical.

**TABLE 8. GRAIN YIELD OF MAIZE AS INFLUENCED BY TIME OF WEED ELIMINATION**

<table>
<thead>
<tr>
<th>Time of weed elimination (Days after planting)</th>
<th>Grain yield (g/ha)</th>
<th>% reduction compared with weeding at 20DAP+</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>48.0</td>
<td>-</td>
</tr>
<tr>
<td>27</td>
<td>30.0</td>
<td>37.5</td>
</tr>
<tr>
<td>34</td>
<td>18.0</td>
<td>62.5</td>
</tr>
</tbody>
</table>

+ DAP = Days after planting

**REFERENCES**


THE EFFECT OF EXCLUSION OF LARGE HERBIVORES AND SUBSEQUENT TREE REGENERATION ON SOIL NUTRIENT STATUS OF RED-BROWN LOAM SOILS, UGANDA

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P O Box MP 167, Harare, Zimbabwe

SUMMARY

The effects of excluding large herbivores from a Sporobolus-Setaria grassland on red-brown loam soils in the Murchison Falls National Park, Uganda are described.

After 14 years of exclusion of large herbivores, the grassland plot showed marked tree regeneration, especially Acacia sieberiana. Concomitant with this, there was a build-up of soil organic matter (S OM) and the release of major nutrients into the soil. Chemical analyses showed a dramatic increase in extractable Ca, K, and Mg, but Mn levels declined. The increase in extractable cations is reflected in an increase in pH. Associated with the build-up of S OM, total N and labile forms of P increased. The increase in labile P fraction is discussed in detail in relation to P-mineralization.

The possibility of reversing deleterious trends in soil nutrient status by excluding large herbivores is discussed.

INTRODUCTION

Severe overgrazing and browsing of both domestic animals and wildlife can lead to a dramatic reduction in vegetative cover with subsequent deleterious effects on soil physical properties and nutrient status (Braunack & Walker, 1985; Buechner & Dawkins, 1961; Laws, 1970). Other agricultural practices such as the removal of forest for conversion to arable land may similarly result in declines in soil nutrient status (Nye & Greenland, 1964; Juo & Lal, 1977). A key factor in the decline in soil fertility in these situations is the rapid loss of soil organic matter (S OM) through oxidation and mineralization without any concomitant replenishment as litter fall and decomposition.
In Africa, a period of fallow is often used as an agricultural practice to allow natural regeneration to restore soil fertility. Aweto (1981) found that an increase in soil fertility could be detected after only three years natural regeneration on a tropical ferrallitic soil in south-western Nigeria. Similar results were found by Juo & Lal (1977) on an alfisol in western Nigeria.

Studies in domestic grazing systems have shown that soil physico-chemical properties may benefit from a period of removal of grazing pressure (Braunack & Walker, 1985; Barnes, 1979). There are, however, fewer investigations into the effect of removal of grazing and browsing pressure in 'natural' ecosystems such as National Parks and Game Reserves, despite the fact that it has long been recognized that large herbivores, especially elephant, may have a dramatic impact on the vegetation and soil (Laws, 1970). A dramatic example of the latter occurred in the Tsavo National Park, Kenya during the 1960's where a combination of high elephant numbers and drought resulted in the almost complete destruction of woody plant cover and the loss of top soil.

One of the few experiments to investigate the effects of exclusion of large herbivores on vegetation and soils, however, has been set up in Murchison Falls National Park, Uganda.

**METHODOLOGY**

Exclusion plots were set up in 1967 in Sporobolus-Setaria grassland and Combretum-Terminalia woodland. These plots were subjected to controlled burning or no burning in the presence or absence of large herbivores. Originally the plots were to be monitored at two-yearly intervals over a long period of time to assess the changes occurring under the various management regimes. Unfortunately, because of the security situation in Uganda, only preliminary results were obtained before the monitoring programme had to be abandoned in 1971 (Spence & Angus, 1971). However, by 1981 the situation in Uganda was sufficiently stable for the present author and colleagues to resume the monitoring of the exclusion plots at Murchison Falls. As the burning regime had not
been implemented during the intervening years it was, therefore, not possible to assess the effect of this management practice and the investigation focused only on the grazing/no grazing intervention.

Soils were sampled from areas within the grassland control plot (unburnt and continually grazed) and within the grassland exclusion plot (unburnt and ungrazed since 1967). Both plots were contiguous, approximately 60m x 60m and located on the red-brown loam soils. Three replicate soil samples were taken at random from each plot at 0 - 10cm depth. The soils were air-dried and stored in plastic bags at room temperature until laboratory analyses could be carried out.

Air dried soils were put through a 2mm sieve prior to analysis. Soil pH was measured in a 1:1 suspension of soil in deionized water. Organic matter content was measured as loss-on-ignition (L O I) of oven-dry soil after 2 hours in a muffle furnace at 550°C (Allen, Grimshaw, Parkinson & Quarmby, 1974). Extractable Ca, K, Mg and Mn were determined using ammonium acetate extraction at pH7 (soil-solution ratio 1:25), K was measured using flame photometry and the other three elements by atomic absorption (Allan et al., 1974). For total P content the air-dried soil was digested in nitric-perchloric-sulphuric acid followed by colorimetric determination using the stannous chloride-ammonium molybdate method (Allan et al., 1974. Labile phosphorus fractions, i.e. extractable organic and inorganic P were determined using the buffered (pH 8.5) bicarbonate procedure of Olsen (cited in Allen et al., 1974); the amounts of organic P were calculated as the difference between (i) the total P in the extract after digestion with nitric-perchloric-sulphuric acid and (ii) the inorganic P component. Both (i) and (ii) were determined using the stannous chloride-ammonium molybdate method.

Total N content was determined on air-dried soils by micro-Kjedahl using potassium sulphate and mercuric oxide followed by the automated indo-phenol-blue colorimetric method (referenced in Allen et al., 1974).
All properties except pH are expressed on a soil-dry-weight basis.

RESULTS

(1) Vegetation and field soil Characteristics

The results of the 1981 survey show that, with the exclusion of large herbivores, from both woodland and grassland, tree species are able to re-establish themselves to a considerable degree with dramatic changes occurring in floristic composition of the herbaceous layer (Smart, Hatton & Spence, 1985). This effect was particularly evident in the grassland exclusion plot where the once open Sporobolus - Setaria grassland had become dominated by fully grown Acacia sieberiana trees, 7 - 10m high. The floristic composition of the herbaceous layer was completely altered; almost all the graminaceous species were replaced by two prolifically spreading herbs Achyranthes aspera and Acalypha bipartita. Soil characteristics in the grazed and ungrazed plots also showed dramatic differences. The surface of the red-brown loam soils on which the exclusion plot was located had developed into a darker brown layer. SOM and soil nutrient levels had increased markedly under the regenerating Acacia woodland in the grassland exclusion plots (Hatton & Smart, 1948).

(2) Soil Analyses

There was an appreciable increase of 20 - 30% in the organic matter content in the soils of the ungrazed grassland plot (Table 1). As organic matter and organic carbon content are within any single soil type it may be inferred that the organic carbon content of the ungrazed grassland soil has also increased by some 20 - 30%.
TABLE 1. SOIL ANALYTICAL DATA FROM GRAZED AND UNGRAZED GRASSLAND PLOTS

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Grazed</th>
<th>Ungrazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate</td>
<td>1 2 3</td>
<td>1 2 3</td>
</tr>
<tr>
<td>pH</td>
<td>66.0 6.0 6.0</td>
<td>7.4 7.5 7.4</td>
</tr>
<tr>
<td>Ca (mg/100g)</td>
<td>75 73 72</td>
<td>220 240 150</td>
</tr>
<tr>
<td>K (mg/100g)</td>
<td>8.4 9.9 8.5</td>
<td>46 45 42</td>
</tr>
<tr>
<td>Mg (mg/100g)</td>
<td>24 23 22</td>
<td>59 65 45</td>
</tr>
<tr>
<td>Mn (mg/100g)</td>
<td>3.5 3.5 3.3</td>
<td>0.35 0.26 0.70</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>6.5 6.5 6.3</td>
<td>7.7 8.1 7.1</td>
</tr>
<tr>
<td>Total P (mg/100g)</td>
<td>45 46 46</td>
<td>36 43 43</td>
</tr>
<tr>
<td>Extractable organic P (mg/100g)</td>
<td>0.20 0.39 0.47</td>
<td>1.3 1.4 *</td>
</tr>
<tr>
<td>Total N (%)</td>
<td>0.19 0.17 0.18</td>
<td>0.28 0.30 0.22</td>
</tr>
</tbody>
</table>

* No figure

Concomitant with the measured increase in S 0 M, there was a dramatic increase in extractable Ca, K and Mg (Table 1). Only Mn, which was initially present in relatively small amounts declined. K showed the greater build-up increasing approximately five-fold in the top soils in the ungrazed exclusion plot. Ca and Mg showed on average a two- to - three - fold increase. The increase is reflected by a rise of approximately 1.5 units in pH. Mn, an element which becomes insoluble as the pH increases, shows a big decline in the ungrazed plot as it is lost from the soil solution. Levels of total nitrogen increased on average 50% in the ungrazed plot (Table 1). Total nitrogen measured by the method described includes all organic and ammonia nitrogen present in the soil. Nitrates are not included in this estimate but amounts present in unfertilized soil are usually extremely low. No figures are available separately for mineral forms of nitrogen (ammonia - N and nitrate -N) as fresh soils are preferred for their determination.

There was little difference in total phosphorus content in the soil of the ungrazed and grazed grassland plots although there are indications that total phosphorus declines slightly in the soils under the regenerating woodland of the ungrazed plot (Table 1).
FIG. 1. - SIMPLIFIED PHOSPHORUS CYCLE

VEGETATION

UPTAKE BY ROOTSYSTEMS
RETURN IN LITTER, DEAD ROOTS, ETC.

MICRO-ORGANISMS

RETURN BY DECOMPOSITION

FAUNA

UP TAKE BY MICRO-ORGANISMS
DIRECT LEACHING

HUMIFICATION VIA MICRO-ORGANISMS DURING DECOMPOSITION

LABILE Pi

FIXED Pi

STABLE Po

LABILE Po

Pi = inorganic phosphorus
Po = organic phosphorus

-mineral soil only
FIG. 2. - SCHEME SHOWING RELATION OF SOIL FACTORS TO PHOSPHATE ACTIVITY AND ORGANIC PHOSPHORUS MINERALIZATION

LABILE Po ——> LABILE Pi

MINERALISATION

ACTIVITY OF PHOSPHATASES
(phosphomonoesterases)

ENZYME PRODUCTION
BY MICRO-ORGANISMS
ROOTSYSTEMS
LEAF LITTER

INFLUENCES OF SOIL FACTORS
e.g. organic matter, pH,
moisture, temperature,
extr. magnesium.

Pi = inorganic phosphorus, Po = organic phosphorus.
Labile phosphorus fractions viz. extractable organic phosphorus represent only a small proportion of the total phosphorus pool. There are, however, marked differences in the levels of the labile phosphorus fractions in soils in the ungrazed grassland plot compared to those in the grazed plot. Extractable inorganic phosphorus increased on average seven-fold when grazing was excluded whilst extractable organic phosphorus increased on average four-fold in the ungrazed plot.

**DISCUSSION**

The results clearly demonstrate that under climatic and edaphic conditions existing in the Park the deleterious effects of large herbivores can be reversed. After only 14 years exclusion of large herbivores a *Sporobolus-Setaria* grassland with scattered *Acacia* scrub showed marked tree regeneration. In comparison to the continually grazed central plot the exclusion plot developed into closed canopy *Acacia* woodland with a much altered herbaceous stratum.

Concomitant with the development of woodland a marked increase in SOM and soil nutrient status occurred. A comparison of the soil analytical data from the grazed and ungrazed grassland plots indicates that after only 14 years protection from herbivores, *Acacia* trees were able to extract nutrients from a relatively nutrient-poor soil and returned these to the soil via litter fall and decomposition resulting in an increase in soil fertility.

The key component in the increase in soil fertility is the build-up of SOM which occurs following natural regeneration. In view of the increase in SOM the increase in soil nutrient status is to be expected. The dramatic increase in Ca, K and Mg is probably a direct result of the build-up of SOM which not only provides a substrate for the release of these ions but also positively affects the capacity of the soil to hold cations. Following the increase in these cationic forms, pH increased sharply in the top soils of the exclusion plot. Although no data are available regarding the availability or otherwise of aluminium it
should be noted that this element has an important role in the chemistry of some East African soils. Ca and Mg both compete with Al on the exchange sites and it may be that Al levels decline as Ca and Mg levels increase in the exclusion plots. If this were the case it may further account for the large increase in plant-available P measured in the exclusion plot compared to the extremely low level in the grazed plot as Al binds extractable P making it unavailable for plant uptake.

The increase in total N is a direct consequence of the build-up of SOM since the major component of the total N pool is comprised of organic N. In terms of soil fertility, total N content is important as it represents a mineralized reserve of organic N which, through the processes of mineralization, releases ammonia-N and nitrate N into the plant available pool.

Although there are indications of a slight decline in levels of total P in the ungrazed plot, levels of labile (extractable) inorganic and organic P showed a dramatic increase. The total P pool included all phosphorus fractions, both inorganic and organic.

It is convenient to recognize two inorganic and two organic fractions within the total P pool. A major proportion of both the inorganic and organic fractions occur in fixed or bound forms. (fixed Pi and stable Po in Fig. 1 respectively). Fixed Pi occurs as insoluble compounds of iron and aluminium whilst stable Po is similarly insoluble occurring as inositol hexaphosphates (Phytins) bound to iron and aluminium compounds or to clay particles. Both fixed Pi and stable Po play a relatively minor role in the short-term biological turnover of P. In contrast the two labile fractions viz extractable inorganic P (labile Pi) and extractable organic P (labile Po) may undergo rapid biological turnover through the soil-plant sub-system. Labile Po is intrinsically linked to SOM and represents an immediate mineralizable reserve of P which, through the activity of phosphatase enzymes, releases labile Pi into the soil solution from which it is taken up by plant systems and incorporated into the above-ground parts of the plant. Labile Po is subsequently replenished via litter return and microbial activity.
Fig. 1). Whilst the vegetation component has a controlling influence on the replenishment of \( \text{S}_0\text{M} \) and labile \text{Po}, the continued supply of plant available \text{Pi} is dependent on the processes of mineralization (Fig. 2.)

The process of mineralization of labile \text{Po} to labile \text{Pi} is mediated by the activity of phosphatase enzymes. \( \text{S}_0\text{M} \) not only positively affects the production of phosphatases but also enhances the activity of the enzymes becoming bound to the humo-protein complexes thereby preventing decomposition. Other soil factors such as pH, temperature, moisture and extractable Mg also affect the activity of the phosphatases. It is evident, therefore, that conditions existing in the ungrazed plot greatly favour the replenishment and supply of the labile \text{P} fraction.

**CONCLUSION**

The results presented here further highlight the interaction between the animal, plant and soil sub-system in a natural ecosystem with special reference to the dynamics of phosphorus turnover in the soil component. The necessity of preventing over-grazing and over-browsing to maintain the integrity of the vegetation and soil components is also considered.

In the context of the National Parks in East Africa the experimental exclusion of large herbivores from a degraded environment demonstrates the close relationship between animals, vegetation and soils. It is evident that wholesale destruction of existing woodland and forest cannot be permitted to occur within the boundaries of the Parks. Such a situation would inevitably lead to a decline in soil nutrient status. It has been shown that, under the conditions existing in Murchison Falls National Park, it is possible to reverse such deleterious trends. This, however, may not always be the case. Efforts should, therefore, be made to encourage tree regeneration, maintain a diversity of habitats and prevent widespread soil nutrient losses.
REFERENCES


ACIDITY AND PHOSPHORUS MANAGEMENT IN THE RED SOILS OF THE HUMID TROPICS: A REVIEW

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Department of Soil Science, University of Zambia, Lusaka, Zambia.

ABSTRACT

This paper attempts to expose the controversy surrounding soil acidity, phosphorus deficiency and crop performance in some red soils of the tropics. The results of a liming experiment carried out on a Zambian red soil, an Oxic Rhodic Paleustalf are presented. On the basis of these results and information from the literature, an attempt is made to identify and explain the causes of the behaviour of phosphorus under varying conditions in these soils.

INTRODUCTION

Soil acidity and phosphorus deficiency are the most frequently encountered problems in the red soils of the humid tropics. In Zambia, these soils cover about 45 percent of the land area but mostly occur in the high rainfall areas of the north. Liming has for long been the traditional remedy for acidity and phosphorus deficiency.

There are considerable differences in response to lime among red soils of the humid tropics. The reasons involved have been a subject to controversy for many years. However, the development of acidity in some of these soils implies that, in general, liming is a basic requirement for their continued use. Lime requirement of tropical soils is generally lower than that of soils of the temperate regions. The objective in the tropics is simply to lower the exchangeable aluminium content rather than raising the pH to some pre-determined level. A lime supply of 1.5 times exchangeable aluminium is generally believed to be adequate for this purpose.
The effect of lime on phosphorus availability has been demonstrated to vary from beneficial to detrimental. Its effect on crop yield is similarly in dispute. Some workers have suggested that differences in response to lime among tropical soils may be due to that the pH at which maximum yields occur differs according to the degree of weathering of the soil.

A review of some of the work done in Zambia and other parts of the world on these problems has revealed numerous contradictions particularly regarding the effect of liming on phosphorus solubility. Three opposing results have been reported; first, that phosphorus sorption decreases with increasing pH (Munyinda, 1983; Hingston et al., 1967; Obihara and Russell, 1972); second, that liming decreases phosphorus in solution (Ensminger and Pearson, 1957); and third, that liming causes no change at all in phosphorus in solution (Shoop et al., 1961). These wide differences have not been satisfactorily explained (Pearson, 1973).

Friesen et al., (1980) asserted that phosphorus availability, whether measured by adsorption techniques or lability techniques may be increased, decreased, or unaffected by lime amendments. Similarly, crop yield response to increasing pH varies widely even among closely related soils (Adams, 1968). Under these circumstances therefore, there is need to be cautious about making general statements on the effect of lime on phosphorus solubility and crop performance.

We can make two general observations from published work regarding the effect of lime on acid soils. The first is that lime seldom affects soil pH. The second is that,where soil pH is increased by lime, the crop seldom responds.

The paper attempts to expose the controversy surrounding soil acidity, phosphorus deficiency, and crop performance in the red soils of the humid tropics and speculate on the causes.
Soil acidity and Liming

Table 1 shows some physical and chemical properties of an Oxic Rhodic Paleustalf from Zambia to which were applied 3 or 6 tonne CaCO$_3$/ha, 30 tonne manure/ha, or a combination of 30 tonne/manure and 3 tonne CaCO$_3$/ha in December 1985.

### TABLE 1 - SOME PHYSICAL AND CHEMICAL PROPERTIES OF AN OXIC RHODIC PALEUSTALF FROM ZAMBIA

<table>
<thead>
<tr>
<th>Depth cm</th>
<th>pH (CaCl$_2$)</th>
<th>% Org. C</th>
<th>Bulk density g cm$^{-3}$</th>
<th>Extractable Al, me/100 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>3.9</td>
<td>0.72</td>
<td>1.69</td>
<td>1.3</td>
</tr>
<tr>
<td>15-30</td>
<td>4.2</td>
<td>-</td>
<td>1.66</td>
<td>1.9</td>
</tr>
<tr>
<td>25-50</td>
<td>4.3</td>
<td>0.58</td>
<td>1.50</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Soil pH was measured five months later, and the response of a maize crop to these treatments, indicated by plant height at 71 days from planting, was determined. The results are given in Table 2.

### TABLE 2 - EFFECT OF LIME AND MANURE AMENDMENTS ON AN ACID OXIC RHODIC PALEUSTALF (FROM O. LUNGU AND J. TEMBA 1986. UNPUBLISHED)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Soil pH</th>
<th>Maize height at 71d (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-20 cm</td>
<td>20-40 cm</td>
</tr>
<tr>
<td>Control</td>
<td>3.9</td>
<td>4.1</td>
</tr>
<tr>
<td>3t CaCO$_3$/ha</td>
<td>4.4</td>
<td>4.1</td>
</tr>
<tr>
<td>6t CaCO$_3$/ha</td>
<td>4.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Manure</td>
<td>4.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Manure + CaCO$_3$</td>
<td>4.9</td>
<td>4.2</td>
</tr>
</tbody>
</table>
It is shown that neither 3 nor 6 t CaCO₃/ha increased soil pH by any great margin. This is surprising since the 6 t CaCO₃/ha rate is twice the lime requirement for this soil based on the formula: \( t \text{ CaCO}_3 \text{eq/ha} = 1.65 \times \text{meq exch. Al/100g soil} \) (Kamprath, 1970). There were no further pH increases during January 1986 when the plots were sampled again.

Foster (1970), reported that 5 t/ha of lime only increased soil pH by 0.6 units on ferrallitic soils at several locations in Uganda. Similar results have been reported on ultisols and oxisols in the high rainfall (>1000 mm annual rainfall) areas of Zambia by Larsen, 1984**(unpublished). This peculiar behaviour has not been satisfactorily explained beyond recognition that the soils are highly resistant to pH change induced by lime.

Rixon and Sherman (1962), reported that lime applications of up to 46 t/ha on three Humic Latosols and a hydrol Humic Latosol did not reduce extractable Al (NH₄OAc-BaCl₂) more than 40%. The need for such high rates of lime is partly attributed to the high pH-dependent charge in these soils. Rixon and Sherman's data show that theoretically some 74 t/ha of CaCO₃ would be required to satisfy the high negative charge densities developed on the surface of hydrous oxides of Fe, Al, and Si by liming. In practice, such high rates of lime are not applied and, according to the foregoing discussion, high soil pH values cannot be expected on certain soils from nominal lime applications.

Perhaps the results of significance in Table 2 are that a good crop can be grown without necessarily raising soil pH to 5.5 and that this can be achieved through use of manure alone, or in combination with lime. Organic matter has some beneficial effects on soil physical properties which are not adequately appreciated in soil fertility evaluations. Nutrient deficiencies and imbalances which may not be corrected by mere liming of acid soils can affect crop response.

Figure 1: Examples of P sorption isotherms determined by the method of Fox and Kamprath.

Figure 2: P sorption isotherms for an acid (B) and non-acid (A) soil.
Liming and phosphorus solubility

One of the primary reasons commonly given for liming acid soils is to improve phosphorus availability. However, as pointed out by Kamprath (1972), published results show that the effect of lime on phosphorus availability can vary from beneficial to detrimental.

Friesen, et al. (1980) studied this problem on two Nigerian soils; an Oxic paleudult and a Ustoxic paleustult. They did this by adsorption of phosphorus on to soils using 6-day adsorption isotherms; by subsequent desorption of adsorbed phosphorus in 0.01M CaCl₂; and by estimating the concentration of phosphorus in the soil solution of soils incubated with various rates of lime and phosphorus using the null point method.

Figure 1 shows the phosphate adsorption isotherms at four levels of lime. The variability of the lime - phosphorus interaction effect is clearly demonstrated. In the Ustoxic paleustult it is observed that from 0.005 to 0.2µg P/ml of phosphorus in solution, which is usually the range of plant response, the effect of lime was one of increasing phosphorus sorption except at high levels of 4g CaCO₃/kg soil. In the Oxic paleustult the same response occurred but only in the range 0.04 to 0.06 µg P/ml in solution. However, at equilibrium solution concentrations of 0.2 µg P/ml and higher, there was a reduction of sorbed phosphorus as a result of liming. This response clearly shows that response to liming can vary considerably even between soils of the same taxonomic order.

Amarasiri and Olsen (1973) studied the effect of adding lime to an oxisol from Colombia on soluble phosphorus and labile phosphorus in 0.01M CaCl₂. Fig. 2 shows that, for any given level of phosphorus added to the soil, liming decreased both soluble and labile phosphorus to a minimum at a pH between 6 and 7 even with extended periods of shaking where equilibrium was more nearly approached. A comparison of the phosphorus adsorption maxima of the limed and unlimed soils showed that the limed soil ended up with a higher maximum phosphorus sorption capacity. The soil studied had an initial aluminium content of
Figure 3: Phosphate sorption on Kaolinite as a function of pH (Chen et al. 1973)
The authors suggested that the freshly precipitated iron and aluminium hydroxides were responsible for the increased inactivation of added phosphorus as lime rate increased. This factor may have been more important in this study than in Friesen's experiment because both the ultisols he studied had aluminium contents less than 2 me/100g. In similar experiments Reeve and Sumner (1970) found that liming did not reduce phosphorus fixation in eight Natal soils. They also found that phosphorus retention was not related to exchangeable aluminium levels in these soils. A fairly extensive study cited in Pearson (1973) was done by Anastacio (1968) on 55 soils from different regions of Brazil. The selection included a number of latosols and terra roxa soils. Surprisingly enough, the data did not show any relationship between phosphorus recoverable by dilute acid extraction and phosphorus applications, pH and exchangeable aluminium.

The effect of lime on chemical activities of gels containing aluminium, iron, silicon and titanium has been reported by Sherman (1952) to be small. Some tropical soils contain substantial amounts of these amorphous materials which fix high amounts of phosphorus. If Sherman's observation is valid, then this could account, at least in part, for the failure by many workers to show either reduction in phosphorus fixation after liming or improvement in solubility in various extractants.

There are many experiments reported where the lime-phosphorus interaction led to increase in phosphorus availability. Munyinda (1983) studied the effect of liming of the utilization of phosphorus applied as triple super phosphate in two Zambian soils.

Table 3 shows a substantial increase in utilization of both fertilizer and soil phosphorus as a result of liming. Munyinda attributed this to both increased ability of the maize crop to take up phosphorus and increased phosphorus supply by the soil. Reeve and Sumner (1970) attributed the lime-phosphorus interaction to an improved ability of the plant to take up phosphorus rather than an improved rate of phosphorus supply by the soil. This
TABLE 3 - EFFECT OF LIMING ON PHOSPHORUS UPTAKE BY MAIZE IN TWO ZAMBIAN SOILS (MUNYINDA, 1983).

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Treatment</th>
<th>Total uptake of fertilizer P(mg/g)</th>
<th>Total uptake of soil P(mg/g)</th>
<th>% utilization of fertilizer P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxic Paleust-ult</td>
<td>TSP*</td>
<td>0.47</td>
<td>0.88</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>TSP+CaCO₃</td>
<td>7.02</td>
<td>4.34</td>
<td>5.95</td>
</tr>
<tr>
<td>Oxic Paleustalf</td>
<td>TSP</td>
<td>6.00</td>
<td>7.80</td>
<td>5.05</td>
</tr>
<tr>
<td></td>
<td>TSP+CaCO₃</td>
<td>11.53</td>
<td>4.05</td>
<td>9.71</td>
</tr>
</tbody>
</table>

*TSP = Triple Super Phosphate

improved ability may be effected by improved root/soil contact as suggested by Amarasiri and Olsen (1973). However, Uehara and Gavin (1981) cautioned that unless an experiment is designed to separate out the pure effects of such liming on phosphorus nutrition, the results lead to confusion because lime corrects other effects such as calcium deficiency, aluminium toxicity, and trace element imbalances. The correction of these soil factors invariably results in increased phosphorus uptake even though the lime had no effect on reducing phosphorus sorption. When the effect on these soil factors is removed from consideration, the pure effect of lime application on reducing phosphorus fixation is generally small.

The data in table 3 sharply contrasts with that reported in Ghana (Lathwell 1979) where greater response to applied P on Oxisols and Ultisols was observed at zero lime. There was a sharp decline in yield with lime application, being lowest at 4 t/ha of lime. Part of the data is shown in Table 4.
TABLE 4 - MAIZE RESPONSE TO APPLIED PHOSPHORUS AS INFLUENCED
BY LIME. FIGURES ARE EXPRESSED AS A PERCENTAGE OF
THE CONTROL TREATMENT (+ = ABOVE AND - = BELOW THE
YIELD OF THE CONTROL).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Oxisol</th>
<th>Ultisol</th>
</tr>
</thead>
<tbody>
<tr>
<td>zero lime</td>
<td>+ 170</td>
<td>+ 50</td>
</tr>
<tr>
<td>1 t/ha lime</td>
<td>+ 102</td>
<td>+ 13</td>
</tr>
<tr>
<td>2 t/ha lime</td>
<td>+ 21</td>
<td>+ 7</td>
</tr>
<tr>
<td>4 t/ha lime</td>
<td>- 4</td>
<td>- 5</td>
</tr>
</tbody>
</table>

Most common designs of lime-phosphorus experiments do not
distinguish between various possible indirect beneficial effects
of lime. Improved phosphorus nutrition of the crop upon liming
the soil could result from different factors including (i) improved
rooting of the crop, (ii) alleviated Ca deficiency, (iii) corrected
micronutrient imbalances, and (iv) enhanced mineralization of
organic phosphorus. Contradictory results in the literature
could be due to non uniform initial conditions regarding these
factors in the different experiments. There is no basis for
comparing results from different experiments if reference data
on these factors is lacking.

Fig. 3 from Chen et al, (1973) shows a favourable effect
of liming on phosphorus sorption. Uehara and Gavin (1981)
observed that the wide differences in the phosphorus sorbed
at high concentrations virtually disappear at low concentrations.
In fact the curves coalesce into a single curve, and it is this
coalesced region of the phosphorus sorption curve that is relevant
to the agronomist. In this low concentration range the reduced
effect of high pH on phosphorus fixation is marked by other
uncontrolled variables. This is why it is generally difficult
to demonstrate the direct benefits of liming in field experiments.
Effect of liming on yield

Most of the data of liming experiments on maize in Zambia and other tropical areas show a positive response to liming but the degree of response varies among different soils. Unpublished results from research stations in Zambia have shown a strong yield response to lime on oxisols. However, yield depression in maize and groundnuts have been reported by Brams (1971) at the rate of 1969 kg/ha on two oxisols in West Africa. He did not observe any differences in micronutrient composition of leaves which suggests that micronutrient deficiency was not responsible for the yield depression; nor was there any phosphorus-lime interaction on yield. Thus the mechanism of yield reduction by overliming was not identified.

Some reports suggest that at high pH levels there is a lime induced phosphorus deficiency (Fox et al., 1964) but the mechanism involved in reducing phosphorus activity in solution at high lime rates has not been adequately explained. While it is generally accepted that most of the micronutrients except molybdenum become less soluble as pH is increased, no study seems to have succeeded in showing that depressed crop yield after liming was due to micronutrient deficiency. For example, Mclung et al., (1969) conducted a series of experiments on latosols in which lime rates of up to 6 t/ha were included. They also applied micronutrients as a variable at high lime rates. The results obtained were inconclusive although they reported several responses and observed scattered deficiency symptoms.

Assuming that soluble P in the soil is controlled by some discrete phosphorus compounds, the concentration can then be estimated from solubility isotherms. The relationship between pH and P concentration is shown in Figure 4 from Lindsay and Moreno (1960). However, there is no apparent pH dependence of P concentration of soil solution extracts (indicated by dots see Ryden and Pratt, 1980). Miscellaneous phosphorus compounds in soils are indicated but the effect of increasing pH on their solubility is not demonstrated. Variscite and strengite, the only compounds that show increased solubility at high pH are too highly-crystalline to form under normal soil conditions (Lindsay et al. 1962).
Figure 4: Solubility isotherms for various phosphate compounds as a function of pH, and data (.) for P concentration in soil solution extracts. Figure is redrawn from Ryden and Pratt (1980)
CONCLUSION

The controversy on the effects of lime in tropical soils continues. However, all workers agree that liming is a necessary means of combating aluminium toxicity and calcium and micronutrient deficiency as long as the needs are based on exchangeable aluminium rather than pH. As far as differences in response to lime among tropical soils are concerned, the causes are still a matter of speculation. However, since yield depression due to lime is more prevalent in the tropics than in temperate regions it may suggest that the extent of weathering is an important consideration. The degree of weathering among tropical soils is immensely variable and so is the content of iron and aluminium. Therefore, the response of a soil to liming may be influenced by the stage of weathering which could be expressed in terms of more than pH and exchange properties but also by such parameters as the types and amounts of clay minerals, amongst others.
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INFLUENCE OF CROPPING AND PARTICLE SIZE DISTRIBUTION ON DEPTHWISE CHANGES IN SOIL BULK DENSITY

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ABSTRACT

Soil cores down to 90 cm depth were extracted from a number of sites on the Katito Wheat Farm, Mbala, Northern Province, Zambia. The farm area was mechanically cleared for cropping during the period 1978 to 1980. One set of cores was collected in July 1980 and another set in January, 1985. Bulk density and particle size distribution were determined for both sets of samples.

For the 1980 set of samples, the bulk density (Db) values, in all cases, decreased with an increase in soil depth and these changes were strongly related to the changes in sand and clay percentages of the profiles. Slight evidence of compaction due to tillage was also noticed. In case of the 1985 set of samples the distribution of sand and clay contents within the profile again showed a very strong influence on the depthwise Db changes. The maximum Db values for cropped sites were within the top 15 cm soil depth. There was evidence of surface soil layers being compacted due to land clearing and tillage.
INTRODUCTION

The physical condition of a soil is an important factor influencing overall plant growth in general and plant roots in particular. Lal (1979) stated that if productivity is to be maintained, an agricultural system able to preserve a satisfactory physical condition in the soil must be developed. His review of the physical characteristics of tropical soils reveals that, due to downward movement of clay and other suspended colloids, surface horizons can have a coarse texture followed by a clay bulge in the subsoil.

It is generally believed that soil structure of tropical soils deteriorates with their cultivation. Van der Weert (1974) reported a dramatic increase in bulk density due to land clearing which resulted in decreased aeration, infiltration rate and root development. Ramzan (1980) observed slightly reduced bulk density in soils cultivated for four years as compared to virgin soils.

Depthwise changes in bulk density and amounts of soil separates were determined for the sites cropped for different lengths of time. An attempt was made to examine the influence of particle size distribution and the number of crops grown on bulk density of the soil.

SITE DESCRIPTION

Katito Wheat Farm Mbala, Northern Province, Zambia, situated at an altitude of 1662 m.a.s.l. is located approximately 9°32' south and 31°22' east (Slordal, 1978). It is part of an interfluve on the so-called high level Mbala - Kawambwa Plateau. Geological material consists of quartzites, sandstones and grits of the Precambrian Kibaran System. The natural vegetation consists mainly of open Miombo woodlands. There is a wet season from November to April and a dry season from May to October. The annual rainfall is normally around 1200 mm and is quite reliable. The mean temperature varies between 10°C (July) and 30°C (October). The soils are deep, strongly leached, strongly to very strongly
acid with a low ability to provide nutrients for plant growth.

Land Management

The clearing of land took place during the 1978 to 1980 period and was done with heavy equipment. Land clearing involved tree felling, windrowing, one ripping and one heavy discing. Land preparation was usually done with cultivators and discs.

Sampling site selection Methodology

For the July 1980 sampling, the area which had already been cleared was divided into three groups, based on the number of times a given area had been cropped. Samples were collected from four randomly selected sites in each group. The results of particle size analysis showed that all but two sites had almost similar depthwise distribution of sand, silt and clay contents. Consequently the 10 sites with almost similar texture were grouped into three groups shown in Table 1. All these 10 sites plus a virgin site were sampled again during January, 1985. These sites were regrouped as shown in Table 1, again based on the number of times an area had been cropped.

Bulk density determination (Db)

At each site a pit was dug to collect soil cores for Db determination. For July 1980 sampling, a 10 cm inner diameter and 15 cm high metal core sampler was used to extract one set of soil cores for every 15 cm layer down to 90 cm. The January, 1985 soil cores were collected with 5 cm inner diameter and 5 cm high metal core sampler. Two sets of cores were extracted for each soil layer at 0-5 cm, 5-10 cm, 10-15 cm and at every 15 cm interval down to 90 cm. The oven dry weights of soil cores and total volumes of the samples were used to calculate the Db. Although different core devices were used for sampling at these 2 times, a qualitative comparison may be made between the 2 sets of results.

Particle size analysis

Part of each soil core was air dried, passed through a 2 mm sieve and used for particle size analysis. For both the 1980
and 1985 sets of samples, the hydrometer method was used with calgon (sodium hexametaphosphate) as the dispersant, followed by mechanical stirring. The soil separates were grouped into sand (2-0.05 mm), silt (0.05-0.002 mm) and Clay (<0.002 mm). The textural class was determined using the USDA textural triangle.

**TABLE 1. - GROUPS OF FIELDS FOR THE 1980 AND 1985 SAMPLES BASED ON THE NUMBER OF CROPS GROWN IN AN AREA.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Field names 1980 Samples</th>
<th>Number of crops grown</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 (80)</td>
<td>A2, B1, B2, C1</td>
<td>Two</td>
</tr>
<tr>
<td>G2 (80)</td>
<td>D1, D2, F1, F2</td>
<td>One</td>
</tr>
<tr>
<td>G3 (80)</td>
<td>C3, D3</td>
<td>Zero</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Field names 1985 Samples</th>
<th>Number of crops grown</th>
</tr>
</thead>
<tbody>
<tr>
<td>G4 (85) A2, B1, B2, C1, D1, D2</td>
<td>Five or Six</td>
</tr>
<tr>
<td>G5 (85) C3, D3, F1, F2</td>
<td>Two or Three</td>
</tr>
<tr>
<td>G6 (85) C4</td>
<td>Zero</td>
</tr>
<tr>
<td>Soil depth (cm)</td>
<td>0-15</td>
</tr>
<tr>
<td>----------------</td>
<td>-------</td>
</tr>
<tr>
<td>Sand %</td>
<td>50</td>
</tr>
<tr>
<td>Silt %</td>
<td>08</td>
</tr>
<tr>
<td>Clay %</td>
<td>42</td>
</tr>
<tr>
<td>Texture</td>
<td>SC</td>
</tr>
</tbody>
</table>

**G1 (80)**

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand %</td>
<td>52</td>
<td>45</td>
<td>41</td>
<td>38</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Silt %</td>
<td>10</td>
<td>06</td>
<td>07</td>
<td>10</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Clay %</td>
<td>38</td>
<td>39</td>
<td>52</td>
<td>50</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>Texture</td>
<td>SC</td>
<td>SC</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

**G2 (80) - 1 Crop**

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand %</td>
<td>58</td>
<td>54</td>
<td>48</td>
<td>47</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Silt %</td>
<td>07</td>
<td>06</td>
<td>04</td>
<td>05</td>
<td>06</td>
<td>05</td>
</tr>
<tr>
<td>Clay %</td>
<td>35</td>
<td>40</td>
<td>48</td>
<td>48</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td>Texture</td>
<td>SCL</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
</tr>
</tbody>
</table>

**G3 (80) - No Crop**

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand %</td>
<td>60</td>
<td>54</td>
<td>52</td>
<td>52</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>Silt %</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Clay %</td>
<td>35</td>
<td>40</td>
<td>43</td>
<td>44</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Texture</td>
<td>SCL</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
</tr>
</tbody>
</table>

**G4 (85) 5-6 Crops**

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand %</td>
<td>61</td>
<td>54</td>
<td>52</td>
<td>52</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>Silt %</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Clay %</td>
<td>34</td>
<td>42</td>
<td>43</td>
<td>44</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Texture</td>
<td>SCL</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
</tr>
</tbody>
</table>

**G5 (85)**

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand %</td>
<td>65</td>
<td>63</td>
<td>59</td>
<td>59</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Silt %</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Clay %</td>
<td>30</td>
<td>34</td>
<td>36</td>
<td>38</td>
<td>42</td>
<td>40</td>
</tr>
<tr>
<td>Texture</td>
<td>SCL</td>
<td>SCL</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
</tr>
</tbody>
</table>

SCL = Sandy clay loam
SC = Sandy clay
C = Clay
### TABLE 3. - BULK DENSITIES OF VARIOUS SOIL LAYERS

#### July 1980 samples

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 (80)</td>
<td>1.44</td>
<td>1.32</td>
<td>1.26</td>
<td>1.21</td>
<td>1.21</td>
<td>1.20</td>
</tr>
<tr>
<td>G2 (80)</td>
<td>1.37</td>
<td>1.33</td>
<td>1.26</td>
<td>1.23</td>
<td>1.21</td>
<td>1.20</td>
</tr>
<tr>
<td>G3 (80)</td>
<td>1.40</td>
<td>1.36</td>
<td>1.24</td>
<td>1.18</td>
<td>1.13</td>
<td>1.17</td>
</tr>
</tbody>
</table>

#### January 1985 samples

<table>
<thead>
<tr>
<th></th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>G4 (85)</td>
<td>1.39</td>
<td>1.36</td>
<td>1.28</td>
<td>1.24</td>
<td>1.23</td>
<td>1.20</td>
</tr>
<tr>
<td>G5 (85)</td>
<td>1.40</td>
<td>1.36</td>
<td>1.24</td>
<td>1.21</td>
<td>1.16</td>
<td>1.14</td>
</tr>
<tr>
<td>G6 (85)</td>
<td>1.35</td>
<td>1.38</td>
<td>1.36</td>
<td>1.28</td>
<td>1.29</td>
<td>1.15</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

#### Particle Size analyses

Textures of analysed samples ranged from sandy clay loams through sandy clays to clays (Table 2). In both the 1980 and 1985 sets of samples, the percentages of sand were higher in the surfacelayers and decreased with depth, the reverse being true for clay percentages. The higher sand and lower clay percentages in the surface are produced as a result of clay eluviation (Lal, 1979) and/or erosion losses of clay.

#### Bulk density analyses

The bulk density (Db) values for both the 1980 and 1985 sets of samples exhibited changes as a function of soil depth (Table 3). For the 1980 samples, the Db in all the groups decreased with an increase in soil depth. As with clay and sand contents, the major changes in Db also occurred within the surface 45 cm soil. Below 45 cm, the decline in Db values of surface soils were possibly due to combined influences of sandier textures and compaction from tillage.
The uncropped sites (G3 and G6) exhibit lower surface (0-15 cm) bulk densities, presumably as a result of fewer tillage operations being performed over the years, although G6 appears to exhibit higher bulk densities at depth.

REFERENCES


SOME SPECIAL FEATURES OF RED SOILS OF
THE HIGH RAINFALL AREA OF ZAMBIA
WITH REFERENCE TO THEIR FERTILITY AND MANAGEMENT PROBLEMS

ALFRED MAPIKI
Soil Scientist
Department of Agriculture
Soil productivity Research Programme, Misamfu, Kasama, Zambia

SUMMARY

This paper highlights some features of the red soils in the high rainfall areas of Zambia. The soils are predominantly Ultisols and Oxisols. These soils are characterised by low native fertility, extreme acidity, low nutrient status, medium to high phosphorus fixation and low water holding capacities.

It also deals with traditional agricultural systems and highlights the merits of the "Chitemene" lop and burn system in restoring soil fertility. It also discusses the disadvantages arising therefrom.

Current research work envisaged by the Soil Productivity Research Programme (SPRP) is outlined. This is work which was launched to provide alternative farming methods to small holders with emphasis on low input technology, alternative cropping systems utilizing natural and local resources. Research on solving the soil chemical constraints by liming, use of inorganic fertilizers, rock phosphate, green manure, mulching and Agro-forestry are discussed.
INTRODUCTION

Red acid tropical soils which are acid sands and easily acidifying ultisols cover an extensive proportion of Zambia's 75 million hectares. They are found predominantly in the high rainfall areas between latitudes 8 - 13°S, usually where annual precipitation exceeds 1000mm. The altitude of the area ranges from 1200 to 1500m. The average annual temperature ranges from 20 to 24°C. The extreme average daily temperatures are in the region of 10 to 28°C. Frosts occur for 1 to 5 days per year during the cool dry season. The soil temperature is dominantly hyperthermic.

Rains are seasonal and confined between October and April with the rest of the year very dry. During the rainy season, drought spells may occur which sometimes adversely affect crop yields due to low moisture retention of the soils. The natural vegetation is woodland savannah ranging from a closed tree canopy to a predominantly grass savannah. The predominant agricultural systems are shifting cultivation, characterized by lop and burn and semi-permanent agriculture. The major food crops are cassava, finger millet, maize, rice, beans, sorghum and sweet potatoes (Livingstone potatoes).

The soil

The soils are mainly Oxisols and Ultisols. Oxisols are found on the more basic rocks as well as in extensive areas in the western part of the North-Western Province on sandstone/siltstone. The rest of the high rainfall zone is not yet well surveyed but seems to consist of ultisols and oxisols. The distinction between the two orders is not always clear (Veldkamp, 1985) and their occurrence cannot always be related to physiographic position or parent material.
A major purpose of this paper is to define the main soil constraints and to discuss various soil management alternatives and conservation systems designed to alleviate them.

Soil constraints

Systematic research towards developing realistic soil management practices for food production in the acid tropics can be done by the "constraint" approach, i.e. analysing soil limitations (Sanchez, 1976; Benites, et al. (1981). In using this approach, the red soils of the high rainfall zone can be treated together, even though there are important differences between the soil orders. As in the case of soils from other parts of the tropics, soils from this region suffer from a number of constraints especially those related to soil fertility, productivity and acidity (Singh, 1985). The soil-related and other potential constraints for the region are cited and tabulated by Singh (1985).

Physical Constraints

1. **Low water holding capacity**

Some red soils have this important soil-related constraint to intensive agriculture. This, combined with barriers to root development (due to high Al-saturation and low Ca-status), may result in severe yield losses due to water stress during dry periods even if the subsoil is always moist.

2. **Erosion hazard**

The Ultisols chemically degrade faster than Oxisols, and are more subject to erosion even on gentle slopes. Unless protected by a plant canopy during periods of heavy rains, Ultisols are quite susceptible to erosion. Otherwise, on plateaus, erosion is moderate.
## TABLE 1. SOIL SAMPLES FROM NORTHERN PROVINCE

Chemical Analysis results. 0-40cm horizon

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Sample No.</th>
<th>meq exchangeable</th>
<th>CEC me. %</th>
<th>CEC clay me. %</th>
<th>Org C %</th>
<th>Avail P ppm</th>
<th>pH CaCl₂</th>
<th>pH H₂O sat</th>
<th>Base sat %</th>
<th>Al ppm</th>
<th>Mn ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mufulira</td>
<td>22</td>
<td>0.60</td>
<td>0.41</td>
<td>0.15</td>
<td>0.02</td>
<td>5.94</td>
<td>16.4</td>
<td>0.71</td>
<td>5.21</td>
<td>4.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Chibesakinda</td>
<td>5</td>
<td>1.27</td>
<td>0.97</td>
<td>0.27</td>
<td>0.02</td>
<td>5.98</td>
<td>13</td>
<td>0.53</td>
<td>2.6</td>
<td>5.0</td>
<td>5.9</td>
</tr>
<tr>
<td>Mwebeshi</td>
<td>3</td>
<td>0.63</td>
<td>0.69</td>
<td>0.19</td>
<td>0.03</td>
<td>14.7</td>
<td>38</td>
<td>1.12</td>
<td>34.8</td>
<td>4.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Mushemi</td>
<td>2</td>
<td>7.20</td>
<td>0.84</td>
<td>0.41</td>
<td>0.03</td>
<td>6.40</td>
<td>16</td>
<td>1.23</td>
<td>20.1</td>
<td>5.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Misamfu I</td>
<td>15</td>
<td>0.46</td>
<td>0.29</td>
<td>0.13</td>
<td>0.02</td>
<td>4.24</td>
<td>19</td>
<td>0.69</td>
<td>9.8</td>
<td>4.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Mulobolo</td>
<td>8</td>
<td>0.92</td>
<td>0.51</td>
<td>0.14</td>
<td>0.02</td>
<td>5.16</td>
<td>21</td>
<td>0.89</td>
<td>1.28</td>
<td>4.4</td>
<td>5.2</td>
</tr>
<tr>
<td>Misamfu II</td>
<td>2</td>
<td>2.85</td>
<td>0.51</td>
<td>0.14</td>
<td>0.03</td>
<td>3.71</td>
<td>15</td>
<td>0.66</td>
<td>11.2</td>
<td>4.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Nsato VI</td>
<td>2</td>
<td>0.65</td>
<td>0.36</td>
<td>0.18</td>
<td>0.04</td>
<td>6.69</td>
<td>28</td>
<td>0.33</td>
<td>5.5</td>
<td>4.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Kalomo</td>
<td>5</td>
<td>1.05</td>
<td>0.67</td>
<td>0.21</td>
<td>0.02</td>
<td>3.46</td>
<td>20</td>
<td>0.51</td>
<td>2.6</td>
<td>5.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Nkatongo</td>
<td>3</td>
<td>0.70</td>
<td>0.40</td>
<td>0.16</td>
<td>0.02</td>
<td>4.01</td>
<td>14</td>
<td>0.58</td>
<td>2.8</td>
<td>4.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Chasonge I</td>
<td>4</td>
<td>0.86</td>
<td>0.26</td>
<td>0.10</td>
<td>0.02</td>
<td>2.30</td>
<td>23</td>
<td>0.47</td>
<td>7.9</td>
<td>5.6</td>
<td>6.3</td>
</tr>
</tbody>
</table>
3. **Workability/Mechanization**

   The soils in the high rainfall zone are easily tilled even after a heavy storm because of their good physical properties, namely, good internal drainage, aeration, and friability.

---

**Chemical Constraints**

1. **Soil Acidity**

   Aluminium toxicity is the main cause of soil acidity. Plants suffer at levels ranging from 10-50% Al-saturation (Benites et al, 1981). The constraint of soil acidity is being solved by plant breeding and soil management. There is a substantial amount of ongoing work to breed and select varieties of crops tolerant to aluminium and good results are already being obtained, notably with maize, wheat and beans. Seed collection and screening from international organizations is being carried out and SPRP takes an active part in this national exercise. Under field conditions the performance of most crops can be correlated with Al-saturation. These relationships can be found for maize, wheat and edible beans. Commonly, the yield drops sharply once the Al-saturation is above 40%. However, the magnitude of this effect differs between varieties and with levels of P applied.

2. **Native fertility**

   The high rainfall zone is relatively low in native fertility except on clayey virgin lands. Only a limited range of adapted species, e.g. finger millet, can thrive successfully. Non-adapted species require high initial fertilization in the form of P and Ca-fertilizers.

3. **CEC, base saturation and nutrient storage capacity**

   These result in less retention of nutrient cations such as K, Ca, Mg under leaching conditions. Rapid losses by leaching and serious Mg-K imbalances appear to be one of the main causes of low yields in these soils.
4. Phosphorus deficiency

"Available" P is very low in most cases (Table 1). Crop responses to phosphorus fertilization in the high rainfall areas manure a range of P application rates which vary according to crop. The performance of most crops without addition of P is poor while large responses are observed with addition of this nutrient. The cost of this nutrient can reach alarming amounts hence improved methods must be found to make the most efficient use of the applied phosphate. Little work has been done to characterize the nature of the P equilibria in the high rainfall areas.

5. Deficiency of other nutrients

All soils in question have less than 0.3 m.e. K/100g soil which is considered to be a critical level for grain crops. Crop responses to K fertilizers may not occur in the first few seasons but do in the long term. Crops on acid soils in the region are often low in sulphur and micronutrients especially zinc. Soil reserves of Cu, B, and Mo may also be inadequate. Detrimental effects of S deficiency in crop production have not been reported despite the low soil reserves, because most of the compound fertilizers that have been in use contain some sulphur. However, fertilizers which do not contain S, such as the high analysis superphosphates are becoming more preferred so the S-deficiency may be expected in the near future.

MANAGEMENT OF THE ACID RED SOILS

Traditional Methods

The soil-related constraints cited in the previous pages led the people living in the high rainfall areas to adopt certain farming systems which enable them to obtain sustenance. The systems so practised come under the general heading of "shifting cultivation" which is a term applied to agricultural systems in which cropping is alternated with a fallow period.

In general, there are two kinds of shifting cultivation systems practised in the high rainfall zone.
These are:

1. The "chitemene" system or lop and burn for people living in thick "miombo" woodland savanna;

2. The mound system practiced by people living in open savanna which has bountiful grass but less trees. The grass is buried in mounds and once decomposed acts as a green manure.

The "chitemene" system relies very much on the release of nutrients from the burning of the wood cut from the clearing. Studies from similar systems have demonstrated that the resultant ash makes a useful nutrient input. According to Seubert et al, 1977 (quoted in Benites et al, 1981) the nutrient content of the ash produced after burning a 17-year-old secondary forest in Yurimaguas contributed the equivalent of 145kg/ha urea, 67kg/ha phosphate, 50kg/ha of muriate of potash, 0.25 tonnes/ha of dolomitic limestone plus significant quantities of sulphur, zinc, copper, manganese and iron. These additions produce major positive changes in soil properties during the first three years after burning.

In the traditional lop and burn system (Chitemene), the yields obtained in the first year are normally satisfactory, but decrease in the following years. The fields are usually left fallow after 5 years. The ash is alkaline and rich in nutrients (Table 2). The cation exchange capacity is high and available P is also very high but the content of both organic carbon and nitrogen is low.


TABLE 2. SOIL ANALYSIS OF CHITEMENE OF DIFFERENT AGES

<table>
<thead>
<tr>
<th>Age</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>Ca</th>
<th>Mg</th>
<th>Exch.</th>
<th>Org C%</th>
<th>CEC me/100g</th>
<th>Total N%</th>
<th>P ppm</th>
<th>BS%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unburned</td>
<td>0-10</td>
<td>4.8</td>
<td>1.64</td>
<td>1.23</td>
<td>0.20</td>
<td>1.20</td>
<td>6.42</td>
<td>0.13</td>
<td>6.15</td>
<td>35</td>
</tr>
<tr>
<td>Chitemene</td>
<td>10-20</td>
<td>4.5</td>
<td>0.57</td>
<td>0.22</td>
<td>0.15</td>
<td>0.74</td>
<td>4.89</td>
<td>0.09</td>
<td>2.45</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
<td>4.2</td>
<td>0.22</td>
<td>0.20</td>
<td>0.04</td>
<td>0.45</td>
<td>4.63</td>
<td>0.05</td>
<td>0.24</td>
<td>11</td>
</tr>
<tr>
<td>One-day old</td>
<td>Ash 0-10</td>
<td>10.2</td>
<td>15.00</td>
<td>13.9</td>
<td>16.90</td>
<td>0.55</td>
<td>1.28</td>
<td>0.13</td>
<td>23.50</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Chitemene 10-20</td>
<td>5.3</td>
<td>0.27</td>
<td>0.31</td>
<td>0.10</td>
<td>0.24</td>
<td>2.17</td>
<td>0.03</td>
<td>0.63</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
<td>4.4</td>
<td>0.34</td>
<td>0.50</td>
<td>0.16</td>
<td>0.20</td>
<td>3.97</td>
<td>0.05</td>
<td>0.25</td>
<td>25</td>
</tr>
<tr>
<td>Two-month old</td>
<td>0-10</td>
<td>5.2</td>
<td>1.86</td>
<td>0.31</td>
<td>0.11</td>
<td>0.88</td>
<td>5.14</td>
<td>-</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>4.5</td>
<td>1.21</td>
<td>0.29</td>
<td>0.07</td>
<td>0.67</td>
<td>5.24</td>
<td>-</td>
<td>62</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Chitemene 20-40</td>
<td>4.4</td>
<td>0.84</td>
<td>0.20</td>
<td>0.07</td>
<td>0.56</td>
<td>4.82</td>
<td>-</td>
<td>51</td>
<td>25</td>
</tr>
<tr>
<td>4-year old</td>
<td>0-10</td>
<td>5.2</td>
<td>2.41</td>
<td>0.51</td>
<td>0.12</td>
<td>-</td>
<td>6.14</td>
<td>-</td>
<td>21</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Chitemene 10-20</td>
<td>4.5</td>
<td>1.13</td>
<td>0.32</td>
<td>0.10</td>
<td>-</td>
<td>5.32</td>
<td>-</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
<td>4.1</td>
<td>0.21</td>
<td>0.12</td>
<td>0.10</td>
<td>-</td>
<td>4.64</td>
<td>-</td>
<td>1.5</td>
<td>10</td>
</tr>
<tr>
<td>13-year old</td>
<td>0-10</td>
<td>5.8</td>
<td>3.06</td>
<td>0.51</td>
<td>0.51</td>
<td>0.20</td>
<td>1.09</td>
<td>5.14</td>
<td>15</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>5.5</td>
<td>2.39</td>
<td>0.52</td>
<td>0.18</td>
<td>0.77</td>
<td>4.87</td>
<td>-</td>
<td>-</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Chitemene 20-40</td>
<td>4.5</td>
<td>0.91</td>
<td>0.45</td>
<td>0.45</td>
<td>0.12</td>
<td>0.38</td>
<td>5.46</td>
<td>-</td>
<td>48</td>
</tr>
</tbody>
</table>

Boyd (1985) showed an increase in soil pH from 4.5 to 7 as well as increases in available P, K, and CEC after burning. After one year of cropping there was a return of normal soil conditions, except for some effects of total P, available K and CEC. If burnt in October and planted late in December, N, P, and Mg are returned to normal, while Ca was still higher after one year. On the whole, the nutrient supply and especially the nitrogen problem in the Chitemene system is not yet well understood (Njos, 1983). Variability in the quantity of ash and its nutrient content occurs because of the age and proportion of the forest biomass actually burned, related to the soil type and clearing technique (Benites et al, 1981).

ON-GOING RESEARCH ON SOIL MANAGEMENT

Soil Acidity Management

Major constraints to crop production in these acid soils are toxicities of aluminium and manganese and deficiencies of calcium and magnesium. In order to have successful agriculture in this zone, acid stresses need to be overcome. Two main
strategies are being used in SPRP to alleviate acidity problems: (1) Liming to raise the pH and to reduce aluminium saturation below toxic levels; (2) Use of plant species and varieties tolerant to aluminium toxicities.

**Lime Comparison Trial**

Three lime sources were evaluated for their effects on crop performance and soil properties from 1982-1986. Two lime sources (Isoka and Chilanga) were dolimitic whilst the third (Ndola) was calcitic. The trial was laid out on a Kasama red benchmark soil with 0.2 and 4 t/ha of lime applied at the start and 0 and 400kg/ha of single superphosphate (SSP) in a split plot design. Maize and groundnuts were grown in rotation. A marked yield response to lime was observed for all crops. However SSP proved superior to lime as well as lime/SSP interactions as shown in table 3.

**TABLE 3 : MAIZE YIELDS (1984/1985 SEASON) IN LIME COMPARISON TRIAL**

<table>
<thead>
<tr>
<th>Lime, t/ha</th>
<th>Yields (kg/ha)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0 SSP</td>
<td>400kg SSP</td>
</tr>
<tr>
<td>No lime</td>
<td>784</td>
<td>2305</td>
<td></td>
</tr>
<tr>
<td>2 t Chilanga</td>
<td>908</td>
<td>2133</td>
<td></td>
</tr>
<tr>
<td>4 t Chilanga</td>
<td>1 366</td>
<td>2059</td>
<td></td>
</tr>
<tr>
<td>2 t Isoka</td>
<td>1 116</td>
<td>1 897</td>
<td></td>
</tr>
<tr>
<td>4 t Isoka</td>
<td>1 431</td>
<td>2059</td>
<td></td>
</tr>
<tr>
<td>2 t Ndola</td>
<td>1 217</td>
<td>2197</td>
<td></td>
</tr>
<tr>
<td>4 t Ndola</td>
<td>1 404</td>
<td>1 519</td>
<td></td>
</tr>
</tbody>
</table>

Low levels of Al which could have been neutralized by SSP coupled with its sulphur and Ca contents seem responsible for SSP superiority over other treatments.

**LOW INPUT TECHNOLOGIES**

Many research efforts in the tropics and the Soil Productivity Research Programme in particular, are directed towards developing low input soil management technologies which do not attempt to eliminate the use of fertilizers or amendments but rather attempt to maximize the efficiency of purchased inputs. The main low input technologies required to manage low native fertility are:

1. Maximum use of nitrogen fixation by legumes in acid soils;
2. Increasing the K-, N- efficiency of these fertilizers;
3. Identification and correction of micronutrient deficiencies; and
4. Promotion of nitrogen cycling

Besides the activities listed above the SPRP also includes
5. Phosphorus management with a focus on P-fertilization rates, placement methods and rock phosphate evaluation under acid conditions.

Phosphorus deficiency is the single most widespread production constraint in the high rainfall zone. The performance of all crops without addition of P is poor, and large responses are observed with addition of this nutrient.

**FUTURE PERSPECTIVES**

Most of the research work reported in this paper is conducted on a few benchmark soils and does not cover all the crops grown in the high rainfall zone. The extrapolation of the research findings to other soils and climatic conditions and with other crops cannot be guaranteed. General surveys of soil fertility and crop nutritional status of northern Zambia would be useful for this purpose. The changes in soil properties,
chemical, physical and biological, over a longer period have

to be monitored under different management and farming systems.

The rate and amount of nutrient cycling are not yet known.

Crop rotation practices should include a fallow of legumes or

grasses. The leaching processes and their connection with

improvement of subsoil conditions for root growth need further
evaluation.

ACKNOWLEDGEMENTS

The author wishes to thank Karl H. Solberg, Dr B.R. Singh,

W. Ngambi for advice and positive criticisms in preparing

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handwriting and made the typing possible.

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COMPARISON OF THE PHYSICAL PROPERTIES OF TWO ZAMBIAN PALEUSTALFS

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P O Box 32379    Lusaka

ABSTRACT

It has been observed that some of the Zambian red soils have poor physical properties apart from having low chemical fertility. Weakly developed structure, low water holding capacity and high bulk density downgrade the agricultural value of a number of these soils.

Two Paleustalfs near Lusaka have been studied. After growing several rainfed and irrigated crops such as maize, sunflower, soyabean, groundnuts, sorghum and wheat, under identical management for two consecutive years, it was found that the two soils produced different yields.

Differences in physical properties were held responsible for the yield difference. A full characterisation of the two soils is presented.

INTRODUCTION

In studies of tropical soils, emphasis has always been placed on the chemical characteristics of the soils while studies on the physical characteristics are lacking. In this paper, an attempt will be made to relate soil productivity to physical properties especially in as far as they relate to water balance.

Two "reddish soils", 5YR 5/8 at the Field Station site and 2.5YR 3/6 at the UNZA Farm were studied. Profiles at the
two sites were characterised and classified. Their crop productivity will be reported on. The third part of the paper will deal with some hydrodynamic properties of the soils.

MATERIALS AND METHODS

Soils

The soils are located in the neighbourhood of Lusaka at a latitude of 15 degrees South and a longitude of 28 degrees East. The altitude is approximately 1200m. The "Field Station soil" is located on the Campus of the University of Zambia and the "UNZA Farm soil" is located 18 km East of the Zambian capital.

The soils have been described by Sys (1983) and analysed by Verbruggen (1984). Valuable information has been made available by MSS (1985), since the UNZA Farm soil was selected as an IBSNAT site. The soils have been classified according to Soil Taxonomy, as published by the Soil Survey Staff (1975).

Design of field experiments

The productivity of the two soils has been studied by comparing the performance of six rainfed crops, under identical management for two consecutive years. Plot sizes were 30m² and all crops received 300 kg of a compound fertilizer (10, 20, 10) as basal dressing and 200 kg urea as top dressing. Purely rainfed supplemented by irrigation during dry spells are the two treatments per site. Every treatment is repeated four times.

Soil physical determinations

All physical analyses of the soil were carried out at the University of Zambia. Bulk density determinations were carried out on undisturbed core samples having a volume of 100 cm³. The soil water characteristic curve was determined in the high matric potential range according to the vapour pressure method as described by Stakman (1968). Field capacity and wilting point were determined using the porous plate technique as described
by the Soil Conservation Service (1972). In order to monitor low matric potential water columns rather than manifolds were used. The relationship between the hydraulic conductivity and moisture content was determined in the field on 30 m² plots according to the internal drainage method as described by Watson (1966) and Hillel (1980). Tensiometers were installed at different soil depths up to 150 cm and a neutron moisture meter was used to monitor the soil moisture.

RESULTS AND DISCUSSION

Classification of the two soils

Both soils have an ochric epipedon, a pale argillic horizon, high base saturation but low cation exchange capacity, and an ustic moisture regime. The texture in the upper part of the argillic horizons is fine loamy. The mineralogy of the two profiles is mixed. The soil temperature regime in the region is isohyperthermic. Both soils have therefore been classified as fine loamy mixed isohyperthermic Oxic Paleustalfs.

Table 1 presents some of the results of the chemical analysis which supports the classification. The organic carbon content in the topsoil of the Field Station soil is low and probably does not represent the average situation. The pH value in the lower part of the UNZA Farm profile as measured by MSS (1985) is lower than that presented in Table 1. The two soil profiles at the UNZA Farm were 100 m apart. The two soils showed some important differences in morphology which may be related to differences in parent material and genesis. The Field Station soil has a gravel layer at some depth and is derived from sandstone strongly influenced by mica schist (Toogood 1982). At the UNZA Farm no gravel layer was observed and the parent material seems to be limestone (Chinene, 1980), strongly influenced by mica schist. The Field Station soil also shows a tendency towards the ultic subgroup.
TABLE 1 A - ANALYTICAL DATA FOR THE SOIL AT THE FIELD STATION
(Verbruggen, 1984)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% sand</th>
<th>% silt</th>
<th>% clay</th>
<th>pH(H₂O)</th>
<th>% O.C % 100g</th>
<th>% B.S Fe %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-18/25</td>
<td>Ap</td>
<td>65</td>
<td>14</td>
<td>21</td>
<td>6.7</td>
<td>0.54</td>
<td>4.64</td>
</tr>
<tr>
<td>18/25-35</td>
<td>B21t</td>
<td>49</td>
<td>16</td>
<td>35</td>
<td>5.6</td>
<td>0.26</td>
<td>8.44</td>
</tr>
<tr>
<td>35 - 70</td>
<td>B22t</td>
<td>54</td>
<td>16</td>
<td>30</td>
<td>5.5</td>
<td>0.32</td>
<td>7.04</td>
</tr>
<tr>
<td>70 - 140</td>
<td>B3</td>
<td>51</td>
<td>14</td>
<td>35</td>
<td>6.5</td>
<td>0.16</td>
<td>9.36</td>
</tr>
</tbody>
</table>

TABLE 1 B - ANALYTICAL DATA FOR THE SOIL AT THE UNZA FARM
(Verbruggen, 1984)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>% sand</th>
<th>% silt</th>
<th>% clay</th>
<th>pH(H₂O)</th>
<th>% O.C % 100g</th>
<th>% B.S Fe %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-23</td>
<td>Ap</td>
<td>58</td>
<td>12</td>
<td>30</td>
<td>6.5</td>
<td>0.90</td>
<td>6.16</td>
</tr>
<tr>
<td>23-35/42</td>
<td>B21t</td>
<td>56</td>
<td>11</td>
<td>33</td>
<td>6.9</td>
<td>0.64</td>
<td>7.12</td>
</tr>
<tr>
<td>35/42-85</td>
<td>B22t</td>
<td>48</td>
<td>10</td>
<td>42</td>
<td>7.1</td>
<td>0.36</td>
<td>7.60</td>
</tr>
<tr>
<td>85 - 160</td>
<td>B3</td>
<td>44</td>
<td>13</td>
<td>43</td>
<td>7.4</td>
<td>0.24</td>
<td>8.56</td>
</tr>
</tbody>
</table>

Productivity of the two soils

Six crops have been grown simultaneously for two consecutive years on both locations. It can be seen from Table 2 that higher yields of groundnuts, maize, soyabees and wheat were achieved at the field station. In contrast, there were no marked differences for sorghum and sunflower. This can be partly explained as during the 1984/1985 season at the Field Station, sorghum suffered from bird attack while sunflower was infected by leaf blotch (*Seproria helianthi*). Both constraints resulted in an undesirable yield decrease. It can be observed that response to supplementary irrigation is higher for maize and sorghum but lower for groundnuts at the UNZA Farm compared to the Field Station. Soyabeen, sunflower and wheat at the two sites
responded in a similar way to supplementary irrigation. In addition Msoni (1985) and Daka (1985) conducted research on irrigated wheat and found that the Field Station Soil yielded an average of 3 606 kg/ha, while at the UNZA Farm a yield of only 3 142 kg/ha was obtained.

TABLE 2 - AVERAGE GRAIN YIELD IN Kg/ha OF VARIOUS RAINFOED CROPS DURING THE SEASONS 1983/1984 AND 1984/1985

<table>
<thead>
<tr>
<th>Crop</th>
<th>Field Station</th>
<th>UNZA Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfed only</td>
<td>Rainfed + Irrigation</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>1 979</td>
<td>2 421</td>
</tr>
<tr>
<td>Maize</td>
<td>7 379</td>
<td>8 320</td>
</tr>
<tr>
<td>Sorghum</td>
<td>3 745</td>
<td>3 832</td>
</tr>
<tr>
<td>Soyabean</td>
<td>2 709</td>
<td>2 795</td>
</tr>
<tr>
<td>Sunflower</td>
<td>1 944</td>
<td>1 918</td>
</tr>
<tr>
<td>Wheat</td>
<td>1 395</td>
<td>1 455</td>
</tr>
</tbody>
</table>

Physical characteristics

The bulk density (Table 3) is around 1.5 for all depths at the Field Station and for depths below 50 cm at the UNZA Farm. Measurements on the UNZA Farm soil, taken at 10 and 30 cm depths show densities of 1.71 and 1.76 respectively. These results are very high and would imply the possibility of poor/low porosity, structure, crust formation and low water intake rate. The UNZA Farm soil discussed here seems to have features comparable to the "hard setting" soil described by McDonald et al. (1984).
TABLE 3 - COMPARISON OF THE BULK DENSITY (g/cm³) BETWEEN THE FIELD STATION AND UNZA FARM SOIL

<table>
<thead>
<tr>
<th></th>
<th>Field Station</th>
<th>UNZA Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>soil depth (cm)</td>
<td>bulk density (g/cm³)</td>
<td>soil depth (cm)</td>
</tr>
<tr>
<td>10</td>
<td>1.44</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>1.49</td>
<td>30</td>
</tr>
<tr>
<td>50</td>
<td>1.50</td>
<td>50</td>
</tr>
<tr>
<td>80</td>
<td>1.47</td>
<td>80</td>
</tr>
<tr>
<td>120</td>
<td>1.49</td>
<td>145</td>
</tr>
</tbody>
</table>

The water characteristic curves at 10 cm and 80 cm depth for the two soils are presented in Fig. 1a and 1b, respectively. The difference between the soils is essentially in the amount of soil moisture available to plants. On these soils pF 2 and pF 3.5 are estimated to be good field values for field capacity and wilting point respectively. From Table 4, it can be seen that the water available to crops, when the soil is at field capacity to a depth of 100 cm, is 142 mm for the Field Station soil and 108 mm for the UNZA Farm soil. These results may also help to explain why the UNZA Farm soil is more responsive to supplementary irrigation.

Finally, the relationship between hydraulic conductivity and moisture content in the soil was determined in the field. The results are presented in Fig. 2. It is clear that all regression lines from the Field Station indicate higher hydraulic conductivity compared to those from UNZA Farm soil. Compared to the top-soils, subsoils have better hydrodynamic properties. This is most probably an indication of soil structure degradation in the top of the tropical soils. The Hydraulic conductivity of the Field Station soil is approximately ten times higher than that of the UNZA Farm soil. Transmission of water towards the root zone will thus be different for the two soils. Some results are presented in Table 5.
Figure 1a: Moisture characteristic curves of the Field Station soil at different depths

Figure 1b: Moisture characteristic curves of the UNZA Farm soil at different depths
Figure 2: Hydraulic conductivity as a function of moisture content.
TABLE 4 - MOISTURE CHARACTERISTICS OF THE TWO SOILS FOR A SOIL DEPTH OF 100 cm

Stock of soil water, expressed in mm

<table>
<thead>
<tr>
<th>Moisture characteristics</th>
<th>Field Station</th>
<th>UNZA Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field capacity (pF 2)</td>
<td>313</td>
<td>298</td>
</tr>
<tr>
<td>Wilting point (pF 3.5)</td>
<td>171</td>
<td>190</td>
</tr>
<tr>
<td>Plant available water (pF 2 - pF 3.5)</td>
<td>142</td>
<td>108</td>
</tr>
</tbody>
</table>

TABLE 5 - COMPARISON OF SOME UNSATURATED HYDRAULIC CONDUCTIVITIES (mm/h), BASED ON DATA BETWEEN 0 to 150 cm SOIL DEPTH

<table>
<thead>
<tr>
<th>Moisture content (cm³/cm³)</th>
<th>Field Station</th>
<th>UNZA Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>1.14 10 exp-2</td>
<td>1.48 10 exp-3</td>
</tr>
<tr>
<td>0.30</td>
<td>33.77 10 exp-2</td>
<td>55.08 10 exp-3</td>
</tr>
<tr>
<td>0.35</td>
<td>998.15 10 exp-2</td>
<td>2046.86 10 exp-3</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Two soils of the same family belonging to the Oxic Paleustalf subgroup have been studied. Although identical in classification, it was found that the one soil produces yields up to 1.4 times higher than the other.

There were major differences in the physical conditions of the soils. The UNZA Farm site has bulk densities as high as 1.76 g/cm³ in the upper part of the profile; an average amount of crop available water of only 0.11 cm³/cm³ and an unsaturated conductivity ranging from 0.001 (at θ = 0.25 cm³/cm³) to 2 mm/h (at θ = 35 cm³/cm³).
The Field Station site has a better physical condition. The bulk density is 1.5g/cm$^3$, the average amount of available water is 0.14 cm$^3$/cm$^3$, and the unsaturated hydraulic conductivities are 0.01 and 10mm/h respectively.

It is thus evident that in some of these red soils, physical degradation of the top soil exists. Soils of the same family can have very different water balances, which affects crop production seriously. The magnitude of the physical differences between these two soils is such as to probably warrant the recognition of these soils as two different series when the definition of Zambian soil series is completed. However, it is also felt that more attention should be paid to the physical attributes of soils for reclassification even at the higher levels of the system.

ACKNOWLEDGEMENTS

The University of Zambia (UNZA) and the Belgian Administration for Development Cooperation (BADC) are thanked for funding the research. Dr Hartmann (1985), a missioner, sponsored by IAEA, was most helpful in advising on soil physical characterisation.

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Abbreviations

S.M.S.S  - Soil Management Support Service

Z.M.A.W.D.  - Zambia Ministry of Agriculture and Water Development
A STUDY OF ZAMBIA'S MAKENI SERIES WITH EMPHASIS ON EXCHANGE PROPERTIES AND RELATED MANAGEMENT ASPECTS

BY

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SUMMARY

The Makeni soil series is introduced and identified as a fertile soil for arable use but its classification as a series is considered too broad and requires refining. Changes in fertility are considered. Emphasis is placed upon the consequences and remedies of soil acidity.

INTRODUCTION

Certain red clay soils with relatively high effective cation exchange capacity (ECEC), high base saturation consistent with a pH status of between 5.0 - 6.0 (1:2 v/v 0.01M CaCl₂) may be considered to represent the greatest potential fertility for the upland plateau soils of Zambia. With good physical attributes in addition, they are an excellent material for both rainfed and irrigated arable agricultural activities. These soil systems would fall into the moderately leached group of red clays of Chileshe and Wen (1986). Soils of the kind represented by the Makeni series are confined to the Southern Provinces of Zambia and are well represented but of limited distribution in the Central, Eastern and Lusaka Provinces where they are often derived from basic rocks. A pedological description with type data obtained at a site in Eastern Province is shown in Table 1.
**TABLE 1. ANALYTICAL DATA FOR MAKENI SOIL SERIES (A PROFILE LOCATED AT MTIRIZI STATE FARM EASTERN PROVINCE)**

**Grain size. mm**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Clay %</th>
<th>Silt %</th>
<th>F. sand %</th>
<th>M. sand %</th>
<th>C. sand %</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>44</td>
<td>35</td>
<td>13</td>
<td>4</td>
<td>4</td>
<td>C</td>
</tr>
<tr>
<td>9-21</td>
<td>68</td>
<td>25</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>C</td>
</tr>
<tr>
<td>21-44</td>
<td>70</td>
<td>23</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>C</td>
</tr>
<tr>
<td>44-77</td>
<td>64</td>
<td>27</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>C</td>
</tr>
<tr>
<td>77-120</td>
<td>62</td>
<td>27</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>C</td>
</tr>
<tr>
<td>120-170+</td>
<td>58</td>
<td>30</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>C</td>
</tr>
</tbody>
</table>

**Chemical Data**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>15.0</td>
<td>5.4</td>
<td>0.36</td>
<td>0.02</td>
<td>20.8</td>
<td>-</td>
<td>-</td>
<td>2.24</td>
<td>3</td>
<td>5.5</td>
</tr>
<tr>
<td>9-21</td>
<td>11.8</td>
<td>4.9</td>
<td>0.11</td>
<td>0.02</td>
<td>16.8</td>
<td>-</td>
<td>-</td>
<td>0.81</td>
<td>3</td>
<td>5.4</td>
</tr>
<tr>
<td>21-44</td>
<td>7.8</td>
<td>2.7</td>
<td>0.05</td>
<td>0.01</td>
<td>10.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>4.9</td>
</tr>
<tr>
<td>44-77</td>
<td>6.7</td>
<td>2.1</td>
<td>0.03</td>
<td>0.02</td>
<td>8.8</td>
<td>24</td>
<td>37</td>
<td>-</td>
<td>3</td>
<td>5.0</td>
</tr>
<tr>
<td>77-120</td>
<td>6.7</td>
<td>2.0</td>
<td>0.05</td>
<td>0.02</td>
<td>8.7</td>
<td>20</td>
<td>44</td>
<td>-</td>
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<td>5.7</td>
</tr>
<tr>
<td>120-170+</td>
<td>6.7</td>
<td>1.5</td>
<td>0.02</td>
<td>0.02</td>
<td>8.2</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>5.6</td>
<td></td>
</tr>
</tbody>
</table>
LAND USE AND FARMING PRACTICE

For land use purposes, the Makeni soil, usually on gently sloping land of the upland plateau, is a class 1 clay with an effective depth adequate for most crops. Sticky and plastic when wet and hard when dry, there are time-related constraints placed upon land preparation and in-crop cultivations. Though only moderately permeable, the soils respond well to irrigation and even after prolonged heavy rainfall, any period of waterlogging is of short duration. Water holding capacity has been estimated at 30% by volume and available water at 13%.

On commercial farms, hard pans have been noted within the soils just below the plough layer. The phenomenon is commonly attributed to the effects of cultivation. Ripping every few years with a view to improving conditions for rooting is a common practice on such soils.

These soils are used for a variety of agricultural purposes. When the woodland is opened and cultivated for the first time, the Makeni soils are fertile and well buffered. Thus, with moderate care, they can be maintained for sustained agricultural production as readily as any soils in Zambia, and with good management, high yields can be obtained.

VARIATION IN THE MAKENI SERIES

As an established series, there is a problem with the Makeni concept in that it may be too broadly defined. This problem can be illustrated by the discussion below.

A member of this series from a woodland site in the Eastern province has satisfactory pH status throughout, good rooting depth and an exchange complex dominated by calcium and magnesium ions. The subsoil ECEC (21cm - 120cm) averages out at 8 m.e. 100g/soil while the topsoil, undoubtedly influenced by the organic fraction, is 19 m.e. per 100g soil. The topsoil potassium level is satisfactory but the potassium
level in the subsoil is much lower. This aspect may in part be due to potassium fixation. The high clay content and associated iron oxides may be responsible for fixation of some of the phosphate. In an investigation of sorption/desorption on another member of the series from a location near Lusaka, 120 µg P/g soil was required to obtain a soil solution P of 0.2 ppm P in the soil. A recovery of 60% was obtained by shaking for six hours in 0.01 M CaCl₂. For sustained production, it may be assumed that, at least, regular maintenance dressings of potassium and phosphate will be required. In almost all cases, responses to nitrogen would be expected.

Two points emerge. The description suggests a good arable soil with constraints that can be readily overcome in many farming systems. Yet for this and many soil types too little is known of behaviour under different management practices. There is a paucity of information about behaviour and temporal change in relation to agricultural activity for there have been no in-depth studies of a benchmark site for this soil type. Indeed even with in-depth knowledge from a benchmark site, extrapolation to other members of the series may be erroneous.

The example in Table 1 and Appendix 1 has an average exchange capacity (CEC) determined in the Bu 2 and Bu 3 of 22 m.e. per 100g soil and for base saturation about 20-25% could be expected if the dominant clay mineral was kaolinite. Thus, with the higher base saturation here, other minerals, possibly 2:1 intergrades associated with oxides and with pronounced variable charge characteristics, may be expected. With CEC established at pH 7.0, the considerable difference between ECEC and CEC suggests pH-dependent charge as an important component of the system. This use of CEC and base saturation is the historical form of reporting and may be misleading. Nevertheless, these data do enable some separation between members of the series as can be seen by comparison with another example, the profile from Makeni itself as given below.
The data of Table 2 for the soil at Makeni stand in considerable contrast to those in Table 1. The high CEC values recorded in Table 2 and the base saturation at 60% or greater provides a marked contrast to the 41% of the Eastern province soil illustrated in Table 1. Investigations have shown that both soils are effectively base saturated. This finding agrees with the work of Coleman et al. (1959) on some soils of North Carolina. In the topsoil, the ECEC of the mineral material is distorted by the higher organic content. In the subsoil, the Eastern Province soil has an ECEC of around 9 m.e. % while at Makeni the figure is around 14 m.e. %, over the same depth range from about 20-120 cm. This is an important fertility distinction.

For soil at Makeni some mineralogical data is available in support. The fine sand mineralogy, illustrated in Table 3, is indicative of the passing of a weathering front through the profile. There is apparent concentration of quartz in the upper part and an increase of plagioclase down the profile. The mineral suite is reasonably in accord with development from the underlying gabbro, though some colluvial mixing may have occurred. Hypersthene and olivine as magnesium rich minerals associated with actinolite in the gabbro, are not represented in either the saprolite or the soil material, suggesting advanced weathering throughout the profile. In
the profile, the presence of biotite and plagioclase implies considerable reserves of calcium and potassium.

**TABLE 3. SOME MINERALS IDENTIFIED IN THE LESS THAN 250µm SAND FRACTION OF A MAKENI SERIES AT MAKENI**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Mineral</th>
<th>Estimated %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-17</td>
<td>biotite</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>quartz</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>opaque</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>tourmaline</td>
<td>&lt;5</td>
</tr>
<tr>
<td>37-80</td>
<td>biotite</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>epidote</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>quartz</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>opaque</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>tourmaline</td>
<td>5</td>
</tr>
<tr>
<td>115-185</td>
<td>biotite</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>epidote</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>quartz</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>opaque</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>tourmaline</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Saprolite</td>
<td>biotite</td>
<td>&lt;5</td>
</tr>
<tr>
<td>320</td>
<td>quartz</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>magnetite</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>muscovite</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>50</td>
</tr>
<tr>
<td>Gabbro</td>
<td>Actinolite</td>
<td>Not estimated</td>
</tr>
<tr>
<td>Pebble</td>
<td>biotite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypersthene</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Magnetite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Olivine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td></td>
</tr>
</tbody>
</table>

X-ray diffraction demonstrated a mineral suite comprising biotite, feldspar, halloysite, illite, kaolinite, quartz, smectite, talc and vermiculite. 2:1 minerals may be interlayered and intergraded and possible combinations are smectite/chlorite, smectite-illite and smectite-vermiculite. Peaks for 2:1 minerals were particularly well established in the B horizon where small kaolinitic peaks, though present, were somewhat diffuse. Kaolinite peaks are more consistent in the A horizon.
Within the rooting depth, there are undoubtedly nutrient reserves though little is known of the supplying power of the material. In the case of potassium the presence of vermiculite with illite creates a strong possibility for fixation, yet the exchangeable values for potassium below the upper layer would be described as rich in the interpretative scheme adopted by the Ministry of Agriculture of Zimbabwe. This is in marked contrast to the example from Eastern Province.

Another feature may be contrasted. At Makeni there are high levels of exchangeable magnesium in relation to calcium. The Ca/Mg ratios of about 0.7 in the upper part of the profile and 0.4 at depth for the soil at Makeni, illustrate a problem for land managers, for these values are well below the lowest acceptable limit suggested by Fauck et al. (1969). Put another way, in relation to ECEC, magnesium occupies 55% of the exchange complex in the A horizon (0-9cm) and 60% in the Bt 1 at Makeni (9-21cm). The corresponding values for calcium are 44% and 37%. In 'normal' situations magnesium might be expected to occupy 4-20% of the exchange complex.

This sort of contrast may be limited in a geographic sense. In the Lusaka area, the fertile red soils are associated with underlying metamorphic limestones, dolomites and intrusive gabbro. In some localities, the gabbro is close to the surface and in others rises above the general level of the landscape as small outlying hills. It is in the colluvial materials near the gabbro hills and where gabbro lies immediately below the soil, that high magnesium levels have been recorded.

Thus, the type concept of the Makeni series is of a fertile red clay very suitable for arable agriculture. It is well buffered and various farming systems are practised by commercial and smallholder farmers, especially around Lusaka under both irrigated and rainfed conditions. Yet there are variants, with
contrasting attributes of importance to the management of these soils suggesting that some refining and review of the Makeni series is required.

Under cultivation, two distinct trends occur, one towards alkalization and one towards acidification. These trends provide further confusion within the series.

VARIABILITY OF ACIDITY

In the north of the country, topsoil and subsoil acidity are ubiquitous and economic amelioration of the soil to provide sufficient rooting depth remains an intractable problem. On the Makeni soils, it is topsoil acidity only that is generally considered to prevail, as demonstrated in Table 4. Acidity trials with beans amply demonstrate the severe consequences of acidification through yield depression.

TABLE 4. SOME EXAMPLES OF ACIDITY OBTAINED BY SAMPLING A MAKENI SERIES SOIL AT GOLDEN VALLEY FARM/ NEAR LUSAKA

<table>
<thead>
<tr>
<th>Example</th>
<th>Depth (cm)</th>
<th>Aluminium 4 ppm 0.02M CaCl2</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00-15</td>
<td>4</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>0</td>
<td>5.3</td>
</tr>
<tr>
<td>2</td>
<td>00-15</td>
<td>13</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>4</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>1</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>45-60</td>
<td>0</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>00-15</td>
<td>30</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>15</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>14</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>45-60</td>
<td>5</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>60-75</td>
<td>1</td>
<td>4.7</td>
</tr>
</tbody>
</table>
Example number 3 above, relates to spots in which deep-seated acidity may occur either due to topographic effects or may have been management-induced.

Together with horizontal variability, the effect is one of 'acid holes' in the land. Cases of vertical variation are usually associated with micro-depressions. There, deep seated acidity is to be found. In respect of the data in Table 5 the best and worst conditions are associated with a drop in elevation of just 12 cm. These depressions can be a few to several hundred metres across. The highest levels of extractable aluminium and lowest pH values are usually found in the depressions. The reason for this is open to debate.

Notes on methods used

Calcium, magnesium and potassium were extracted by leaching with ammonium acetate, buffered to pH 7.

Aluminium for ECEC was extracted by leaching with 1M potassium chloride.

Hydrogen and aluminium as components of exchangeable acidity were determined by repeated shaking with potassium chloride, centrifugation and eventual titration.

Manganese was determined by shaking with 0.02M calcium chloride.

Potassium was determined by flame photometry and other cations by atomic absorption spectrophotometry.

ECEC is the sum of exchangeable bases plus aluminium extracted by leaching.

ECECl is the sum of exchange bases plus the exchangeable acidity. Aluminium saturation percentage is derived from this value.

pH was determined on a 1:2 v/v basis in 0.01M calcium chloride. Samples were composites from five subsamples collected within each plot.
CONCLUSION

The Makeni series, which can be classed in soil taxonomy as an alfisol or mollisol, is considered as a fertile soil, very suitable for agricultural production. However, there are variants that merit special consideration such as the illustrative example with a high calcium: magnesium ratio.

It has been demonstrated that there is sufficient variation in properties and response to management among soils of this series to warrant further investigation of properties that are important for management inorder to reach a series classification that is based on parameters that are mutually exclusive.

ACKNOWLEDGEMENTS

Much of the work recorded in this paper has been undertaken under the authority of the Director of Agriculture, Mr Nicholas Mumba. The Acting Chief Agricultural Research Officer, Dr Bharati Patel has offered much practical assistance. Indeed without the encouragement of both officers this presentation would not have been possible and the authors are grateful to them both.

The views expressed in the paper are solely those of the authors and do not necessarily represent those of the Department of Agriculture or any other agency of the Government of the Republic of Zambia.

APPENDIX 1 : PROFILE DESCRIPTION OF MAKENI SERIES

Location: Mtirizi State Farm, Eastern Province
Soil Series: Makeni
Land Use Class: Cl
Physiography: Very gently sloping plateau
Elevation: c.750m
Parental Material: Metacarbonate rocks
Vegetation/Land Use: Combretum-Pterocarpus woodland
Slope: less than 1%
Permeability: Moderate
Author: D.B. Dalal-Clayton
Date Sampled: 29-10-1981
<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (CM)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ah1</td>
<td>0-9</td>
<td>Dark reddish brown (5YR 3/2 and 5YR 3/3) moist and dry; organic stained; clay; fine and medium, moderate, sub-angular blocky; sticky and plastic; friable moist; hard dry; many fine and medium, few coarse pores; many fine and medium, few coarse, roots; abrupt, smooth boundary.</td>
</tr>
<tr>
<td>Ah2</td>
<td>9-21</td>
<td>Dark reddish brown (5YR 2/3 and 5YR 3/3) moist and dry; organic stained; clay; fine and medium, strong, sub-angular blocky; sticky and plastic, friable moist, very hard dry; broken, moderately thick cutans; many find and medium, few coarse, pores; many fine and medium, few coarse, roots; clear, smooth boundary.</td>
</tr>
<tr>
<td>Bul</td>
<td>21-44</td>
<td>Dark reddish brown (2.5YR 3/4 moist and red (2.5YR 4/6) dry, clay; fine and medium, strong sub-angular blocky, very sticky, very plastic, friable moist, extremely hard dry; broken, moderately thick cutans; many fine and medium, few coarse pores; many fine and medium, few coarse pores; many fine and medium, common coarse, roots; gradual, smooth boundary.</td>
</tr>
<tr>
<td>Bu2</td>
<td>44-77</td>
<td>As Bul; but many fine, common medium and few coarse, roots; few fine quartz gravel; diffuse, smooth boundary.</td>
</tr>
<tr>
<td>Bu3</td>
<td>77-120</td>
<td>As Bu2; but common fine quartz gravel.</td>
</tr>
</tbody>
</table>
REFERENCES


THE INTERACTION OF LIMING AND PHOSPHORUS ADSORPTION
ON TWO RED SOILS FROM ZAMBIA

R.F.P. DYNODT and T.M. MWAMBASI
Department of Soil Science, University of Zambia
P.O. Box 32379, Lusaka

INTRODUCTION

The availability of phosphorus in red soils of the tropics and subtropics is governed mainly by pH and charge distribution, which in their turn are dependent on clay mineralogy and organic matter content (Lopez-Hernandez and Burnham, 1973; Mendez and Kamprath; 1978; Murmann and Peech 1969; Amyth and Sanchez, 1980). The combination of these factors will ultimately lead to precipitation and/or adsorption reactions, which lead to fixation. Precipitation is essentially a transformation of the amorphous to the crystalline phase. The adsorption situation is less clear, but primarily involved either a coating of the adsorbed P by sesquioxides in acid soils or the formation of a binuclear complex on the sesquioxides or on the edges of clay minerals, (Biermans 1977).

This fixation may not be considered as a totally irreversible process, but rather as an increase of the capacity factor at the expense of the intensity. If the intensity falls below a certain critical level (specific for each crop) deficiency will occur (Fox and Kamprath, 1970). To make a distinction between adsorption and precipitation reactions, there exist certain chemical characteristics such as:

1. Reaction time: adsorption is a rapid process and will be completed in less than 48 hours. However, this is not an exclusive characteristic of adsorption.

2. The cation concentration of the soil solution must exceed a certain level in order for Fe-, Al- or Ca-phosphates to precipitate. However, in view of the complex reaction products which are possible, these levels are hard to determine.
3. Adsorption can be described by a Langmuir isotherm. However, conditions on the soil colloidal surface do not conform with the physico-chemical requirements of the theoretical model, viz: uniformity of adsorption energy and absence of interaction between adsorbed and non-adsorbed ions.

4. Adsorbed P remains isotopically exchangeable. This is probably the only unambiguous indication.

The possible reactions of phosphate in a red soil over a wide pH-range are thus complex and difficult to determine. Through certain simple experiments, combining different factors, several aspects of P adsorption are examined in this paper.

GENERAL SOIL CHARACTERISTICS

The two soils under study are situated at the University Farm, about 20 km east of Lusaka. Soil A was characterized as a fine-loamy Rhodic Paleustalf, while soil B has been classified as a sandy-clay Rhodustult. The distance between the two soils is about 500 m. Soil A is under continuous cropping with irrigation during the dry season, while soil B is only cultivated during the rainy season. Samples were taken from the top layer (0-20 cm) and from the subsoil (20-50 cm). General characteristics are listed in table 1.

TABLE 1: GENERAL SOIL CHARACTERISTICS

<table>
<thead>
<tr>
<th>Depth/Soil</th>
<th>pH-water</th>
<th>Exchangeable Base (meq/100 g)</th>
<th>Sum bases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>K</td>
<td>Na</td>
</tr>
<tr>
<td>0-20 A</td>
<td>6.9</td>
<td>1.51</td>
<td>0.23</td>
</tr>
<tr>
<td>20-50 A</td>
<td>6.9</td>
<td>0.63</td>
<td>0.19</td>
</tr>
<tr>
<td>0-20 B</td>
<td>4.6</td>
<td>2.34</td>
<td>0.34</td>
</tr>
<tr>
<td>20-50 B</td>
<td>4.6</td>
<td>0.42</td>
<td>0.20</td>
</tr>
</tbody>
</table>
From Table 1 it is clear that soil B is a typical acid soil, with a rather high amount of exchangeable acidity, while Soil A is neutral with satisfactory mineral fertility characteristics and a completely base saturated exchange complex. Both soils have a moderately low to low organic matter content and soil B has about 80 to 60% more clay in top- and subsoils respectively.

P-ADSORPTION ISOTHERMS

One of the most important features in terms of P behaviour is the adsorption isotherm. Fig 1 shows the adsorption isotherms of the two topsoils in comparison to topsoils from other parts of the world. It has been assumed that an intensity of 0.2 ppm P in solution is the minimum requirement for adequate plant growth. This level then is considered as the agronomically relevant estimate of P-fixation (Sanchez and Uehara, 1976). Thus the term "fixed P" means the amount of P sorbed to leave 0.2 ppm P in solution. This critical value is an estimate and certainly depends on the nature of the crop, but in a number of experiments it has been found to be a reasonable approximation for many crops. Soils that require additions of 150 mg P/kg or more in order to provide 0.2 ppm P in solution are considered to be high P-fixing soils. Under this assumption, soil B has to be considered as a high P-fixing soil (addition of 200 mg P/kg or 400 kg P/ha needed to provide 0.2 ppm), while soil A is not (only about 50 mg P/kg needed). Obviously the high clay content and the acidity of soil B enhance its capacity to sorb and fix substantial quantities of P.

Soil test data for available P by the Bray II method showed 54 and 36 ppm P for topsoil A and B resp., and 25 and 21 ppm P for the subsoils. These values are quite high taking into account the normal ratings for this soil
Figure 1: Phosphate adsorption isotherms for a Ustoxic Paleustult and an Oxic Paleudult previously incubated with various rates of lime and phosphorus (Friesen et al. 1980)

Figure 2: Effect of shaking time on the relationship between pH and soluble phosphorus in an Oxisol (Amarasiri and Olsen 1973)
test (i.e. higher than 25 ppm is considered as rich in available P). However, clear responses to P-dressings of 100 kg/ha have been obtained for maize on soil B, and even on soil A, especially where the subsoil had been exposed after levelling. The discrepancy between soil test and adsorption isotherms may indicate the unsuitability of the Bray II method for Zambian soils, or at least the need for a recalibration.

Fig. 2 shows the adsorption isotherms for both top- and subsoils. Clearly, the subsoils have a higher fixing capacity, and the added P remains more labile in the topsoil. Since the pH-values for both layers are identical for both soils. Differences must be due to the small increase in clay content with depth, but mainly to the decrease in organic matter content (Table 1). It has been shown that organic radicals can block exposed hydroxyls on the surface of Fe or Al oxides, and thus decrease P-fixture capacity (Sanchez and Uehara, 1976).

Adsorption isotherms are often transformed through the Langmuir equation, which gives the relation between the equilibrium concentration (C) and a term C/x/m, which represents the equilibrium concentration divided by the amount of P adsorbed. The relation should fit a straight line of the form: C/x/m = 1/b + c/b, in which b is the adsorption maximum and k is a measure of the adsorption energy. b is thus a quantity parameter, and k is related to the intensity factor. It is not the purpose of this paper to go into a critical discussion concerning the absolute physical values of these two parameters. They have, however, proved useful in comparing different soils and in providing certain information regarding the adsorption mechanism. Table 2 lists the Langmuir expressions for the four soils with their correlation coefficients and the respective parameters derived from these expressions.

**TABLE 2 : LANGMUIR PARAMETERS**

<table>
<thead>
<tr>
<th>Depth/Soil</th>
<th>Expression</th>
<th>r</th>
<th>ads. max. (b) (ppm)</th>
<th>bond. energy (k) (1/ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20 A</td>
<td>C=56+16C/x/m</td>
<td>.8920*</td>
<td>160</td>
<td>0.29</td>
</tr>
<tr>
<td>20-50 A</td>
<td>C=28+19C/x/m</td>
<td>.9169*</td>
<td>518</td>
<td>0.68</td>
</tr>
<tr>
<td>0-20 B</td>
<td>C=6+14C/x/m</td>
<td>.9834**</td>
<td>713</td>
<td>2.34</td>
</tr>
<tr>
<td>20-50 B</td>
<td>C=5+14C/x/m</td>
<td>-9847**</td>
<td>691</td>
<td>2.92</td>
</tr>
</tbody>
</table>
All correlation coefficients were significant at least at the 5% level. The adsorption maxima of both acid soils were higher than those of the top- and subsoils of site A. However the differences are not very large (20-30%). Differences were more marked in terms of the intensity factor, where the bonding energy of soil B is about 5 - 10 times higher than that of soil A. Surface soils appear to possess a higher adsorption maximum but a lower bonding energy.

**P-ADSORPTION AND LIMING**

Red, acid soils are normally limed in order to eliminate Al toxicity and to raise the base saturation. Results are listed in Table 3.

**TABLE 3:** pH AND Bray II - P OF THE LIMED ACID SOILS

<table>
<thead>
<tr>
<th>Soil</th>
<th>pH 0-20 cm</th>
<th>Bray-P</th>
<th>pH 20-50 cm</th>
<th>Bray-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.9</td>
<td>47</td>
<td>6.9</td>
<td>30</td>
</tr>
<tr>
<td>B</td>
<td>4.4</td>
<td>41</td>
<td>4.6</td>
<td>19</td>
</tr>
<tr>
<td>B+2t/ha</td>
<td>5.2</td>
<td>36</td>
<td>5.1</td>
<td>19</td>
</tr>
<tr>
<td>B+5t/ha</td>
<td>6.5</td>
<td>35</td>
<td>6.0</td>
<td>16</td>
</tr>
<tr>
<td>B+10t/ha</td>
<td>7.3</td>
<td>32</td>
<td>6.7</td>
<td>13</td>
</tr>
</tbody>
</table>

The pH of the subsoils treated with equal amounts of lime, did not increase to the same extent as the topsoils, especially at higher liming rates. Data concerning the free iron content are not yet available, but a higher amount of sesquioxides in the subsoil could account for the higher buffering capacity. Extractable P showed a gradual decline with increasing pH. The Bray II method uses an extracting solution buffered at pH 1.6, and has generally been recommended for acid soils since at higher pH values some of the extracting power might be lost, with would account for the decline in extractable P.

Adsorption of P as a function of the different lime treatments was measured by adding 200 ppm P (approx. 500 kg P/ha), equilibrating for 48 hours in 0.01 M CaCl₂ and measuring the final solution concentration. Results are given in Table 4.
TABLE 4: EQUILIBRIUM P-CONCENTRATIONS AFTER ADDITION OF
200 mg P/KG SOIL (IN ppm)

<table>
<thead>
<tr>
<th>Soil</th>
<th>0-20 cm</th>
<th>20-50 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.70</td>
<td>1.18</td>
</tr>
<tr>
<td>B</td>
<td>0.37</td>
<td>0.17</td>
</tr>
<tr>
<td>B+2t/ha</td>
<td>0.46</td>
<td>0.21</td>
</tr>
<tr>
<td>B+5t/ha</td>
<td>0.48</td>
<td>0.28</td>
</tr>
<tr>
<td>B+10t/ha</td>
<td>0.20</td>
<td>0.19</td>
</tr>
</tbody>
</table>

In the surface soil of site B, P-solubility remains at a maximum level between pH 5.0 to 6.5 and drops sharply above pH 7.0. For the subsoils, maximum solubility is more clearly defined around pH 6.0, and starts declining at pH values above 6.5. P-solubility for soil B never reached the solubility level of soil A, and, for the subsoils, remained close to the critical level of 0.2 ppm, even after additions equivalent to 500 kg P/ha.

P-SORPTION AND CHARGE DISTRIBUTION

An important consequence of liming or pH-manipulation is its influence on the charge distribution of the exchange complex. P-sorption or fixation has also been reported to increase the negative charge of red soils (Obihara and Russell, 1972; Sawhney, 1974).

The following experiment was carried out on the limed and unlimed soils of site B. A relatively large amount of P, 500 mg P/kg P/ha, was added to the different soils, which were subsequently kept at field capacity for 48 hours, air dried and crushed to pass a 2 mm sieve. 10 g of each soil was mixed with an equal amount of sand, placed in a percolation tube and leached with 250 ml of unbuffered 1 N KC1, in order to displace the Ca and to saturate the adsorption complex with K. After washing with ethanol, the K-saturated soils were leached with 1 N NH₄OAc at pH7, in order to displace the adsorbed K, which is expected to give a measure of the amount of negative charges. A final washing/leaching with NaHCO₃ (pH 8.5), or Olsen's extractant gives an estimate of the availability of the fixed or adsorbed P. The entire procedure was also carried out on the same soils, untreated with P, in order to detect differences in charge distribution due to eventual P-fixation.
Table 5 shows the amount of Ca desorbed from the soils by 1 N KC1. Obviously liming increased the amount of exchangeable Ca in top- as well as subsoils. Differences between P-treated and untreated soils were not substantial, except for the highest liming rate of the subsoils, where about 1 meq Ca/100g less was adsorbed after treatment with 500 ppm P. Since all soils were treated with equal amounts of lime, and stored in air-tight containers, no losses due to leaching could have occurred. The only way in which such an amount of Ca could become unavailable is through precipitation of CaHPO\textsubscript{4}. The formation of this precipitate apparently did not take place in the topsoils where interference with organic matter probably accounts for a situation where Ca and P can coexist in solution at higher activities which, under normal circumstances, would exceed the solubility product (log K = -6.78).

<table>
<thead>
<tr>
<th>Soil</th>
<th>0-20 cm without P</th>
<th>0-20 cm with P</th>
<th>20-50 cm without P</th>
<th>20-50 cm with P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>1.42</td>
<td>1.32</td>
<td>1.21</td>
<td>1.30</td>
</tr>
<tr>
<td>B+2t/ha</td>
<td>2.54</td>
<td>2.60</td>
<td>2.28</td>
<td>2.36</td>
</tr>
<tr>
<td>B+5t/ha</td>
<td>3.88</td>
<td>3.45</td>
<td>3.65</td>
<td>3.78</td>
</tr>
<tr>
<td>B+10t/ha</td>
<td>6.21</td>
<td>6.92</td>
<td>5.74</td>
<td>4.68</td>
</tr>
</tbody>
</table>

Results on the evolution of the negative charges are reported in Table 6. There is a pronounced increase with pH especially in the sub-surface layer. At low pH P-fixation does not seem to have an impact on charge distribution. At higher liming rates, however P-sorption does increase negative charges, except for the previously mentioned subsoil limed with 10 tons of lime per ha. Apparently, in that case, the sorption product was converted into a precipitate which instead of increasing the amount of negative charges, deceased them, probably by physically blocking the exchange sites. The increase in CEC upon sorption of P has been explained by the displacement of not only O\textsubscript{G}-groups, but also of octahedrally coordinated H\textsubscript{2}O from the surface of the sesquioxides. At low pH, where part of the OH-groups are protonated, displacement by an anion can produce an increase in CEC. At pH 5,
nearly all P is present as $H_3PO_4^-$ and exchange between $OH^-$ and $H_2PO_4^-$ will have no influence on the charges. Each increase can then only be due to an exchange between $H_3PO_4^-$ and $H_2O$. At higher pH more and more P will be present as $HPO_4^{2-}$ (50% as $H_2PO_4^-$ and 50% as $HPO_4^{2-}$ at pH 7.2) and in that case exchange with $OH^-$ as well as with $H_2O$ can produce a net increase in negative charge. At higher pH, less P will thus be needed to acquire the same CEC-increase, unless the adsorption complex is converted into a precipitation product. In this case, about 1.5 mmole of P was adsorbed per 100 g of soil, which gives an increase of 0.4 to 0.6 meq/100 g per mmole P adsorbed, which corresponds fairly well with data found by other authors (Mekaru and Uehara, 1972; Smyth and Sanchez, 1980).

<table>
<thead>
<tr>
<th>Soil</th>
<th>0-20 cm without P</th>
<th>0-20 cm with P</th>
<th>20-50 cm without P</th>
<th>20-50 cm with P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>7.04</td>
<td>7.23</td>
<td>5.21</td>
<td>5.33</td>
</tr>
<tr>
<td>B+2t/ha</td>
<td>7.00</td>
<td>7.59</td>
<td>5.52</td>
<td>5.80</td>
</tr>
<tr>
<td>B+5t/ha</td>
<td>7.53</td>
<td>8.02</td>
<td>6.36</td>
<td>6.98</td>
</tr>
<tr>
<td>B+10t/ha</td>
<td>8.39</td>
<td>9.24</td>
<td>7.82</td>
<td>7.25</td>
</tr>
</tbody>
</table>

The final leaching with NaHCO₃ (pH 8.5), did not differentiate between the liming treatments. Without addition of P, an average of 0.2 mg/l (10 mg P/kg) was extracted, after addition of 500 mg P/kg this increased to 3 mg/l (150 mg P/kg) for the topsoils. 10 mg P/kg is normally regarded as the critical level for the Olsen extractant. However, where normally a shaking period of 30 min has to be observed, these data can only serve as a crude guide.

**SUMMARY AND CONCLUSIONS**

Different aspects of P-sorption in terms of adsorption isotherms and with special emphasis on the effect of liming of an acid red soil from Zambia were investigated. It was found that that this soil was high in P-fixation capacity as compared to a neutral soil at the same
location. Differences were attributed to clay content and pH, and interpreted in terms of Langmuir parameters. Sub-surface soils invariably proved to be stronger P-fixers than their corresponding topsoils, which was attributed to differences in the organic matter.

Liming the acid soil improved P-solubility up to a pH range of about 6.0 to 6.5 after which a sharp decline in solubility took place. This was accompanied by a decrease in exchangeable Ca in the subsoil, which could be an indication of precipitation of a Ca-P compound. P-sorption caused an increase in negative charges, especially at pH values above 6.0.

The different trends observed through adsorption experiments, were not confirmed by classical soil tests such as Bray II and Olsen. Presumably these tests are not equally effective over wide pH ranges such as those encountered in this study.

ACKNOWLEDGEMENT

The authors wish to thank Belgian Development Cooperation: (BADDG) and the UNZA, for supporting this study.

REFERENCES


A COMPARISON OF THE USDA SOIL TAXONOMY
AND
THE ZIMBABWE SOIL CLASSIFICATION SYSTEM
WITH REFERENCE TO
SOME RED SOILS OF ZIMBABWE

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P O Box 167, Mount Pleasant
Harare, Zimbabwe

and

RAY R. WEIL
Department of Agronomy, University of Maryland
College Park, Md 20742, U.S.A.
SUMMARY

In order to enable Zimbabwean scientists to interact better with scientists from the international arena, the Zimbabwe soil classification system was compared to the United States Department of Agriculture Soil Taxonomy in terms of logical structure, diagnostic criteria and applicability to some red soils in central Zimbabwe. Soil Taxonomy places little direct emphasis on parent materials and surface soil texture in contrast to the Zimbabwe system. At the higher levels, especially the soil order, the Zimbabwe System is less quantitatively defined than is Soil Taxonomy. The use of the latter system requires a considerably larger number and more sophisticated type of laboratory analyses than does the Zimbabwe System.

Four pedons, two on mafic and two on granitic rocks, were studied. The first two pedons were classified as 7E and 5E, while the third and fourth were classified as 7G and 5G, respectively, in the Zimbabwe System. Using Soil Taxonomy, the first two pedons were classified as clayey mixed isothermic Oxic Haplustalf and the fourth as sandy, mixed isothermic Haplustalf.

INTRODUCTION

Soil forming processes are influenced by, among other things, the past and present physiographic and geological environment. Because the factors of soil formation differ from place to place, there is a great deal of geographic variability in soil properties. Some workers believe that it is important for different countries to develop their own national soil classification systems. They feel that a classification system that works well in one country may not necessarily be equally applicable to another country and that a classification system developed with local soil conditions and land use in mind will be most likely to provide meaningful groupings of the soils present in that region (Thompson and Purves, 1978). However, equally valid arguments can be made to support the use of a universal soil classification system both for correlation purposes and for enhancing comprehension and communication amongst scientists from different countries.
In Zimbabwe, the national classification system currently in use was evolved by J.G. Thompson and first published in 1965 and subsequently published with modifications by Thompson and Purves (1978). This system of soil classification will be referred to as the Zimbabwe System throughout this paper. Although agricultural workers and pedologists have found the Zimbabwe System to provide meaningful and useful classifications of Zimbabwe soils, like any other classification system, it should remain dynamic and be able to incorporate new ideas generated through continuing research both within Zimbabwe and internationally. It is useful to occasionally compare the Zimbabwe System with other classification systems as a means of monitoring its continued ability to enhance international comprehension and exchange of ideas amongst soil scientists.

In the study reported in this paper, we attempt to determine whether the differentiae used in the USDA Soil Taxonomy (Soil Survey, Staff 1975) and the Zimbabwe System, group soils differently or similarly into categories. This is of particular concern at this time, in view of the fact that Zimbabwe, and other countries in the SADCC region, might become collaborators in the program of International Benchmark Sites Network For Agrotechnology Transfer (IBSNAT), an international collaborative research program that coordinates both vertical and horizontal transfers of agrotechnology using the USDA Soil Taxonomy as the system of soil classification.

The Zimbabwe System groups soils principally, but not exclusively, on the basis of soil properties that reflect the degree of mineral weathering and leaching that have taken place in profiles as well as on the basis of properties inherited from specific parent materials (Thompson and Purves, 1978). The Zimbabwe System was built from the top down as is true of a number of European soil classification systems. Much more information is available on the characteristics of the broad groups at the upper levels of the classification system than on the specific soil series at the lowest level of the system. This top-down approach is in marked contrast to the bottom-up approach used by the USDA.
In the latter system, a great deal of information is available on specific soil series, and on the basis of this information, soil series are grouped together into higher level taxa, and so on. Thompson and Purves (1978) defend their methodology on the grounds that most of the important soil characteristics and properties necessary for classifying soils under their system are adequately defined at the higher taxonomic levels and therefore lack of data on soil series is not a serious limitation. They admit, however, that there is a rather poor definition of soils at the series level in the Zimbabwe System. There are few, if any, definite class limits defined for many soil series, and only a small proportion of the soil series probably existing in Zimbabwe have been classified to that level.

Another contrast between the Zimbabwe System and the USDA Soil Taxonomy is the degree of rigidity and specificity required in differentiating taxa at the highest taxonomic levels. Very rigidly specified boundaries between taxa increase the chance that very similar soils will be classified into different higher-level classes. Thompson and Purves (1978) imply that this type of classification "error" is more serious at higher levels in the taxonomy than at lower taxonomic levels. That is, it is more important that similar soils fall into the same soil order than that they fall into the same family or series. The differentiae for the soil orders in the Zimbabwe System are therefore purposely left rather vague and non quantitative. At lower levels the boundaries are specified in a more rigid, quantitative manner. In the USDA Soil Taxonomy, on the other hand, class boundaries are very rigidly specified at all levels of the taxonomy and "errors" in classification are clarified only at the subgroup level.

For example, in the Zimbabwe System the Kaolinitic order is defined as including all soils that are "markedly leached and weathered" and in which the clay fraction "consists predominantly of 1:1 lattice minerals especially kaolinite, together with an appreciable amount of free sesquioxides. Some 2:1 lattice clay minerals and some weatherable minerals remain in most of the less leached soils of this order". The Calcimorphic order is defined as including all soils that are "relatively unleached and unweathered". The clay fraction of these soils "contains
at least an appreciable portion of the relatively active, silica-rich 2:1 lattice clay minerals". Obviously such definitions at the highest level of classification leave a considerable amount of discretion to the trained pedologist who can group soils into the order in which they most logically fit without being limited by strict quantitative definitions. In the USDA Soil Taxonomy, by contrast, soil orders are defined principally by the presence or absence of diagnostic horizons which, in turn, are defined by specific morphological and analytical parameters. For example, the Alfisols, Oxisols and Ultisols are separated by the presence or absence of an argillic or an oxic horizon and by the percent base saturation at a specified depth in the profile.

The Zimbabwe Soil Classification System

There are four taxonomic levels in the Zimbabwe System of soil classification, the highest being the order and the second highest being the group. Within each group are the families, and within each family are the soil series. Table 1 lists the classification categories in both the Zimbabwe System and the USDA Soil Taxonomy. USDA Soil Taxonomy has two more levels of categorisation than does the Zimbabwe System, specifically the suborder and the subgroup levels. The four soil orders and eight soil groups of the Zimbabwe System are listed in Table 2. As indicated by the descriptions in Table 2, the four soil orders are differentiated principally on the basis of the degree of leaching and weathering and, in the case of the Natric order, on the basis of the amount of exchangeable sodium. The present paper will concentrate on Order III, the Kaolinitic soil order, as that is the order to which nearly all red soils in Zimbabwe belong (some shallow rocky red soils also belong to the Amorphic soil order).

The more quantitative and rigid nature of the definitions of the soil groups can be seen in the examples of three soil groups from the Kaolinitic soil order shown in Table 3. The three soil groups within this order are the Fersiallitic, the Paraferallitic, and the Orthoferallitic groups. These are differentiated principally on the basis of (1) the amount of 2:1 clays, (2) the amount of exchangeable bases per 100g of clay (S/C value) (3) the cation exchange capacity per 100g of clay (E/C value), (4) the amount of weatherable minerals remaining in the sand fraction and (5) in some cases, the percent base saturation. These are all properties that affect the fertility and
TABLE 1: HIERARCHICAL CATEGORIES IN THE ZIMBABWEAN SOIL CLASSIFICATION SYSTEM AND THE USDA SOIL TAXONOMY

<table>
<thead>
<tr>
<th>Zimbabwe Category</th>
<th>No. of Taxa</th>
<th>Taxonomy Category</th>
<th>No. of Taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order</td>
<td>4</td>
<td>Order</td>
<td>10</td>
</tr>
<tr>
<td>Group</td>
<td>8</td>
<td>Suborder</td>
<td>50</td>
</tr>
<tr>
<td>Family</td>
<td>50</td>
<td>Great Group</td>
<td>&gt;230</td>
</tr>
<tr>
<td>Series</td>
<td>many</td>
<td>Subgroup</td>
<td>&gt;1,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Family</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Series)</td>
<td>&gt;20,000</td>
</tr>
</tbody>
</table>

TABLE 2: SOIL ORDERS AND GROUPS IN THE ZIMBABWEAN SOIL CLASSIFICATION SYSTEM

<table>
<thead>
<tr>
<th>Order</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. AMORPHIC (little or no horizon development)</td>
<td>1. Regosol</td>
</tr>
<tr>
<td>II. CALCIMORPHIC (relatively unleached; high base sat'n; appreciable 2:1 lattice clays.)</td>
<td>2. Lithosol</td>
</tr>
<tr>
<td>III. KAOLINITIC (marked leaching and weathering, predominately 1:1 lattice clay minerals.)</td>
<td>3. Vertisol</td>
</tr>
<tr>
<td>IV. NATRIC (exchange complex dominated by sodium.)</td>
<td>4. Siallitic</td>
</tr>
<tr>
<td></td>
<td>5. Ferrallitic</td>
</tr>
<tr>
<td></td>
<td>6. Paraferrallitic</td>
</tr>
<tr>
<td></td>
<td>7. Orthoferrallitic</td>
</tr>
<tr>
<td></td>
<td>8. Sodic</td>
</tr>
</tbody>
</table>
### TABLE 3: DIFFERENTIAE FOR GROUPS IN THE KAOLINITIC SOIL ORDER

<table>
<thead>
<tr>
<th>Soil Group</th>
<th>Differentiating Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fersiallitic (5)</td>
<td>small amount of 2:1 clays S/C = 6 to 30; E/C = 12 to 35 base sat'n &gt; 80% if clayey texture some weatherable minerals in sand</td>
</tr>
<tr>
<td>Paraferrallitic (6)</td>
<td>no 2:1 clays &gt;5% weatherable minerals in sand S/C &lt; 6; E/C &lt; 12.</td>
</tr>
<tr>
<td>Orthoferrallitic (7)</td>
<td>no 2:1 clays &lt;5% weatherable minerals in sand S/C &lt; 5; E/C &lt; 11</td>
</tr>
</tbody>
</table>

### TABLE 4: SOME COMMON SOIL FAMILIES WITHIN THE KAOLINITIC ORDER IN THE ZIMBABWEAN SYSTEM

<table>
<thead>
<tr>
<th>Group</th>
<th>Family</th>
<th>Main Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5E</td>
<td>Red clays from mafic rocks</td>
</tr>
<tr>
<td></td>
<td>5A</td>
<td>Silty soils from siliceous meta sediments</td>
</tr>
<tr>
<td></td>
<td>5G</td>
<td>Coarse sandy soils from granite</td>
</tr>
<tr>
<td>6</td>
<td>6G</td>
<td>Coarse sandy soils from granite</td>
</tr>
<tr>
<td>7</td>
<td>7E</td>
<td>Red clays from mafic rock</td>
</tr>
<tr>
<td></td>
<td>7M</td>
<td>Fine sandy soils from sandstones</td>
</tr>
<tr>
<td></td>
<td>7G</td>
<td>Coarse sandy soils from granite</td>
</tr>
</tbody>
</table>
Within each soil group, soils are classified into a number of families. At the family level the classification is based primarily on soil properties that reflect the parent material from which the soil was formed. For the purpose of defining soil families, 12 different parent material groups are recognized in the Zimbabwe System. Table 4 describes seven soil families within the 3 soil groups of the Kaolinitic soil order. Four different parent materials are represented in this table. The soil family provides important information for the management of soils. For instance, within a given rainfall region, principal factors affecting soil management are the soil's parent material and the texture resulting from the influence of the parent material. Recommendations for the management of soils in Zimbabwe are often considered separately for sandy soils formed from granites as opposed to red clay soils formed from mafic rocks (for example, Grant, 1981; Tanner and Grant, 1977).

The lowest level in the Zimbabwe System is the soil series. Only a few of the series probably existing in Zimbabwe have been clearly defined. The criteria used in differentiating soil series are identical to those outlined in the Soil Survey Manual of the U.S. Soil Conservation Service (Soil Survey Staff, 1951). In the Zimbabwe System the classification of soil series is strongly influenced by the concept of the catena. As shown in Fig 1, soil series from several soil orders are defined with regard to their topographic position on the catena. A soil series is designated by a geographic name plus an Arabic numeral, a Roman letter, and a second Arabic numeral, for example Harare 5E.2. In this example 5 stands for Group 5, (the Fersiallitic group of the Kaolinitic order), the E stands for igneous and metamorphic mafic rocks other than basalt, giving rise to soils of high clay content, and the number 2 stands for the position in the soil catena, indicating an upper slope in this case. The catenal positions are numbered from the top of the slope down to the valley floor. A zero position indicates a rocky, shallow Lithosol at the crest of the hill. Position 1 indicates a fairly shallow soil, on a somewhat steep position with an only moderately leached profile. Position number 2 is generally occupied by a typical upland soil with a well developed profile. Position number 3 is the lower part of the
Figure 1.
Five soil series of the Salisbury (Harare) catena on mafic rock. The first digit indicates the soil group, the letter indicates the family and the final digit indicates the slope position.
slope where some evidence of hydromorphy can be seen in the lower part of the profile. Positions 4 and 5 are in the valley bottoms where pronounced hydromorphy and usually Calcimorphic soils or Vertisols are found. Thus a typical catena on mafic rocks may have representatives of 4 different soils orders.

**USDA Soil Taxonomy**

In the USDA Soil Taxonomy, six different taxonomic levels are used to categorize the world's soils (though, strictly speaking, the soil series level is not a part of the Soil Taxonomy). At the highest level, soils are divided into 10 soil orders as described in Table 5. Soils in one order, Histosols are dominated by organic matter. The soils in the other nine orders are essentially mineral soils. The Alfisols, Ultisols and Oxisols in tropical areas may be considered to represent a weathering sequence somewhat analogous to the Fersiallitic, Paraferallitic and Orthoferrallitic groups within the Kaolinitic order of the Zimbabwe System. However an examination of the boundary criteria makes it clear that the boundaries between the 3 groups in the Zimbabwe System and between the 3 orders of the USDA Soil Taxonomy do not always coincide. Also many Alfisols would fall into the Calcimorphic Order, especially the Siallitic group in the Zimbabwe System. Table 6 gives a brief description of the criteria for the Alfisols, Ultisols and Oxisols in the USDA Soil Taxonomy and should be compared to Table 3. Percent base saturation at a specified depth in the lower subsoil plays a much more important role in the USDA Soil Taxonomy than does base saturation as a criterion in the Zimbabwe System. Also, it should be noted that for calculating base saturation in the USDA Soil Taxonomy CEC is taken to be the sum of the exchangeable bases plus exchangeable acidity (the latter determined by barium chloride exchange at pH 8.2). In the Zimbabwe System base saturation is defined as the sum of exchangeable bases divided by the cation exchange capacity as determined by ammonium replacement. Thus for a given soil, values of base saturation using the methods of the Zimbabwe System are likely to be somewhat higher than those using the methods of the USDA Soil Taxonomy, especially for soils with much pH-dependent charge. Both systems also use as a criterion, the cation exchange capacity per 100g of clay (E/C), 16 mg equivalents being a criterion for an Oxic horizon in the USDA Soil Taxonomy while 35 mg equivalents is used to separate Fersiallitic soils from Siallitic soils and 12 mg equivalent is used to separate Paraferallitic soils from
Fersiallitic soils in the Zimbabwe System. Thus, upper-level taxa in
the USDA Soil Taxonomy are unlikely to correlate consistently with upper-
level taxa in the Zimbabwe System either for the various groups of
Red Soils or for the wider range of soils addressed by the two systems.

In the USDA Soil Taxonomy the ten orders are divided into sub-
orders (Table 7) largely on the basis of properties that reflect a certain degree of genetic homegeneity and are of importance to plant growth. In
making suborder distinctions extensive use is made of data on moisture and temperature regimes in the soil (often inferred from climatic data, Van Wambeke, 1982). Thus within the order Alfisols there are Aqualfs,
Ustalfs, Udalfs and Xeralfs differing in moisture and temperature regimes. At the great group level, soils are differentiated using horizon assemblages that reflect the entire soil profile make-up. Emphasis at the great group level is placed on the number of horizons and their morphological features as well as chemical properties. Within a great group the number of sugroups is defined on the basis of soil properties in relation to the typical member (typic member) of the great group. A typic subgroup is one in which the soils closely fit the central concept of the class (Allen, 1977). Other subgroups are defined on the basis of characteristics that are indicative of processes that may be dominant in a different great group in addition to features diagnostic of the typic class. This allows accommodation of soils having transitional properties between the dominant or typic classes of several great groups. Thus, for example, there are Ultic Haplustalfs, a subgroup of Haplustalfs that resemble Ultisols in their degree of leaching.

At the family level in the USDA Soil Taxonomy, soils are grouped according to properties which are important from an agricultural as well as engineering point of view. At this level little consideration is given to pedogenetic processes. Table 8 lists some of the important criteria used in distinguishing families for the orders Alfisol, Ultisol and Oxisol in which most red soils fall. The family particle size class is based on a slightly different definition than that used for soil texture and reflects the particle size distribution in the control section of the subsoil (usually the upper part of the argillic horizon, if present). The mineralogical class of a soil family reflects the dominant type of mineral(s). If no single mineral is dominant then the mineralogy is called mixed. Soil temperature is another family
Figure 2
Map of the study area showing geologic materials, mean annual rainfall, and the location of the study pedons.

KEY

- GRANITES
- DOLERITES
- GREAT DYKE
- SEDIMENTS
- METASEDIMENTS
- METAVOLCANICS
- DOLOMITES, SHALE, QUARTZITES

X STUDY PEDON

-800 ANNUAL RAINFALL (mm)
criterion. In tropical soils the difference between the mean summer and
the mean winter soil temperature is usually less than 5°C and the isothermic
or isohypothermic soil family temperature classes apply. To fall within
the isothermic soil temperature class, for example, the mean annual
soil temperature at a depth of 50 cm or at lithic or a paralithic
contact, whichever is shallower, should be from 15 to 22°C. If an Alfisol
or Ultisol has less than 50 cm to a paralithic or lithic content, or
if an Oxisol has less than 2 m to such a contact, the depth class
"shallow" is used in the family name. Thus a family name includes a
description of several differentiating properties. An example of a
soil family in USDA Soil Taxonomy would be: "fine, loamy, kaolinitic,
Oxic Haplustalf".

THE STUDY AREA

Four locations were studied (Fig. 2). Two of the locations
were underlain by granitic rocks, the other two by mafic rocks. In
altitude, the four sites ranged from 1500 to 1800 meters. The mean
annual rainfall ranged from 750 mm at site 4 to 1000 mm at site three.
A brief description of the soils studied at these locations is provided
below. Detailed field soil profile descriptions are provided in the
appendices.

Soils Formed From Mafic Parent Materials

7E Family Soils

These are mainly deep red clays formed on mafic rocks. A typical
profile was described on Pascoe Farm, about 30 km northeast (Fig. 2)
of Harare and 100 meters north of the Harare-Mutoko Highway. The uner-
lying rocks are dolorites. The moisture regime is ustic and the mean
annual rainfall is approximately 1000 mm.

5E Family Soils

These are moderately deep to deep reddish brown granular clay
formed from mafic rock. The profile studied was located approximately
20 km north-northwest of Harare (Fig. 2) on Thornpark Estate (present
day University of Zimbabwe Farm), about 50 meters off the Harare-Mazowe
Highway. The geology is epidiorite. The mean annual rainfall is
approximately 850 mm and the moisture regime is ustic (van Wambke, 1982).
Soils Formed From Granitic Parent Materials

7G Family Soils

The soils in this group are moderately deep to deep reddish brown, coarse grained sandy loams over yellowish red to red similar clays. A typical profile was described at the Marondera Grasslands Research Station located about 8km east of Marondera, approximately 3km south of the Harare-Marondera Highway (Fig. 2). The underlying parent rocks are coarse grained granites. The area has an ustic moisture regime and the mean annual rainfall is approximately 950 mm.

MATERIALS AND METHODS

Profile pits approximately 2m deep were dug at all 4 locations. Field classification, using the USDA Soil Taxonomy (Soil Management Support Services, 1983) was attempted. This approach enabled relevant sections of the profiles to be sampled taking into consideration the nature of the analyses that would be required for comprehensive classification of the pedons under USDA Soil Taxonomy. Soil samples were analyzed by the Department of Research and Specialist Services in the Soil Survey Division using routing pedological methods (Thompson and Purves, 1978). All analyses, except percent gravel, were done on fine earth fraction, i.e. materials passing a 2mm sieve, and the results expressed on an oven dry basis. Mechanical analysis was done by the hydrometer method after dispersion of the soil with sodium hexametaphosphate reagent. Sedimentation times were 5 minutes for the silt plus clay and 5 hours for the clay. Coarse and medium sand fractions were seperated by seiving. The fine sand fraction was calculated by difference. Particle size limits used were as follows: coarse sand (CS) 2-0.5mm, medium sand (MS) 0.5-0.2mm, fine sand (FS) 0.2-0.02mm, silt (Si) 0.027-0.002mm and clay (C) 0.002mm.

The soil pH was measured in a 1:5 suspension of soil and 0.01 M CaCl₂. Cation exchange capacity (expressed as mg equivalents per 100g dry soil) was determined by leaching the soil with 0.2M ammonium chloride at approximately field pH for soils having pH values of less than 6.5 (Russell, 1973). Ammonium ions were displaced by the direct distillation method of Pech, et al. (1947) after washing with 96% ethly alcohol.
Exchangeable cations were determined in the ammonium leachates and expressed as mg equivalents per 100g of soil. Calcium, magnesium and sodium were determined by atomic adsorption spectrophotometry and potassium by emission spectrophotometry. Total exchangeable bases (TEB) were taken as the sum of the exchangeable cations.

RESULTS AND DISCUSSION

Analytical data for selected horizons in the 4 study Pedons are given in Tables 9, 10 and 11. In the two red clay soils, pedons number 1 and 2, total exchangeable bases (TEB) tended to be much higher in the surface soil than in the subsoil horizons. This trend was not evident in the two pedons formed from granite, pedons number 3 and 4 (Table 9). The exchange complex properties indicative of degree of weathering and important in classifying soils in both systems are shown in Table 10. In this table, percent base saturation is calculated by dividing the total exchangeable bases from Table 9 by the CEC in Table 10 as determined by ammonium replacement at a pH approximately the pH of the soil. Percent base saturation calculated in the manner described by the USDA Soil Taxonomy (i.e. using the sum of the cations plus exchangeable acidity as the denominator) would undoubtedly have slightly lower values than those shown in Table 10.

The Zimbabwe System specifies that the delineations are to be based on the exchange properties in the subsoil horizon with the greatest accumulation of clay. These properties have been underlined in Table 10.

In Soil Taxonomy the percent base saturation at a depth of 1.25 meters below the top of the argillic or 1.8 meters below the surface (with some modifications) is used to ascertain the difference between Alfisols and Ultisols. The values used in classifying these pedons by the USDA Soil Taxonomy are also underlined in Table 10. In all the pedons except number 3, both the E/C and the S/C values are within the range of the Fersiallitic group (i.e. E/C 12 and S/C 6). Only for pedon number 3 are the E/C and S/C values below those for Fersaillitic soils and within
the range considered to be Orthoferrallitic (group 7).

On the other hand, all four pedons had base saturations at the required depth well in excess of the 35% boundary between Alfisols and Ultisols. All 4 pedons also contained argillic horizons and therefore are all classified as Alfisols. In pedons 3 and 4, the upper part of the argillic horizon had much lower values of base saturation than the rest of the profile. Use of base saturation values from these horizons would erroneously have placed these pedons in the order Ultsols rather than Alfisols.

The E/C values in the surface horizon were 2 to 3 times those in the lower horizons. Since it is very unlikely that the clay minerals were less weathered in the surface soil, this relationship indicates that the major part of the CEC in the surface horizons could be attributed to organic matter. Although the percent organic matter in the soil is not shown, the horizons used in classifying the soils are all below the zone of appreciable organic matter accumulation and their CEC values should be little affected by humus. Thus the E/C and S/C values given for the lower horizons should be indicative of the mineralogy of the clay fraction.

It is interesting to note from Table 10, that there is very little relationship evident between soil pH and percent base saturation. Measurement of pH (in 0.01 M CaCl₂) was, therefore not useful as a quick field test to estimate base saturation. All soils were in the strongly acid range and pH tended to increase with depth, though this was not consistently the case with base saturation.

From Table 11 it is evident that the granitic soils, pedons 3 and 4, were high in coarse sands but low in silt whereas the pedons formed from mafic rocks were much lower in coarse sands but considerably higher in silt. Field estimates of texture agreed quite closely with the particle size analysis in the laboratory except for pedon 3, for which field texturing considerably underestimated the amount of clay in the subsoil, probably because the clay fraction in this pedon was markedly kaolinitic and lacked appreciable amounts of the stickier lattice clays.
### TABLE 5: THE TEN SOIL ORDERS OF THE USDA SOIL TAXONOMY

<table>
<thead>
<tr>
<th>Soil Order</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfisols</td>
<td>Argillic horizon, &gt;35% base sat'n.</td>
</tr>
<tr>
<td>Aridisols</td>
<td>Some profile development, arid climate.</td>
</tr>
<tr>
<td>Entisols</td>
<td>Little or no profile development.</td>
</tr>
<tr>
<td>Histosols</td>
<td>Predominately organic matter</td>
</tr>
<tr>
<td>Inceptisols</td>
<td>Inception of B horizon, cambic horizon</td>
</tr>
<tr>
<td>Mollisols</td>
<td>Mollic epipedon, dark prairie soils</td>
</tr>
<tr>
<td>Oxisols</td>
<td>Oxic horizon; highly weathered, oxic mineralogy</td>
</tr>
<tr>
<td>Ultisols</td>
<td>Argillic horizon, leached, &lt;35% base sat'n.</td>
</tr>
<tr>
<td>Spodosols</td>
<td>Spodic horizon, acid, sandy soils, usually with albic.</td>
</tr>
<tr>
<td>Vertisols</td>
<td>Dark colored, cracking clays, self-inverting.</td>
</tr>
</tbody>
</table>

### TABLE 6: SOIL PROPERTIES DIFFERENTIATING THE SOIL ORDERS

<table>
<thead>
<tr>
<th>Soil Order</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfisols</td>
<td>a. argillic horizon (illuvial clay)</td>
</tr>
<tr>
<td></td>
<td>*b. base sat'n in lower subsoil &gt;35%</td>
</tr>
<tr>
<td>Ultisols</td>
<td>a. argillic horizon (illuvial clay)</td>
</tr>
<tr>
<td></td>
<td>*b. base sat'n in lower subsoil &lt;35%</td>
</tr>
<tr>
<td>Oxisols</td>
<td>1. aquic moisture regime with continuous phlinthite or</td>
</tr>
<tr>
<td></td>
<td>2. oxic horizon (not overlain by argillic)</td>
</tr>
<tr>
<td></td>
<td>a. CEC/100 g clay ≤ 16 meq;</td>
</tr>
<tr>
<td></td>
<td>b. &gt;15% clay;</td>
</tr>
<tr>
<td></td>
<td>c. only traces of weatherable minerals</td>
</tr>
</tbody>
</table>

*base saturation=exch. bases+(exch. bases + exch. acidity at pH 8.2)
The classification of the study profiles as shown on the 1:1,000,000 soils map of Zimbabwe (Surveyor-General, 1979) and as derived by the present data using the Zimbabwe System and the USDA Soil Taxonomy is given in Table 12. In only one case did our classification of the pedon differ from that indicated by the 1:1,000,000 soils map. Although located in an area of over 1000mm annual rainfall mapped as Orthoferralitic soils, pedon number 1 had E/C and S/C values well within the range specified for the Fersiallitic Group.

The E/C value appeared to be a good indicator of the severity of the weathering environment of these pedons. There was little difference in slope among the four sites in this study, but both annual rainfall and soil texture would be expected to influence the degree of weathering, since this is largely a function of the amount of water passing through the profile under a given temperature regime. Coarse textured soils would allow more rainwater to infiltrate and percolate rather than run off the soil surface.

Thus the E/C values in the subsoil of pedon number 3 are lower than those in pedon number 1, despite the somewhat greater annual rainfall at the location of the latter, because the surface soil texture is considerably coarser in the former. Grouping pedons 1 and 2 with sandy clay loam surface soils together on one hand, and pedons 3 and 4 with sandy loam or loamy sand surface soils on the other, the E/C values are inversely related to the annual rainfall at each site (compare Table 11 and Fig. 2).

Table 13 indicates that both classification systems grouped all four pedons together at the order level and made sharper distinctions among the pedons at the lower levels in the hierarchy. The USDA Soil Taxonomy lumped all 4 pedons into the order Alfisols and the suborder Ustalfs based on the presence of an argillic horizon, 35% base saturation at the critical depth and their occurrence in an ustic climate.

At the great group level, Soil Taxonomy distinguished between pedons 1 and 2, on the one hand, and pedons 3 and 4, on the other, on the basis of soil color. In the case of the present study the criteria employed (colours redder than 5 YR and values less than 4 in subsoil with no more than 1 unit increase in value upon drying) served quite well to divide the four pedons into the two obviously different groups.
Table 7

Taxonomic Categories Under the Order Alfisols in the USDA Soil Taxonomy

ORDER
Alfisols

SUBORDERS OF ALFISOLS
Aqualfs Boralfs Ustalfs Xeralfs and Udalfs

GREAT GROUPS OF USTALFS
Durustalfs Plinthusalfs Haplustalfs
Paleustalfs Natrustalfs Rhodustalfs Kandiustalfs

SUBGROUPS OF RHODUSTALFS
Lithis, Oxic and Udic Rhodustalfs

Table 8

USDA Soil Taxonomy
Criteria for Soil Family Differentiation
in the Orders Alfisols, Ultisols and Oxisols

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td>fine clayey...coarse loamy...sandy</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>mixed...kaolinitic...micaceous</td>
</tr>
<tr>
<td>Soil Temperature</td>
<td>mesic...thermic...isothermic</td>
</tr>
<tr>
<td>Profile Depth</td>
<td>shallow (50 cm for alfisols and ultisols)</td>
</tr>
</tbody>
</table>
Table 9

Exchangeable Bases in Selected Horizons of the Study Pedons.

<table>
<thead>
<tr>
<th>No.</th>
<th>Depth cm</th>
<th>TEB* meq/100g soil</th>
<th>Exch. Ca</th>
<th>Exch. Mg</th>
<th>Exch. Na</th>
<th>Exch. K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-26</td>
<td>9.52</td>
<td>6.30</td>
<td>3.10</td>
<td>.04</td>
<td>.08</td>
</tr>
<tr>
<td>1</td>
<td>52-82</td>
<td>5.84</td>
<td>4.23</td>
<td>1.55</td>
<td>.04</td>
<td>.02</td>
</tr>
<tr>
<td>1</td>
<td>82-118</td>
<td>6.35</td>
<td>4.55</td>
<td>1.73</td>
<td>.04</td>
<td>.02</td>
</tr>
<tr>
<td>2</td>
<td>0-22</td>
<td>11.29</td>
<td>6.88</td>
<td>4.20</td>
<td>.06</td>
<td>.15</td>
</tr>
<tr>
<td>2</td>
<td>64-100</td>
<td>7.29</td>
<td>3.55</td>
<td>3.66</td>
<td>.04</td>
<td>.04</td>
</tr>
<tr>
<td>2</td>
<td>100-127</td>
<td>6.02</td>
<td>2.81</td>
<td>3.13</td>
<td>.06</td>
<td>.02</td>
</tr>
<tr>
<td>3</td>
<td>0-10</td>
<td>1.89</td>
<td>0.91</td>
<td>0.71</td>
<td>.04</td>
<td>.22</td>
</tr>
<tr>
<td>3</td>
<td>30-63</td>
<td>0.59</td>
<td>0.41</td>
<td>0.10</td>
<td>.04</td>
<td>.04</td>
</tr>
<tr>
<td>3</td>
<td>120-150</td>
<td>1.72</td>
<td>0.92</td>
<td>0.72</td>
<td>.04</td>
<td>.04</td>
</tr>
<tr>
<td>4</td>
<td>0-14</td>
<td>0.93</td>
<td>0.50</td>
<td>0.30</td>
<td>.04</td>
<td>.08</td>
</tr>
<tr>
<td>4</td>
<td>56-84</td>
<td>0.72</td>
<td>0.20</td>
<td>0.40</td>
<td>.04</td>
<td>.08</td>
</tr>
<tr>
<td>4</td>
<td>106-120</td>
<td>1.57</td>
<td>0.30</td>
<td>1.11</td>
<td>.04</td>
<td>.12</td>
</tr>
</tbody>
</table>

*Total Exchangeable Base = \( \Sigma \) Exch. Ca, Mg, Na and K.

Table 10

Chemical Properties Indicative of Weathering Stage in Selected Horizons of the Study Pedons.

<table>
<thead>
<tr>
<th>No.</th>
<th>Depth cm</th>
<th>pH</th>
<th>CEC* meq/100g soil</th>
<th>Base Sat'n+</th>
<th>E/C‡</th>
<th>S/C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0-25</td>
<td>5.1</td>
<td>9.11</td>
<td>100</td>
<td>29.6</td>
<td>29.6</td>
</tr>
<tr>
<td>1</td>
<td>52-82</td>
<td>5.5</td>
<td>8.30</td>
<td>70</td>
<td>17.2</td>
<td>12.1</td>
</tr>
<tr>
<td>1</td>
<td>82-118</td>
<td>5.5</td>
<td>8.16</td>
<td>78</td>
<td>15.4</td>
<td>12.0</td>
</tr>
<tr>
<td>2</td>
<td>0-22</td>
<td>5.0</td>
<td>13.7</td>
<td>83</td>
<td>42.7</td>
<td>35.2</td>
</tr>
<tr>
<td>2</td>
<td>64-100</td>
<td>5.2</td>
<td>9.22</td>
<td>79</td>
<td>19.3</td>
<td>15.2</td>
</tr>
<tr>
<td>2</td>
<td>100-127</td>
<td>5.3</td>
<td>7.84</td>
<td>77</td>
<td>18.9</td>
<td>14.5</td>
</tr>
<tr>
<td>3</td>
<td>0-10</td>
<td>4.8</td>
<td>3.42</td>
<td>55</td>
<td>21.4</td>
<td>11.8</td>
</tr>
<tr>
<td>3</td>
<td>30-63</td>
<td>4.4</td>
<td>3.18</td>
<td>19</td>
<td>7.8</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>120-150</td>
<td>5.2</td>
<td>3.18</td>
<td>54</td>
<td>7.3</td>
<td>3.9</td>
</tr>
<tr>
<td>4</td>
<td>0-15</td>
<td>4.9</td>
<td>1.83</td>
<td>51</td>
<td>48.2</td>
<td>24.5</td>
</tr>
<tr>
<td>4</td>
<td>56-84</td>
<td>5.1</td>
<td>2.09</td>
<td>35</td>
<td>23.5</td>
<td>8.1</td>
</tr>
<tr>
<td>4</td>
<td>106-120</td>
<td>5.6</td>
<td>2.35</td>
<td>67</td>
<td>13.7</td>
<td>9.2</td>
</tr>
</tbody>
</table>

*CEC by 0.24 M NH₄Cl replacement  
+Base sat'n = TEB + CEC  
‡E/C = CEC/100g clay;  S/C = TEB/100 g clay
### Table 11: Particle Size Distribution of Selected Horizons of the Study Pedons

<table>
<thead>
<tr>
<th>Pedon No.</th>
<th>Depth cm</th>
<th>C Sand</th>
<th>M Sand</th>
<th>F Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9 - 2</td>
<td>10.6</td>
<td>9.7</td>
<td>31.2</td>
<td>17.8</td>
<td>30.8</td>
<td>SCL</td>
</tr>
<tr>
<td>1</td>
<td>52 - 82</td>
<td>5.3</td>
<td>6.1</td>
<td>23.6</td>
<td>16.7</td>
<td>48.3</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>82 - 118</td>
<td>4.4</td>
<td>5.6</td>
<td>19.5</td>
<td>17.6</td>
<td>52.9</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>0 - 22</td>
<td>18.8</td>
<td>9.9</td>
<td>18.6</td>
<td>20.7</td>
<td>32.1</td>
<td>SCL</td>
</tr>
<tr>
<td>2</td>
<td>64 - 100</td>
<td>9.3</td>
<td>5.7</td>
<td>17.1</td>
<td>20.1</td>
<td>47.8</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>100 - 127</td>
<td>12.0</td>
<td>4.8</td>
<td>19.6</td>
<td>22.1</td>
<td>41.5</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>0 - 10</td>
<td>33.1</td>
<td>29.5</td>
<td>18.2</td>
<td>3.2</td>
<td>16.0</td>
<td>SL</td>
</tr>
<tr>
<td>3</td>
<td>30 - 73</td>
<td>19.8</td>
<td>14.4</td>
<td>15.7</td>
<td>9.4</td>
<td>40.7</td>
<td>SC</td>
</tr>
<tr>
<td>3</td>
<td>120 - 150</td>
<td>16.2</td>
<td>10.1</td>
<td>23.6</td>
<td>6.3</td>
<td>43.7</td>
<td>SC</td>
</tr>
<tr>
<td>4</td>
<td>0 - 14</td>
<td>25.9</td>
<td>31.1</td>
<td>31.1</td>
<td>7.3</td>
<td>3.8</td>
<td>S</td>
</tr>
<tr>
<td>4</td>
<td>56 - 94</td>
<td>29.9</td>
<td>30.1</td>
<td>26.9</td>
<td>4.2</td>
<td>8.9</td>
<td>LS</td>
</tr>
<tr>
<td>4</td>
<td>106 - 120</td>
<td>48.9</td>
<td>18.2</td>
<td>14.2</td>
<td>1.6</td>
<td>17.1</td>
<td>SL</td>
</tr>
</tbody>
</table>
TABLE 12:-  CLASSIFICATION OF THE STUDY PROFILES BY THE ZIMBABWEAN SYSTEM AND THE USDA SOIL TAXONOMY

<table>
<thead>
<tr>
<th>Pedon No</th>
<th>On Map</th>
<th>Zimbabwe System by Study Data</th>
<th>Soil Taxonomy** by Study Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7E 5E</td>
<td>Fersiallitic Red Clay on Mafic Rock</td>
<td>clayey, mixed* isothermic Oxic Rhodustalfs</td>
</tr>
<tr>
<td>2</td>
<td>5E 5E</td>
<td>do</td>
<td>clayey, mixed, isothermic Oxic Rhodustalfs</td>
</tr>
<tr>
<td>3</td>
<td>7G 7G</td>
<td>Orthoferrallitic Sandy Soil on Granite</td>
<td>clayey, kaolinitic, isothermic Oxic Haplustalfs</td>
</tr>
<tr>
<td>4</td>
<td>5G 5G</td>
<td>Fersiallitic Sandy Soil on Granite</td>
<td>sandy, mixed, isothermic Oxic Haplustalfs</td>
</tr>
</tbody>
</table>

* Note: mineralogy inferred from S/C and E/C values.

** Not including the concept of the "kandic" horizon.
However pedon number 2 was actually a borderline case, having color just slightly redder than 5YR but not as red as 2.5 YR. Thus pedon number 2 was very close to being classified together with pedons 3 and 4 at the great group level, despite the markedly contrasting nature of the latter two pedons. If the proposed kandic horizon (Moormann, 1978) were included in the Soil Taxonomy, it is likely that all 4 pedons would be classed as Kandiustalfs (only pedon number 4 has a marginal E/C value) since the cation exchange capacity per 100 g clay in the subsoil is generally 24 mg equivalents and the clay skins present are not pronounced or continuous.

At the group level, the Zimbabwe Systems does not clearly distinguish between the contrasting soils represented by pedons 1 and 2 on the one hand and pedon 4 on the other. All three are group 5 (Fersiallitic) soils.

The subgroup level in Soil Taxonomy does nothing to distinguish among the 4 pedons, all are classed in Oxic subgroups as a result of their low values for CEC/100g clay (24 mg equivalents). Pedon number 4 comes very close to being in a Typic subgroup, however.

In both systems, it is at the family level that, amongst the 4 pedons, distinctions are made that appropriately reflect management and plant growth considerations. Each system grouped the 4 pedons into 3 different families, pedons 1 and 2 coming under one family. The criteria by which this was accomplished differed considerably between the two systems, however.

In Zimbabwe one of the most important distinguished among soils is the contrast between the so-called "red clays" and the "sandy soils". These textural terms in this context apply to both surface and subsoil horizon. This is recognized implicitly by the Zimbabwe System at the family level when it describes the parent material designated by G as "granites and gneissic granites that give rise to soils in which the sand faction is coarse grained" and that designated by E as "igneous and metamorphic mafic rocks other than basalt that give rise to soils of high clay content". By contrast, Soil Taxonomy does not incorporate surface soil textures as a criterion at any level.
Pending X-ray analyses, we have inferred the mineralogy classes from the E/C values. This procedure involved a considerable degree of speculation and points to the fact that use of Soil Taxonomy requires significantly more sophisticated laboratory data than does use of the Zimbabwe System. This is true for each level in the hierarchy. For example, thin-section microscopy may be required to identify an argillic horizon, a key criterion at the order level. Also cation exchange capacity must be determined by three different methods for various criteria (Soil Survey Staff, 1975). This feature of Soil Taxonomy makes it rather cumbersome and expensive to use, especially in developing countries.

The USDA Soil Taxonomy does, at the family level, provide significantly more information relevant to soil management and crop responses than does the Zimbabwe system. If sufficient mineralogical data can be compiled to classify Zimbabwe's soil to the Soil Taxonomy Family level a better picture of management requirements may be possible.

CONCLUSIONS

Both the Zimbabwe System and the USDA Taxonomy proved practical in classifying four relatively weathered Zimbabwean soils. Laboratory data adequate for classifying the soils in the Zimbabwe System was insufficient, however, to make a conclusive classification in the USDA Soil Taxonomy. There were broad similarities in the application of both systems, with, for example, all 4 pedons falling under one soil order in both cases. At lower levels (group and family) the two systems also grouped the 4 pedons in 3 different families, the 2 pedons grouped together in one family being the same in both cases.
REFERENCES


APPENDIX 1

PASCOE FARM, PEDON 1.

Site Characteristics

3-5% slope, convex, mid-slope position, SE aspect uncultivated margin of arable field. Tall grass with few scattered trees (no trees within 25m). Ustic, moisture regime (1000 mm rain, Nov-March).

Hilly to rolling terrain. No erosion evident. Rock outcrops (dolerite) more than 50m upslope.

Soil Classification

Soil Taxonomy: Oxic Rhodustalfs

Zimbabwe system: 7E.2 (Orthoferralitic)

Profile Field Description by R. Weil and K. Asumadu, 22-10-85.

0-26cm Dark reddish-brown (2.5YR 3/4 both dry and moist) very fine to fine sandy clay loam (30% C, 50%); few sub-rounded fine weathered epidiorite gravels with occasional quartz gravels; strong medium subangular blocky structure breaking to strong fine granular structure; hard when dry, slightly sticky and slightly plastic when wet, very friable when moist; many fine tubular pores; abundant fine to medium roots, many worm channels (1-3mm diam.), surface sealed with very thin (<1mm) crust, slightly hydrophobic (water drops stand 4-5 sec before being absorbed); distinct boundary.

26-52cm Red (2.5YR 4/6, dry and dark reddish brown, 2.5YR 3/4, moist) very fine to fine sandy clay (40%, 50%); many gravels are above strong medium subangular blocky structure breaking into strong fine to very fine subangular blocky structure, vertical cracks (1-2mm diam.) 15-20cm apart; slightly hard when dry (field moisture at wilting point) sticky and slightly plastic when wet, very friable when moist; many fine pores; many fine roots; few worm channels (1-2mm diam.); diffuse boundary.

52-82cm Red (2.5YR 4/6, dry and dark red, 2.5YR 3/6, moist) very fine to fine sandy clay (43% C, 46%) with gravel as above, strong medium to coarse subangular blocky structure breaking to moderate fine subangular blocky structure with cracks on pit face as above; friable when slightly moist, wet consistence as above; few coarse and fine roots; prominent ant and termite nests (30-40mm diam.) with eggs and channels; few worm channels (1-2mm diam.); gradual boundary.
Appendix 1 (continued)

82-118 cm  Dark red (2.5YR 3/6, both dry and moist) fine sandy clay to light clay (50%c, 40%s) with gravel as above; structure as above, cracks as above; friable at field moist (slightly moist), sticky and plastic when wet; few fine and coarse roots; gradual boundary.

118-155 cm Dark red (colour as above) very fine to fine sandy clay (43%c, 46%s) with very few gravels as above; weak medium prismatic structure breaking to moderate medium subangular blocky structure; few thin patchy clay skins on vertical ped faces; consistence as above; very few coarse and fine roots; distinct boundary.

155+ cm  Dark red (colour as above) gravelly clay (~50% clay) between hard rounded epidiorite fragments (5-20cm) with distinct weathering rind (~10mm); moderate medium subangular blocky structure; consistence as above.
APPENDIX 2

UNIVERSITY FARM PEDON NO. 2

Site Characteristics

0-1% slope, convex, midslope position, S aspect
uncultivated land 75 m from Golden Stairs Road
recently abandoned cropland with short and tall grasses
ustic moisture regime, (850 mm mean annual rain)
slightly undulating terrain
slight to no erosion evident
no rock outcrops visible, diorite parent materials.

Soil Classification

Soil Taxonomy : Oxic Haplustalfs
Zimbabwe system: 5E.2
Profile field Description by R. Weil and K. Asumadu, 26-10-85.

0-22 cm
dark reddish brown (5YR 3/3, dry and moist) fine sandy loam
(22%c); sporadic angular quartz gravels, 5-10mm; strong
fine to medium sub-angular blocky structure, slightly hard
at field moisture (quite dry), slightly sticky and slightly
plastic when wet; horizontal and vertical cracks 1-2mm wide
and 150mmm apart; few coarse and abundant medium to fine roots;
abundant ant channels 2-10mm in diameter; clear boundary.

22-64 cm
dark reddish brown (5YR 3/4, both dry and moist) fine sandy
loam (22% c); quartz gravel as above; few very fine slightly
hard concretions (1mm diam.); strong coarse to medium sub-
angular blocky structure; cracks as above; consistence as
above; few medium roots; few small (2-4mm diam.) ant Channels;
gradual boundary.

64-100 cm
dark reddish brown (5YR 3/4, moist) and yellowish red (5YR 4/6,
dry) fine sandy loam (22%c); quartz gravel as above; few
buckshot concretions (1-1.5mm diam.) with few angular incipient
ironstone concretions (2-3mm diam.); structure as above;
friable at field moisture, wet consistence as above; cracks
as above; few medium and fine roots; few ant channels; gradual
foundary;
Appendix 2 (continued)

100-127cm  dark reddish brown (moist and dry colours as above) gravelly sandy loam grading to gravelly sandy clay loam in the lower part (28% c); common sub-angular incipient black concretions (1-4mm diam); structure as above; dry slightly hard, wet slightly sticky plastic; few medium and fine roots with an occasional coarse root; gradual boundary.

127-160+cm  dark reddish brown (moist and dry colours as above) gravelly sandy clay loam (28% c); many black concretions (3-5mm); weak medium to coarse subangular blocky structure; friable at field moisture, slightly sticky and slightly plastic when wet; few fine roots.
GRASSLANDS RESEARCH STATION PEDON NO. 3

Site Characteristics:

2% slope, convex, mid-slope position, N aspect.
Grazed woodland-savannah, mainly Brachystegia and Hyperrhenia
slightly undulating terrain, little or no erosion evident
10m from granite outcrop
Ustic moisture regime (950 mm rain Nov-March)

Soil Classification

Soil Taxonomy : Oxic Haplustalfs
Zimbabwe System : 7E.2

Profile Field Description by R. Weil and K. Asumadu, 25 November, 1985

0-10 cm very dark brown (7.5YR 3/2, moist) and brown 10YR 5/6, dry)
coarse sandy loam (20%c); weak medium granular structure
within slightly sealed surface; slightly hard dry, friable
moist, slightly plastic and non-sticky wet; frequent medium
to fine roots; common and channels (3mm diam.); pH 4.0:
gradual boundary.

10-30 cm dark brown to brown (7.5YR 4/4, moist) and yellow brown
(10YR 5/4, dry) coarse sandy loam; weak medium subangular
blocky structure; hard dry, friable moist, slightly plastic
and slightly sticky wet; common fine roots with occasional
coarse root; ant channels as above; pH (H₂O) 4.5; diffuse
boundary.

30-63 cm strong brown (7.5YR 4/6, moist) and reddish yellow (7.5YR 6/6,
dry) loam (30% silt); strong medium subangular blocky structure;
patchy medium to thick clay skins and clay bridging of sand
grains; very hard dry, firm moist, slightly plastic and non-
sticky wet; noticeably more dense than horizon above or below;
common fine roots; pH 5.0; clear boundary (based on bulk
density).
Appendix 3 (continued)

63 - 120 cm  strong brown (7.5YR 5/6, moist) and reddish yellow (7.5YR 6/6, dry) loam; weak medium to coarse subangular blocky structure; clay skins and briding of sand grains as above; slightly hard dry, firm moist, slightly plastic and slightly sticky wet; common fine, few medium and occasion coarse roots; pH 5.5 gradual boundary.

120 - 150 cm  strong brown (moist and dry colours as above) coarse sandy clay loam; weak medium to coarse subangular blocky structure; common angular quartz gravel (2-5mm diam.); incipient ironstone concretions (5-10mm diam.) of yellowish red (5YR 4/6 moist) interior colour; slightly hard dry, slightly firm moist, sticky and plastic wet; common termite nests, chambers (10-40cm diam.) and channels; few medium to coarse and fine roots; diffuse boundary.

150 - 190+ cm  yellowish red (5YR 4/6, moist) and reddish yellow (7.5YR 6/6, dry) gravelly coarse sandy loam to gravelly coarse sandy clay loam; moderate medium subangular blocky structure; gravel and concretions as above; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; few termite channels; few medium to fine roots.
APPENDIX 4

RUMISBORO FARM PEDON NO. 4

Site Characteristics
1% slope, convex, upper middle-slope position, SE aspect 
grazed bush savannah, mostly short grasses and thorn bushes. 
undulating terrain, slight erosion evident. 
ustic moisture regime (750mm rain Nov-March) 
no rock outcrops nearby, granite parent material.

Soil Classification
Soil Taxonomy : Oxic Haplustalfs 
Zimbabwe System: 5G.2

Profile Field Description by R. Weil and K. Asumadu, 25 Nov. 1985

0 - 14/18cm 
very dark grayish brown (10YR 3/2, moist) and light brownish gray (10YR 6/2, dry) loamy sand to sandy loam; very weak medium subangular blocky structure; slightly hard dry, slightly firm moist, non sticky and non plastic wet; abundant fine and medium roots; irregular boundary;

14/18-32cm 
brown (7.5YR 5/4, moist) and light yellowish brown (10YR 6/4, dry) loamy sand to light sandy loam; moderate medium to coarse subangular blocky structure; slightly hard dry, friable moist, non sticky and non plastic wet; few termite nest (2 - 4cm diam.) and channels; common fine and medium roots; gradual boundary.

32 - 56 cm 
strong brown (7.5YR 5/6, moist) and light yellowish brown (10YR 6/4, dry) loamy sand to sandy loam; structure and consistence as above; termite structures as above; few medium and fine roots; gradual boundary.

56 - 84 cm 
strong brown (7.5YR 5/6, moist) and reddish yellow (7.5YR 6/6, dry) coarse sandy loam; structure as above; hard dry, friable moist, non sticky and non plastic wet; clay bridging of sand grains; termite structures and roots as above; gradual boundary.
Appendix 4 (continued)

84 - 95/106 cm  yellowish red (5YR 5/8, moist) and reddish yellow (7.5YR 6/6, dry) very coarse sandy loam (lighter than above); weak medium subangular blocky structure; clay bridging of sand grains, slightly hard dry, friable moist, non sticky and non plastic wet; termite structures as above, few medium and coarse roots; clear undulating boundary.

95/106-120 cm  red (2.5 YR 4/6, moist) and yellowish red (5 YR 5/6, dry) gravelly very coarse sandy loam (lighter than above); structure as above; patchy thin clay skins and clay bridging of sand grains; occasional fine gravels of weathered feldspar; very few fine to medium roots; abrupt boundary.

120 - 130 cm  stoneline with colours as above, extremely gravelly very coarse sandy loam to extremely gravelly very coarse sandy clay loam; angular quartz fragments (0.5-4cm diam.) 80-85% by volume; some clay bridging of sand grains; very few fine roots; abrupt boundary.

130 - 190+cm  yellowish red (5YR 5/6, moist rubbed) gravelly very coarse sandy loam to very coarse sandy clay loam; quartz and feldspar gravels weakly cemented by iron oxides; common weathered feldspar fragments; very few medium roots with occasional coarse roots.
INVESTIGATIONS INTO THE ERODIBILITY OF A FERSIALLITIC CLAY SOIL BY RAINFALL SIMULATION

H.A. ELWELL
Senior Research Engineer, Soil and Water Inst. Agric. Engng. Box BW 330
Borrowdale, Zimbabwe

SUMMARY

The erodibility of a fersiallitic clay soil (5E.2 Series) derived from epidiorite was studied by simulated rainfall. Under a standard rainfall test consisting of a uniformity treatment of 1000 J m\(^{-2}\) of rain energy followed by a monitoring run of 750 J m\(^{-2}\), the soil showed marked changes in erodibility with management history. Soil loss and runoff increased in the following order: ungrazed virgin land, lightly grazed permanent pasture, high yielding cropland and low yielding cropland.

A commensurate reduction was recorded in the percent organic carbon in the soil which, although varying from only 3.26 to 1.11% between extremes, had a profound influence on proportions of water-stable aggregates in the soil. Mean weight diameter of water-stable aggregates in quadratic equations explained 95.7 and 95.6% of the variation in soil loss and runoff respectively. Percent water-stable aggregates greater than 2mm diameter was also significantly correlated to soil loss and runoff and had the practical advantage of being easier to measure.

In a parallel experiment to investigate the effects of tillage on soil erodibility, soil loss and runoff were found to increase with the number of times the soil was disc-harrowed. Disc harrowing was found to increase the proportions of soil particles ('fines') passing the 53 micron sieve. A soil (also 5E.2) with a higher proportion of water-stable aggregates was more resistant to breakdown by discing. On the latter soil, a cage roller pulverised the soil more than the disc harrow, whereas the proportion of fines did not increase when a spring tine was used.
These results show that, on this soil type, percent organic carbon and indices based on water-stable aggregates have application for managing the vegetative aspects of land use; while the amount of fines passing the 53 micron sieve will assist in the selection of suitable tillage implements.

INTRODUCTION

Most research work concerned with soil erodibility has been influenced by the requirements of the Universal Soil Loss Equation (Wischmeier and Smith, 1978) wherein the value of the soil erodibility factor $K$ is regarded as constant. As a consequence, the weight of research has been directed towards determining the relative erodibility of soil types and little attention has been paid to changes in erodibility within soil types as a result of management (Lal, 1979) and other factors.

Variation in erodibility of tropical soils has been noted in several studies (Rose, 1961; Lal, 1981; Vanelslande, et al 1984; Roose and Piot, 1984.). Deterioration in soil structure is commonly cited as the principal cause but this conclusion has been arrived at by comparing results from two or three samples only.

The purpose of the main part of this study (called the index test) was to investigate in greater detail, physical and chemical properties governing the erodibility of a fersiallitic clay soil; to selected soil indices suitable for monitoring changes in its erodibility; to establish prediction equations between them so that full use can be made of all available data sources; and to relate significant indices to land use history.

Subsequent to the above investigation, anomalous erodibility results were recorded from certain extremes of tillage. Lands which had not been disc-harrowed or had been excessively worked for many years often gave lower than anticipated soil loss and runoff. An investigation was undertaken, therefore, to record the effects of discing
on the erodibility of a previously under-worked soil and to derive a simple index for recording these changes. The effects of three different tillage implements on soil erodibility were then compared in terms of the derived index.

The wisdom of considering the erodibility of the tropical soils as constant is questioned.

**EXPERIMENTAL APPROACH**

The experiments were carried out at the Institute of Agricultural Engineering, Borrowdale, Zimbabwe and at the nearby ART Farm.

The test soil is classified as a Ferric Luvisol in the FAO-UNESCO soil legend (1974) and as a fersiallitic clay (5E,2 Series) according to the soil classification of Zimbabwe (Thompson and Purves, 1978).

It is an important agricultural soil suited to annual crops such as maize and soyabean with good moisture retention and a natural well-developed structure aiding root penetration. Fertility levels are considerably better than those on adjacent weathered fersiallitic or ferrallitic soils on granite.

Two hundred 1-kilogram soil samples were taken from the field in an air dry condition and crushed through a 10mm sieve as a pre-test uniformity treatment prior to a standardised rainfall simulation test. After passing through the sieve the samples were thoroughly mixed, spread out into a 230mm layer and three randomly selected 2kg subsamples taken for soil analysis. Indices are the means of three determinations.

Notations and descriptions of tested soil indices are shown in Table 1. Size ranges of aggregates by dry and wet sieving were determined by the methods described by Kemper and Chepil (1965) and percent organic carbon by Walkley and Black (1934).
All the indices tested in Table 1 were significantly related to each other. Only selected ones are shown in Table 1. Mean weight diameter of water-stable aggregates (MWDW) provided the best fits to soil loss and runoff (95.7 & 95.6) variation explained respectively), followed closely by percent water-stable aggregates in the soil. Runoff increased immediately soil structure began to deteriorate but levelled off at low MWDW values as a minimum infiltration rate was reached. By comparison, soil loss was slower to increase as structure deteriorated but continued to increase rapidly at low MWDW values in spite of runoff levelling out.

The close association between amounts of water-stable aggregates (MWDW and AGG2) and organic carbon (CARB) confirms the importance of organic carbon in maintaining soil structure. The relationship between AGG2 and MWDW is of interest because AGG2 requires considerably less resources and time to determine, and for this reason has been adopted for future routine analyses on this soil type. In Fig.2, soil structure initially shows a rapid response to increases in organic carbon but no response above 2.5% carbon.

Although poorer than most correlations, the positive association between aggregates by wet (MWDW) sieving indicates that the desirable degree of uniformity was achieved in pre-test soil treatment. This undoubtedly contributed to the excellent performance of MWDW as a predictor of soil loss and runoff. The association also indicates that soils with better structure (i.e. more water-stable aggregates) are less likely to be broken down mechanically.

A cubic equation gave the best fit between soil loss and runoff, showing an increasing rate of soil loss with increased runoff.

The derived prediction equations allow the erodibility of soils to be assessed from routine soil tests such as MWDW and CARB, thus allowing full exploitation of existing data banks.

Management history, (Table 3), had a marked effect on soil structure. Proportions of water-stable aggregates were lower under crops than under grassland. Grazing lowered the quality of the soil compared to rested virgin land and the structure deteriorated as the density of row crop vegetation (reflected by yield) declined.
TABLE 1: NOTATIONS, DESCRIPTIONS AND UNITS OF TESTED SOIL ERODIBILITY INDICES

<table>
<thead>
<tr>
<th>Notations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWDD</td>
<td>Mean weight diameter of aggregate by dry sieving (mm).</td>
</tr>
<tr>
<td>MWDD</td>
<td>Mean weight diameter of aggregate by dry sieving (mm).</td>
</tr>
<tr>
<td>AGG1</td>
<td>Percent water-stable aggregate 10-4.76 mm.</td>
</tr>
<tr>
<td>AGG2</td>
<td>&quot; &quot; &quot; &quot; 10-2.0 mm.</td>
</tr>
<tr>
<td>AGG3</td>
<td>&quot; &quot; &quot; &quot; 10-1.0 mm.</td>
</tr>
<tr>
<td>AGG4</td>
<td>&quot; &quot; &quot; &quot; 10-0.2 mm.</td>
</tr>
<tr>
<td>AGG5</td>
<td>&quot; &quot; &quot; &quot; Less than 0.2 mm.</td>
</tr>
<tr>
<td>CARB</td>
<td>Percent organic carbon</td>
</tr>
</tbody>
</table>

After a sample had been thoroughly mixed, it was placed into six 746mm long by 580mm wide runoff trays. A coarse sand layer gave free drainage along the base of the trays through a 12mm diameter outlet pipe.

The trays were placed at 4.5% slope beneath a rainfall simulator capable of reproducing the drop size distributions and kinetic energy of a high intensity tropical storm (Elwell and Makwanya, 1980). Energy amounts were varied by adjusting the duration time of the applied storm. All samples were subjected to an initial uniformity treatment of 1000 J m\(^{-2}\) of rainfall energy followed one hour later by a monitoring run of 750 J m\(^{-2}\). 1000 units represent a major local storm while 750 units is an average size storm. The mean values of soil loss (grams) and runoff (litres) collected from the six replicates during the monitoring run were analysed.

In the case of the index test, thirty soil samples were taken from lands on which the type of land use had been consistent for at least five years prior to sampling. Sites were chosen to represent as wide a range of land use as possible. Virgin lands were ploughed and disced before sampling, while the other sites had been conventionally tilled (ploughed and disced) as part of their on-going treatments. Dependent variates, soil loss and runoff, were fitted by multiple regression analysis to each of the indices and to their squared and cubic terms in the following steps:

\[
Y = a_0 + a_1 X
\]
\[
Y = a_0 + a_1 X + a_2 X^2
\]
\[
Y = a_0 + a_1 X + a_2 X^2 + a_3 X^3
\]
The appropriateness of the derived equations was judged from
goodness of fit based on the multiple correlation coefficient ($R^2$) and
whether the equations realistically represented the observations
throughout their entire range. Equations producing unrealistic
curvatures were screened out.

A land which had not been disced for five years was chosen for
the discing test. The soil gave a lower erodibility under the simulator
than would have been anticipated from the low amounts of water-stable
aggregates it contained. The soil was disc-harrowed 20 times, with
simulator and soil tests being carried out before the start and after
every two discings. Dependent variates soil loss and runoff were related
to AGG2 and to a new index AGD6 in simple bi-variate regression analyses.
AGD6 represents the amount of fine particles, 'fines', passing the 53
micron sieve.

A site with the soil in better structural condition was chosen
for the tillage implement test. The three implements tested were a
disc harrow, coil shank spring tines consisting of 12 tines in three
rows, and a cage roller made up of horizontal bars of angle iron. Each
implement was tested on a field plot 30m long by 3 meters wide, set out
adjacent to one another. Preliminary tests were undertaken to ensure
uniformity of soil properties over the site. Full simulator tests were
carried out only before and after completion of 16 runs with the
implements. Variance analyses were performed to observe any
differences between the plots before the start of the test, to
determine any significant difference within treatments between
the start and finish of the experiment and any differences between
treatments. 10-kg soil samples were taken before the start of the trial
and after every two runs with the implements and bi-variate analyses
performed between AGD6 (Table 1.) as the dependent variate and the number
of discings.

RESULTS AND DISCUSSIONS

Results of the regression analyses relating selected best-fit
soil indices are shown in Table 2; and two of the most interesting
relationships are shown in Figs 1 and 2. Statistical details relating
soil properties to management are given in Table 3. The extreme ranges
of the indices quoted in Table 3, from virgin to bare ground, define the limits over which the equations in Table 2 apply. For fuller details see Elwell (1986).

**TABLE 2: BEST FITTING EQUATIONS FOR RELATING SELECTED PAIRS OF VARIATIONS IN THE INDEX TEST**

<table>
<thead>
<tr>
<th>Dep. Var.</th>
<th>Ind. Var.</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$R^2$</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Loss</td>
<td>MOCW</td>
<td>277.18</td>
<td>-149.16</td>
<td>19.408</td>
<td>N/A</td>
<td>0.9569</td>
<td>15.36</td>
</tr>
<tr>
<td>Soil Loss</td>
<td>MOCW</td>
<td>299.87</td>
<td>-80.333</td>
<td>N/A</td>
<td>N/A</td>
<td>0.9241</td>
<td>20.03</td>
</tr>
<tr>
<td>Soil Loss</td>
<td>AGG2</td>
<td>225.40</td>
<td>-6.5599</td>
<td>0.0431</td>
<td>N/A</td>
<td>0.9402</td>
<td>18.10</td>
</tr>
<tr>
<td>Soil Loss</td>
<td>AGG2</td>
<td>204.61</td>
<td>-4.2208</td>
<td>N/A</td>
<td>N/A</td>
<td>0.9189</td>
<td>20.70</td>
</tr>
<tr>
<td>Soil Loss</td>
<td>Runoff</td>
<td>8.0684</td>
<td>5.3125</td>
<td>-2.3887</td>
<td>0.43236</td>
<td>0.9303</td>
<td>19.92</td>
</tr>
<tr>
<td>Runoff</td>
<td>MOCW</td>
<td>9.0198</td>
<td>0.9179</td>
<td>-1.2385</td>
<td>N/A</td>
<td>0.9557</td>
<td>0.688</td>
</tr>
<tr>
<td>Runoff</td>
<td>MOCW</td>
<td>12.039</td>
<td>-3.4742</td>
<td>N/A</td>
<td>N/A</td>
<td>0.8870</td>
<td>0.107</td>
</tr>
<tr>
<td>Runoff</td>
<td>AGG2</td>
<td>9.1562</td>
<td>0.0165</td>
<td>-0.0036</td>
<td>N/A</td>
<td>0.9495</td>
<td>0.734</td>
</tr>
<tr>
<td>Runoff</td>
<td>AGG2</td>
<td>10.915</td>
<td>-0.1814</td>
<td>N/A</td>
<td>N/A</td>
<td>0.8712</td>
<td>1.152</td>
</tr>
<tr>
<td>AGG2</td>
<td>MOCW</td>
<td>-5.6587</td>
<td>18.849</td>
<td>N/A</td>
<td>N/A</td>
<td>0.9963</td>
<td>1.815</td>
</tr>
<tr>
<td>AGG2</td>
<td>CARB</td>
<td>210.65</td>
<td>294.85</td>
<td>111.20</td>
<td>13.9426</td>
<td>0.8904</td>
<td>5.674</td>
</tr>
<tr>
<td>MOCW</td>
<td>CARB</td>
<td>-9.5288</td>
<td>13.470</td>
<td>-4.8035</td>
<td>0.56732</td>
<td>0.9108</td>
<td>0.270</td>
</tr>
<tr>
<td>MOCW</td>
<td>MOCD</td>
<td>-0.7536</td>
<td>1.0442</td>
<td>N/A</td>
<td>N/A</td>
<td>0.6793</td>
<td>0.493</td>
</tr>
</tbody>
</table>

All relationships significant at the 0.1% level.

$R^2$ = Multiple correlation coefficient - becomes the simple correlation coefficient squared ($r^2$) for bi-variate analyses.

SE = Standard error of the mean for the dependent variate.
### TABLE 3: VARIATION IN AGGREGATE AND ORGANIC CARBON INDICES WITH MANAGEMENT HISTORY

<table>
<thead>
<tr>
<th>History</th>
<th>No. Obs</th>
<th>Statistic</th>
<th>MWDW</th>
<th>AGG2</th>
<th>CARB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>range</td>
<td>2,18-3,03</td>
<td>36,1-51,8</td>
<td>1,77-3,26</td>
</tr>
<tr>
<td>Virgin grassld.</td>
<td>7</td>
<td>mean</td>
<td>2,78</td>
<td>47,04</td>
<td>2,49</td>
</tr>
<tr>
<td>ungrazed</td>
<td></td>
<td>stnd. err.</td>
<td>0,139</td>
<td>2,583</td>
<td>0,218</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95% c.1</td>
<td>0,34</td>
<td>6,32</td>
<td>0,53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>range</td>
<td>1,44-2,96</td>
<td>20,5-44,0</td>
<td>1,34-2,46</td>
</tr>
<tr>
<td>Perm. pasture</td>
<td>10</td>
<td>mean</td>
<td>2,13</td>
<td>34,63</td>
<td>1,63</td>
</tr>
<tr>
<td>lightly grazed or mown</td>
<td></td>
<td>stnd. err.</td>
<td>0,141</td>
<td>2,460</td>
<td>0,101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95% c.1</td>
<td>0,32</td>
<td>5,56</td>
<td>0,23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>range</td>
<td>1,10-1,48</td>
<td>12,9-26,2</td>
<td>1,25-1,45</td>
</tr>
<tr>
<td>High yielding row crops</td>
<td>8</td>
<td>mean</td>
<td>1,26</td>
<td>18,63</td>
<td>1,37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>stnd. err.</td>
<td>0,058</td>
<td>1,516</td>
<td>0,052</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95% c.1</td>
<td>0,14</td>
<td>3,59</td>
<td>0,08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>range</td>
<td>0,36-0,8</td>
<td>0,9-9,3</td>
<td>1,11-1,32</td>
</tr>
<tr>
<td>Low yielding row crops and</td>
<td>5</td>
<td>mean</td>
<td>0,52</td>
<td>3,49</td>
<td>1,20</td>
</tr>
<tr>
<td>bare ground</td>
<td></td>
<td>stnd. err.</td>
<td>0,078</td>
<td>1,52</td>
<td>0,035</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95% c.1</td>
<td>0,22</td>
<td>4,23</td>
<td>0,10</td>
</tr>
</tbody>
</table>

Means are significantly different at the 5% level for all indices.
c.1 = Confidence limits + or -
FIG. 1. RELATIONSHIP BETWEEN SOIL LOSS, RUNOFF AND MEAN WEIGHT DIAMETER OF WATER-STABLE AGGREGATES. QUADRATIC FORMS.
FIG. 2. RELATIONSHIP BETWEEN MEAN WEIGHT DIAMETER WATER-STABLE AGGREGATES AND ORGANIC CARBON. CUBIC FORM.
In Table 4 the results of the bi-variate analysis for the discing experiment are presented, showing only those relationships with a significance better than 5% (i.e. 0.05 level or 95% confidence).

The relationships between the amounts of fines passing the 53 micron sieve (AGD6) and the number of tillage operations for the three types of equipment are shown in Table 5; and the variance analyses are given in Table 6.

### Table 4: Bi-variate Analysis for Parameters in Discing Experiment

<table>
<thead>
<tr>
<th>Dep. Var.</th>
<th>Ind. Var.</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(r)</th>
<th>(p)</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGG2</td>
<td>ND</td>
<td>3,287</td>
<td>-0,054</td>
<td>-0,66</td>
<td>5</td>
<td>0,410</td>
</tr>
<tr>
<td>AGD6</td>
<td>ND</td>
<td>3,727</td>
<td>0,155</td>
<td>0,98</td>
<td>0,1</td>
<td>0,204</td>
</tr>
<tr>
<td>Soil Loss</td>
<td>ND</td>
<td>110,7</td>
<td>5,027</td>
<td>0,91</td>
<td>0,1</td>
<td>14,87</td>
</tr>
<tr>
<td>Soil Loss</td>
<td>AGD6</td>
<td>-1,848</td>
<td>30,85</td>
<td>0,89</td>
<td>0,1</td>
<td>16,86</td>
</tr>
<tr>
<td>Runoff</td>
<td>ND</td>
<td>9,722</td>
<td>0,026</td>
<td>0,64</td>
<td>5</td>
<td>0,206</td>
</tr>
<tr>
<td>Runoff</td>
<td>AGD6</td>
<td>9,068</td>
<td>0,172</td>
<td>0,68</td>
<td>5</td>
<td>0,196</td>
</tr>
<tr>
<td>Soil Loss</td>
<td>Runoff</td>
<td>-726,9</td>
<td>88,99</td>
<td>0,65</td>
<td>5</td>
<td>27,73</td>
</tr>
</tbody>
</table>

ND = No. of discings = 20; No. of pairs of observations = 11;  
\(p\) = significance level expressed as a percentage; and  
SE = standard deviation of the mean of dependent variate.
TABLE 5: BI-VARIATE ANALYSIS WITH AG06 (DEP.VAR.) ON THE NUMBER OF OPERATIONS FOR THREE TILLAGE IMPLEMENTS

<table>
<thead>
<tr>
<th>Implement</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$r$</th>
<th>$p$</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cage roller</td>
<td>3.78</td>
<td>0.106</td>
<td>0.90</td>
<td>0.1</td>
<td>0.285</td>
</tr>
<tr>
<td>Disc harrow</td>
<td>3.39</td>
<td>0.057</td>
<td>0.74</td>
<td>5</td>
<td>0.280</td>
</tr>
<tr>
<td>Spring tine</td>
<td>3.56</td>
<td>0.045</td>
<td>0.50</td>
<td>Nil</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* not significant at the 5% level;

No. of pairs of observations = 9

TABLE 6: DIFFERENCE BETWEEN TREATMENT MEANS COMPARED TO THE TINE

<table>
<thead>
<tr>
<th></th>
<th>Cage Roller</th>
<th>Disc harrow</th>
<th>Tine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Start of the experiment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil loss</td>
<td>0.3°</td>
<td>0.5°</td>
<td>0</td>
</tr>
<tr>
<td>Runoff</td>
<td>0.3**</td>
<td>0.7**</td>
<td>0</td>
</tr>
<tr>
<td>2. Finish of the experiment - differences between treatments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil loss</td>
<td>19.9**</td>
<td>24.4**</td>
<td>0</td>
</tr>
<tr>
<td>Runoff</td>
<td>1.4**</td>
<td>1.2**</td>
<td>0</td>
</tr>
<tr>
<td>3. Between start and finish - differences within treatments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil loss</td>
<td>17.0*</td>
<td>22.3**</td>
<td>2.6°</td>
</tr>
<tr>
<td>Runoff</td>
<td>3.2**</td>
<td>3.4**</td>
<td>1.5**</td>
</tr>
</tbody>
</table>

* Not significant at the 5% level.
* Significant at the 1% level.
** Significant at the 0.1% level.
In the discing experiment, (Table 4), the size of water-stable aggregates in this poorly-structured soil (AGG2+3%) was affected little (a=0.054) by successive discings but a significant change occurred in the amount of 'fines' in the soil AGD6. This is reflected by the higher correlation (r=0.98) and greater significance level (0.1%) and slope to the regression line (0.155). AGD6 proved to be significantly correlated to runoff and soil loss whereas MWDD and other dry size-fractions greater than 53 microns were not. However, greater variation was observed in soil loss at the higher levels of AGD6, indicating a complex interaction between soil properties and erosion. Soil in this state (high AGD6) sometimes became compact during the 1000 units of energy uniformity treatment. When this occurred, lower soil losses than anticipated were recorded from the monitoring run while apparently similar samples gave the expected high losses. On the other hand, runoff did not increase further once the minimum infiltration rate had been reached at an AGD6 value of about 5%. Observations have since confirmed that this phenomenon can also occur on field-size plots.

AGD6 was used to monitor the influence of the three tillage implements on soil erodibility, (Table 5). The cage roller pulberised the soil most (a1=0.106), followed by the disc harrow (a1=0.057). No significant effect could be shown for the spring tine. The soil in this experiment was in better condition (AGG2+13%) than that in the previous discing experiment and showed a lower rate of breakdown per operation with a1=0.057, (Table 5) compared to 0.155 (Table 4).

The analysis in Table 6 Section 1 confirms that there were no significant differences in soil loss from the plots before the start of the implement experiment. But by the end of the experiment, Section 2, soil losses from the cage roller and disc treatments were very significantly higher than from the tine. Section 3 confirms that no significant change had taken place on the tine treatment during the experiment, whereas highly significant changes had occurred on the other two. Similar major differences in runoff were recorded, although the effects were somewhat obscured by the significant differences between plots at the start of the experiment, Section 1. Nevertheless the magnitude of the differences had increased markedly by the end of the experiment (Section 2). A significant change in runoff occurred on the tine treatment, (Section 3) but much greater increases took place on the other two treatments.
CONCLUSIONS

The experiments show that, on this soil type, percent organic carbon and indices based on water-stable aggregates have application for managing the vegetative aspects of land use; while the amount of fines passing the 53 micron sieve will assist in the selection of suitable tillage implements.

On the arable land, practices such a mauring, return of residues, mulching, green cropping and fallow periods should be encouraged to improve soil structure; while great care is needed to select implements which will not pulverise the soil.

More detailed information is required on the extent to which the wide variety of field practices influence the value of the monitoring indices; and the possibility of a relationship existing between grazing pressure and soil condition should be investigated as tool for achieving better veld management.

The results show the greater extent to which soil erodibility can vary with time depending on crop type, crop management and tillage practices. Continuing research at the Institute is indicating that erodibility is also a function of time of year, and of both short and long term fluctuations in climate; drought in particular seems to have a marked effect. In view of this dynamic nature of tropical soils, the wisdom of considering the erodibility of a soil to be a constant is questionable.

ACKNOWLEDGEMENTS

The neighbouring ART farm provided the equipment and ground required for the implement test.
REFERENCES


THE EFFECT OF SUNLIGHT ON THE MANGANESE REDOX CYCLE IN ZIMBABWEAN RED CLAY SOILS

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Department of Chemistry, University of Zimbabwe
P.O. Box MP 167, Mt Pleasant, HARARE
SUMMARY

One of the most puzzling features of the chemistry of manganese in Nature is the apparent ease with which the divalent manganese (II) ion is oxidized in acidic environments. Such acidic conditions are found, for example, in many Zimbabwean red clay soils. This 'acidic' oxidation of manganese (II) is difficult to achieve in the laboratory even under neutral conditions, and microorganisms have long been thought to be responsible for the oxidation in natural environments. In this paper a novel photo-chemical reaction is discussed which can explain this 'acidic' oxidation of manganese (II) without involving the role of microorganisms. The reaction is rapid in direct sunlight and specifically requires nitrate. Some recent work on an acidic-carbohydrate reduction reaction of manganese dioxide is also included in the paper. The nitrogen-carbon redox cycle in soils is discussed in the light of these reactions.

INTRODUCTION

There are many paradoxical features of the redox chemistry of manganese in the soil environment which in various respects challenge conventional chemical wisdom. For example, the reduction of manganese dioxide in water-logged soils of low pH or high acidity is well known (Russel, 1950, p. 473) and readily demonstratd in the laboratory (Page, 1962). But the converse, the oxidation of divalent manganese-manganese (II) ion - in acid aqueous solution, has been widely observed in wet but well-drained acid soils (Mann and Quastel, 1946; Tanner, 1977). This acidic oxidation is surely of unusual interest to chemists because it is unknown in the laboratory (Cotton and Wilkinson, 1980).

Again, while the reduction of manganese dioxide under de-aerated, that is, water-logged conditions is well established in wet soils and is a common cause of manganese toxicity in rice and bog soils (Ponnampemura, Loy and Tianco, 1968; Williams
and Joseph, 1970), the reduction of this oxide in free-draining acid soils has also been observed under drying conditions (Bartlett and James, 1970). Tanner (1966, 1977) has also observed this type of reduction in Zimbabwean red clay soils. It is possible that this reduction by drying may explain why air-dried soil samples tend to deteriorate with storage.

The Zimbabwean red clays and clay loams are rich in iron and its companion element manganese. The red clay soils on the U.Z. campus, for example, have a total iron content of 13-15% wt Fe and a total manganese content of 0.2 - 0.25% Wt Mn (2000-2500 ppm Mn). These values are typical of soils in the locality and Mn:Fe ratios consistently fall within the world average range for crustal rocks and soils (Ure and Berrow, 1977). Grant, Tanner and Madziva (1973) found manganese levels of 2 700 to 3 600 ppm in soils derived from dolerites and banded ironstones.

Tanner's studies (1966, 1977) on these red soils deserve special attention because they touch on many of the most puzzling features of the redox chemistry of manganese. His observations here are summarized as follows:

(i) Manganese oxides are reduced as the soils dry out in the winter months, with the 'available' or divalent manganese reaching a peak at the end of the dry season.

(ii) The 'available' manganese is rapidly reoxidized or 'fixed' as soon as the rains commence, accompanied by a rapid decrease in soil pH.

The pH of unlimed soils used in Tanner's studies falls in all cases in the range pH 4.3 - 4.9. It is assumed here, although not stated by Tanner (1977), that the pH of unlimed soils used in his study underwent seasonal cyclic changes. Thus while wet oxidation of divalent manganese is accompanied by a decrease in pH, reduction of manganese oxides under drying
conditions will be accompanied by an increase in pH, for otherwise, an irreversible pH decrease would result.

At first sight, Tanner's observations can be simply explained in terms of the equilibrium (All thermodynamic values quoted in this paper are taken from Latimer, 1952, at 298K - 25°C):

(1) \[ 2\text{MnO}_2 + 4\text{H}^+ = 2\text{Mn}^{2+} + \text{O}_2 + 2\text{H}_2\text{O}; \Delta G^{\circ} \approx 0 \text{ kcal mol}^{-1}. \]

As an acid soil dries out, the hydrogen-ion concentration will increase, the soil pH will decrease, and the dissolution of manganese dioxide will shift to the right in equation (1). But, as noted above, the oxidation reaction to the left in equation (1) is unknown in the laboratory. In aerated acid solution (pH<7) divalent manganese has always been regarded as indefinitely stable (Cotton and Wilkinson, 1980).

In this paper, we seek to interpret these observations by Tanner of the chemical behaviour of manganese in the red clays in terms of some novel redox reactions which have been investigated by the authors during the last two years.

**THE ACIDIC OXIDATION OF DIVALENT MANGANESE**

In aerated solution, at a concentration of 0.1 mol L\(^{-1}\), divalent manganese is oxidized only at pHs above 7.6; at lower concentrations oxidation takes place only at pHs greater than this value. For example, at 1 x 10\(^{-5}\) mol L\(^{-1}\), oxidation does not take place until a pH of 9.2 is reached (Coughlin and Matsui, 1976; Bals and Mesmer, 1976).

Although the free energy change for the oxidation reaction (1) is not unfavourable, it has generally been assumed by chemists that the reason oxidation does not take place in acid solution is that it involves the formation of trivalent manganese, or a trivalent manganese oxo species, as an intermediate. This ion, which is unstable, then disproportionates in solution.
to give divalent manganese and manganese dioxide, according to the scheme:

\[(2.\text{i})\ 2\text{Mn}^{2+} + \frac{1}{2}\text{O}_2 + 2\text{H}^+ = 2\text{Mn}^{3+} + \text{H}_2\text{O}; \Delta G^0 = 12.5 \text{ kcal mol}^{-1}\]

\[(2.\text{ii})\ 2\text{Mn}^{3+} + 2\text{H}_2\text{O} = \text{Mn}^{2+} + \text{MnO}_2 + 4\text{H}^+; \Delta G^0 = -12.5 \text{ kcal mol}^{-1}\]

the sum of which yields equation (1). By this scheme, reaction (2.\text{i}) is clearly unfavourable and acts as a check on oxidation. There is direct chemical evidence to support the view that trivalent manganese is the active intermediate in this acidic oxidation; for example, from the pulse radiolysis studies of manganese (II) perchlorate solutions by Pick-Kaplan and Rabani (1976). It is also well known that powerful oxidizing agents such as permanganate can oxidize manganese II manganese III in acid solution.

In the soil environment, however, the existence of such oxidizing agents appears most unlikely. Then how does this oxidation occur in acid soils?

**TABLE 1. MANGANESE (II) MICROORGANISMS AND OPTIMAL pH RANGES OF OXIDATION**

<table>
<thead>
<tr>
<th>Organism</th>
<th>Optimal pH Range</th>
<th>Notes</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Chlorococcum humicolum</em></td>
<td>4.5 - 6.5</td>
<td>a,s(pH5),p</td>
<td>Bromfield (1976)</td>
</tr>
<tr>
<td>Numerous bact.</td>
<td>6.0 - 7.5</td>
<td>s,e</td>
<td>Leeper and Swaby (1940)</td>
</tr>
<tr>
<td><em>Corynebact. chromobact.</em></td>
<td>4.2 - 7.0</td>
<td>s,e</td>
<td>Bromfield and Skerman (1950)</td>
</tr>
<tr>
<td><em>Streptomyces sp.</em></td>
<td>4.5 - 6.5</td>
<td>f,s,e, + i (MnO2 formed in aerial mycelia)</td>
<td>Bromfield (1978), 1979</td>
</tr>
<tr>
<td><em>Arthrobact. sp.</em></td>
<td>5.4 - 7.9</td>
<td>s</td>
<td>Bromfield and David (1976)</td>
</tr>
<tr>
<td><em>Cephalosporium sp.</em></td>
<td>&gt; 4.0</td>
<td>s</td>
<td>Ivarson and Heringa (1972)</td>
</tr>
</tbody>
</table>

Notes:  
- a: alga;  
- f: fungus;  
- s(pH): soil and soil pH;  
- e: extracellular oxidation;  
- i: intracellular oxidation;  
- p: photosynthetic organism.
In want of a simple chemical explanation, the generally accepted view today is that manganese (II) is oxidized by bacteria and other microorganisms. The early work in this field has been reviewed by Mulder and Gerretsen (1951) and by Zavarsin (1966). Table 1 presents a brief, though inevitably very selective summary of recent work, but indicates the diversity of organisms involved. As can be seen from this table, the operational pH range of many of these microorganisms is very low. The oxidative ability of these organisms was demonstrated by culturing soil extracts in vitro, in a variety of media.

Little is known, however, of the chemistry involved in the oxidation of manganese (II) by microorganisms, and, in particular, whether an oxidizing agent other than oxygen is involved; see reactions (1) and (2.i). Bromfield (1979) has shown that a soil streptomyces species produced a non-dialysable exudate which oxidized manganese (II). In an earlier study, Bromfield and Skerman (1950) isolated two bacteria which were unable to oxidize manganese (II) separately, but did so together or soil-agar plates.

Furthermore, if the biotic oxidation of manganese (II) proceeds via reaction step (2.i), then a free energy input would be required. But it is not clear whether the source of this free energy would be the organism itself or an extraneous one. However, there are certain pointers here. Bromfield (1976), in a study of the alga Chlorococcum humicolum has suggested that light may be important, citing the demonstration by Kenten and Mann (1955) of the oxidation of manganese (II) solutions by free chloroplasts under illumination.

Key and Marks (1984) reported a novel sunlight-induced oxidation reaction of divalent manganese. The reaction specifically involves nitrate and occurs in acid solution over a wide pH range: 4.2 - 7.6. The reaction can be represented by the scheme:

\[
(3) \quad \text{Mn}^{2+} + \text{NO}_3^- + \text{H}_2\text{O} \xrightarrow{\text{sunlight}} \text{MnO}_2, \text{NO}_2^-, \text{O}_2, \text{H}^+
\]

All products have been identified, although oxygen is produced.
only in trace amounts, possibly as the product of some side reaction. If this is the case, the main reaction can be tentatively formulated as

\[
(4) \quad \text{Mn}^{2+} + \text{H}_2\text{O} + \text{NO}_3^- \xrightarrow{h\nu} \text{MnO}_2 + \text{NO}_2^- + 2\text{H}^+
\]

Some details of the reaction are summarized in Table 2. Interestingly, the pH range of the reaction closely corresponds to the pH range of manganese-oxidizing microorganisms. There is evidence in Russell (1950, pp 50) suggesting an antagonistic relationship between divalent manganese and nitrate (in one case as nitrifiable nitrogen).

**TABLE 2. - CHARACTERISTICS OF THE SUNLIGHT-INDUCED OXIDATION REACTION OF DIVALENT MANGANESE BY NITRATE**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH range: 4.2 - 7.5 The pH decreases in the course of the reaction.</td>
</tr>
<tr>
<td>2.</td>
<td>Minimal pH attained: 4.2</td>
</tr>
<tr>
<td>3.</td>
<td>Concentration ranges [Mn²⁺]: 1 x 10⁻⁵ - 1.0 mol L⁻¹ [NO₃⁻]: 1 x 10⁻⁵ - 4.0 mol L⁻¹</td>
</tr>
<tr>
<td>4.</td>
<td>Nitrate salts: K⁺, Na⁺, NH₄⁺, Mn²⁺</td>
</tr>
<tr>
<td>5.</td>
<td>Manganese salts: NO₃⁻, Cl⁻, SO₄²⁻</td>
</tr>
<tr>
<td>6.</td>
<td>Product identification:</td>
</tr>
<tr>
<td></td>
<td>MnO₂: by benzidine acetate test; composition MnO₂ by AA.</td>
</tr>
<tr>
<td></td>
<td>NO₂⁻: by a diazotization reaction</td>
</tr>
<tr>
<td></td>
<td>O₂: by oxygen electrode (under N₂ in N₂-deaerated solutions)</td>
</tr>
<tr>
<td></td>
<td>by gas chromatography (under He in He-deaerated solutions)</td>
</tr>
<tr>
<td>7.</td>
<td>Optimal wavelength: reaction ceases at wavelengths longer than 530 nm</td>
</tr>
<tr>
<td>8.</td>
<td>Kinetics: Reaction is rapid in direct sunlight. Visible signs of oxidation are observable within 15 minutes for manganese (II) nitrate solution, concentration: 1 x 10⁻² mol L⁻¹</td>
</tr>
</tbody>
</table>
THE ACIDIC REDUCTION OF DIVALENT MANGANESE

Besides the question of how microorganisms oxidize manganese, there is the question why? It has been suggested that manganese dioxide is important to many organisms as an oxidizing agent of organic matter (Mulder and Gerretsen, 1951). In acid solution manganese dioxide is a powerful oxidizing agent of carbohydrate materials with a high C:N ratio (Fujimoto and Sherman, 1948). Ammonium salts and proteinaceous materials are not oxidized, however. Thus, the C:N ratio would tend to fall in the course of this oxidation reaction.

The reaction can be represented by the equation:

\[ \text{C}_x(\text{H}_2\text{O})_y + 2x\text{MnO}_2 + 4x\text{H}^+ = x\text{CO}_2 + (y + 2x)\text{H}_2\text{O} + 2x\text{Mn}^{2+} \]

with a free energy change

\[ \Delta G^o = -94.5x - 56.77 - \Delta G_f^o (\text{C}_x(\text{H}_2\text{O})_y) \text{ kcal mol}^{-1} \]

For formaldehyde \((x = 1, y = 1, \Delta G_f^o (\text{C}_x(\text{CH}_2\text{O})) = 31.0 \text{ kcal mol}^{-1})\),

\[ \Delta G^o = -120.2 \text{ kcal mol}^{-1} \]

For D - glucose \((x = 6, y = 6)\),

\[ \Delta G^o = -690.0 \text{ kcal mol}^{-1} \]

and for sucrose \((x = 12, y = 11)\),

\[ \Delta G^o = -1371.6 \text{ kcal mol}^{-1} \]

Thus considerable energies are released. Since the free energy for reaction (5) is strongly negative, it is evidently far more important than reaction (1) under the same pH conditions, as a source of manganese (II), so long as suitable organic matter is also available.

This is confirmed in practice. The effects of this acid reduction were compared with reaction (1) using air-dried straw and an ultra pure form of cellulose in sulphuric and nitric acids. The initial pH was deliberately set low to control bacteria and other microorganisms. Drying was carried out at 80°C to minimize bacteriological activity. Experimental
details are given below.

**MATERIALS**

Air-dried straw, chopped in lengths of 2 cm.
MK cellulose, Merck.
Manganese Dioxide, precipitated, BDH laboratory - Reagent.
Nitric Acid, BDH 'Analar', 0.388 mol L\(^{-1}\)
Sulphuric Acid, BDH 'Analar', 0.295 mol L\(^{-1}\)

**METHODS**

Mixtures were made up in quadruplicate as follows:
100 ml of acid, 20g straw or MK cellulose, 2g precipitated MnO\(_2\) according to the scheme indicated in Table III.

After initial pH measurements were taken, mixtures were heated to dryness in an oven preset at 80°C. This drying process took about 36 hours. The mixtures were then removed from the oven, air-cooled and reconstituted to the original volume with double-distilled water. pH measurements were made one hour after rewetting. In the case of mixtures treated with nitric acid, precautions were taken to exclude light while cooling by wrapping the beakers with aluminium foil. The process of drying and rewetting was repeated six times.

**Manganese analysis:** 10 ml of solution was removed from each mixture after the first and sixth drying and rewetting cycle. The solution was filtered to remove solid manganese dioxide. 5 ml of filtrate was withdrawn with a pipette and transferred to a 100 ml volumetric flask. 1 ml of concentrated hydrochloric acid was added to control microorganisms and the solution was made up to the mark with double-distilled water. Solutions for analysis were stored in polythene bottles. The remaining filtrate solution and as much as possible of the filtered MnO\(_2\) was returned to the original mixture. However, in no case was all the MnO\(_2\) consumed and so the loss of some MnO\(_2\) could not lead to any serious error. Manganese analysis was carried out using an atomic absorption spectrophotometer.
OBSERVATIONS

In all cases, where straw or MK cellulose was a component of the mixture the measured pH showed a steady rise over the first three cycles but tended to level off after the fourth. The pH rise in acid-manganese dioxide, acid-straw and acid-MK cellulose mixtures, was far smaller than mixtures where all components (straw or MK cellulose) were present. The straw in acid-MnO₂-straw mixtures was bleached in comparison to mixtures consisting only of acid and straw alone.

RESULTS AND DISCUSSION

The results are presented in Table 3. The effectiveness of carbohydrates on the reduction of manganese dioxide compared to the simple acid reduction reaction (1) is quite evident.

Similar results have been demonstrated in acidic manganese-rich soils. Fujimoto and Sherman (1948) observed spectacular increases in the available manganese in Hawaiian soils after treatment with sucrose, ground pineapple leaves and other cellulose materials. The reduction of manganese dioxide by glucose in soils has also been demonstrated by Mann and Quastel (1946). They interpreted this reduction as being biological in origin.

It seems likely that many soil microorganisms may have harnessed reaction (5) and even reaction (3) to their own advantage; there being considerable gains both in free energy and nutrient supply by doing so. At the same time, it must be recognised that both reactions (3) and (5) are inorganic processes. The hypothesis advanced by Mann and Quastel (1946) that the redox transformations of soil manganese are essentially biological in nature is therefore questionable.
REDOX CYCLES OF MANGANESE

The general points that emerge from the redox reactions of manganese, discussed in this paper, can be more clearly seen by representing these reactions as a system of contiguous redox cycles as shown in Fig 1.

TABLE 3. - COMPARISON OF THE EFFECTS ON THE REDUCTION OF MANGANESE DIOXIDE BY ACID, AND BY ACID-CARBOHYDRATE MIXTURES.
(Each line performed in quadruplicate. f : final)

<table>
<thead>
<tr>
<th>Carbohydrate</th>
<th>Acid</th>
<th>MnO₂</th>
<th>pHf</th>
<th>±</th>
<th>[Mn²⁺]f/ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>straw</td>
<td>Nitric</td>
<td>+</td>
<td>6.2</td>
<td>0.2</td>
<td>8250 ± 180</td>
</tr>
<tr>
<td>straw</td>
<td>Nitric</td>
<td>-</td>
<td>2.8</td>
<td>0.1</td>
<td>3 ± 1</td>
</tr>
<tr>
<td>-</td>
<td>Nitric</td>
<td>+</td>
<td>4.5</td>
<td>0.3</td>
<td>570 ± 20</td>
</tr>
<tr>
<td>MKCell</td>
<td>Nitric</td>
<td>+</td>
<td>5.4</td>
<td>0.2</td>
<td>4100 ± 1000</td>
</tr>
<tr>
<td>MKCell</td>
<td>Nitric</td>
<td>-</td>
<td>1.8</td>
<td>0.05</td>
<td>&lt;1</td>
</tr>
<tr>
<td>straw</td>
<td>Sulph.</td>
<td>+</td>
<td>6.4</td>
<td>0.2</td>
<td>8800 ± 1750</td>
</tr>
<tr>
<td>straw</td>
<td>Sulph.</td>
<td>-</td>
<td>1.9</td>
<td>0.3</td>
<td>8 ± 1</td>
</tr>
<tr>
<td>-</td>
<td>Sulph.</td>
<td>+</td>
<td>2.1</td>
<td>0.2</td>
<td>1100 ± 80</td>
</tr>
<tr>
<td>MKCell</td>
<td>Sulph.</td>
<td>+</td>
<td>6.1</td>
<td>0.3</td>
<td>2600 ± 1500</td>
</tr>
<tr>
<td>MKCell</td>
<td>Sulph.</td>
<td>-</td>
<td>1.9</td>
<td>0.3</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Cycles L and M are adapted from the manganese redox diagram of Mann and Quastel (1946). The oxidation of nitrite to nitrate and the photosynthetic reduction of carbon dioxide have been included for completeness.

The redox cycles shown in Fig 1 are arranged as a closed system. In the soil environment, however, such a closed system will only be approached in wet conditions when the photosynthetic reduction of CO₂, cycle M, can proceed. In drying conditions, CO₂ will continue to be lost via the L-M couple. Furthermore, nitrite oxidation, cycle K, must compete with various denitrification processes, including those affected by microorganisms. In this
FIGURE 1. Schematic Diagram of the Redox Chain

- $\text{H}_2\text{O}$
- $\text{O}_2$
- $\text{NO}_3^-$
- $\text{NO}_2^-$
- $\text{MnO}_2$
- $\text{Mn}^{2+}$
- $\text{CO}_2$
- $\text{CH}_2\text{O}$

Free Energy Release
Photon Capture

Photosynthesis
connection, in soils where the main source of nitrate is ammonium nitrate fertilizer, the decomposition reaction,

\[ \text{NH}_4\text{NO}_2 = \text{N}_2 + 2\text{H}_2\text{O} \]

is likely to be a significant contributor to denitrification. Other nitrate-loss reactions have been investigated by Nelson and Bremner (1969).

Nitrite oxidation, cycle K, has an extensive chemical literature, but many microorganisms are able to perform this oxidation efficiently. In this case, the role of both nitrate and manganese in cycles K and L would be essentially catalytic so that only low nitrate and manganese levels would be required by the organism concerned. Such microorganisms would have achieved the efficient conversion of sunlight into chemical free energy and the release of nutrients from the breakdown of organic matter at no cost to themselves.

The system of cycles can be expected to work continuously in the biotic zone of wet-aerated soils. Addition of nitrate as a top-dressing would suppress the level of available manganese and increase the oxidation of organic matter releasing nutrients into the soil, via couples K-L and L-M. Depletion of organic matter would lead to a decrease in pH via couple K-L. Increasing the organic matter content would increase the level of available manganese but also increase the pH. High (alkaline) soil pHs would tend to suppress the reactions forming cycles K and L. The available manganese would be oxidized spontaneously and nitrite would accumulate in the soil. It is likely that these conditions would occur in over-limed soils.

Under drying conditions, the photooxidation of manganese (II) would cease (couple K-L), while the reduction of manganese dioxide by organic matter would continue since this is essentially a contact reaction. Thus the level of available manganese would increase in the dry-season, in agreement with Tanner's findings.
Because the photooxidation reaction (3), couple K-L, can only occur at the surface of a soil, this leads naturally to the question of how significant the overall process is in the soil environment. If vertical movement within the soil profile is negligible, then fairly obviously, reaction (3) would be of little significance. Such a stasis is seldom observed in a soil profile, however, since there is considerable movement of soluble ions to the surface of the soil as a consequence of physical processes including capillary action and evaporation. Mixing at the surface of the soil would be enhanced by penetrating rain and the actions of soil invertebrates. There is also some evidence that light can be "pumped" into the soil. Mandoli and Briggs (1984a, b) have shown that the roots of germinating plants act as fibre optic systems. Their work could explain earlier reports of oxidation of divalent manganese in the root zone of plants by Russel (1950, p. 50).

More speculatively, there is some evidence to suggest that the system of cycles: KLM may operate synchronously in plants albeit in a highly modified form. Losada and Guerrero (1979) have recently suggested that manganese is involved in photosynthetic nitrate assimilations. Manganese is certainly involved in the water-splitting reactions of photosystem II, which, despite the name, is the primary induction step in photosynthesis. The findings of Kenten and Mann (1955) appear relevant here. This subject has recently been reviewed by Porter (1978). Thus it is possible that plants may represent in their biochemical pathways, systems of reactions which have been adapted from soils.

CONCLUSION

Speculation aside, the photooxidation reaction (3) is the only known example of the oxidation of divalent manganese in acid solution, which does not require the action of powerful oxidizing agents, but possibly of greater significance is the fact that the reaction is rapid in green light and at wavelengths shorter than this (< 500 nm), that is, towards the high energy end of the visible spectrum. It is the light in this part of
the visible spectrum and in the near UV which is very strongly absorbed by the red soils. These soils emit and reflect radiation at longer wavelengths, in the low-energy red and infra-red end of the spectrum. Hence the striking colour of these soils to our eyes. Thus it would appear probable that other, but presently unknown, high-energy photochemical transformations are performed on the exposed surfaces of these soils.
REFERENCES


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Prof J P Watson

2. INTRODUCTION

A wide ranging and interesting discussion was held. The main recommendations are summarized below under the following headings: definitions, research, training and general.

3. DEFINITION OF THE TERM RED SOIL

The following definition is recommended: "A red soil is:

(i) that has a hue redder than 5YR, or

(ii) has a moist rubbed colour in the major part of the B horizon which has a hue of 5YR and a chroma of more than 4"

NOTE:
1. The colour should be a definite 5YR or redder and not a colour transitional to 7.5YR
2. The red soils as defined above should be subdivided according to other criteria. They could for instance, be subdivided into weakly leached, moderately leached and strongly leached divisions on the basis of certain soil properties.

4. RESEARCH RECOMMENDATIONS

Research is needed in the following areas:

4.1 SOIL MINERALOGICAL RESEARCH

There is a definite need for information on the mineralogy of the clay and silt fractions of these soils.
4.2 RESEARCH ON SOIL PHYSICAL PROPERTIES

Further research is needed on soil physical properties. The properties of hard-setting and crusting soils, for example, are not fully understood.

4.3 RESEARCH ON SOIL GENESIS

The relationship between soils and geomorphology needs to be investigated. The relationship between soils and vegetation also deserves further study.

4.4 RESEARCH ON WET LAND SOILS

It should be noted, however, that most of these are lower catenal members of some red soils and are not, themselves, red.

4.5 RESEARCH ON SOIL CAPABILITY

Further research should be undertaken on land capability using, for example, the Benchmark methodology.

4.6 RESEARCH IN LAND EVALUATION

Further research is required on the methodology of land evaluation.

4.7 SOIL SURVEY INTERPRETATION RESEARCH

Methods of interpretation of soil surveys should be developed. More information is needed on the soil requirements of different crops.

5. TRAINING RECOMMENDATIONS

5.1 TRAINING OF EXTENSION AND AGRONOMY STAFF

Agricultural extension and agronomy staff should receive training in basic soil science in order to help bridge the communication gap existing between them and pedologists.

5.2 TRAINING OF SOIL TECHNICIANS

Persons should be trained in soil science and soil survey at College level for employment as soil survey technicians in support of professional soil scientists.
6. **GENERAL RECOMMENDATIONS**

6.1 **STANDARDISATION OF METHODS OF SOIL ANALYSIS**

Methods of soil analysis should be standardised. A particle size analysis, for example, can in some cases give different results according to whether or not iron oxides are removed from the sample.

6.2 **GENERAL PURPOSE SOIL SURVEYS**

General purpose soil surveys should be made as complete as possible so that they can be interpreted for various uses.

6.3 **SPECIAL PURPOSE SOIL SURVEYS**

When an organisation commissions a soil survey the objective of the soil survey should be made clear to the pedologists who undertake the work.

6.4 **SOIL SURVEY REPORTS**

Soil survey reports should be made user-friendly. Interpretations of the soil data must therefore be included in the report.

6.5 **SOIL CORRELATION**

Soil survey reports should include an international soil classification (e.g. FAO legend or Soil Taxonomy) in addition to the local classification of the soils.
GROUP 2: RESEARCH NEEDS IN SOIL FERTILITY AND CROP NUTRITION

Chairman : Prof K Syers (UK)
Rapporteur : Dr O Lungu (Zambia)

1. CONSTRAINTS

The working group recognized data gaps in the following areas of soil fertility and crop nutrition.

1. Soil acidity and liming: Aluminium saturation was suggested to be the desirable basis for lime requirement determination, and liming to eliminate 80% of Al would be satisfactory. The cost of transporting lime was highlighted, and research into alternatives for lime such as manure, and woodash was urged.

2. Nutrient status: Deficiency of major plant nutrients particularly phosphorus is a problem needing close attention. For most countries, phosphorus represents a major cost because it is imported.

3. Soil testing was recognized as being important in order to increase fertilizer efficiency. Particular attention is required in soil sampling for soil testing, calibration of soil test values and crop response in the field needs to be carried out.

4. Fertilizer addition: The major problem in this area is the inadequate amounts of fertilizer available to the farmer. Use of local materials and regional production of fertilizer needs was seen as some of the solutions to the problem. Ammonium phosphate was suggested as a good fertilizer because of the higher P utilization from it than other forms of P fertilizer. Use of calcium ammonium nitrate especially in the acid, low Ca soils should be encouraged.

5. Organic matter management: Management practices that build up soil organic matter should be encouraged. Manure is a good source of plant nutrients and has beneficial effects on the physical properties of soils.

6. Fertility indices: Studies in this area were needed to get fertility indices which could be used for soil classification purposes. One such index parameter could be phosphorus retention.
2. **RESEARCH NEEDS**

The overall objective of research in soil fertility and crop nutrition should be to develop cost-effective crop production and improve fertilizer efficiency. This could be accomplished as follows:

1. Do research on the major plant nutrients particularly because of its cost. The evaluations should, where possible, be done on the farms.

2. Evaluate indigenous fertilizer materials and by-products from industry as source of plant nutrients.

3. Carry out adequate calibrations of laboratory procedures and, possibly, in association with an indepth study of crop physiological measurements in order to obtain soil-test crop response correlations.

4. Study and understand the lime - phosphorus interaction in soils which so far gives contradictory results.
GROUP 3  EROSION, CONSERVATION AND SOIL MANAGEMENT

Membership

Members of the group

M A Stocking  United Kingdom (Chairman)
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We agreed to divide up the consideration into three main sectors:

- DEFINING THE PROBLEM
- OUR EXISTING LEVELS OF KNOWLEDGE
- REQUIREMENTS IN RESEARCH AND IMMEDIATE ACTION

1. DEFINING THE PROBLEM

Agreed that erosion on red soils is a major problem.
Distinguish between erosion and degradation
- where erosion is the physical loss of soil and degradation includes erosion and biological, chemical and structural deterioration.

In many cases these will occur together, but a particular problem with red soils was loss of organic matter.

The problem can be summarised as losing the total fertility of the soil and undermining its productive potential. It is therefore, essentially a management problem but mostly seen within the contexts of:

- the total landscape
- the farming system; many cannot keep up organic matter levels
- the socio-economic background; including ability to utilize technical information, subsidies, high population pressures.
2. **EXISTING LEVELS OF KNOWLEDGE**

It comes back time and time again that we had inadequate knowledge. However, we can make some generalizations:

(a) Erosion levels can be very high on red soils.
   - up to 150 tonnes/ha. But very variable according to detailed conditions; so we really do need more information.

(b) The impact of the erosion affects loss in available water, loss in fields, lost nutrients or applied fertilizers. There are off-site impacts to irrigation schemes, silting reservoirs, water pollution, flooding hazards.

(c) Some controlling variables can be identified. Vegetal cover, possibly most important, certainly they are most easily manipulated. Soil erodibility very responsive to good and bad management. We also felt that soil compaction (i.e. the physical depression of the soil by wheels etc) should be distinguished from loss in structural stability (i.e. the collapse of the soil)
   - both are prevalent controlling variables on erosion.

(d) Knowledge of the technical effectiveness of the types of soil conservation is largely observational. However, according to detailed conditions both;
   - mechanical/physical control measures
   - biological preventive measures are required. Maintenance of mulch and organic matter is again stressed.

(e) There are many management systems. In the high rainfall areas the possibilities are large, including
   - high technology systems which can maintain continuous intensive cropping.
   - low technology; small-scale subsistence including agro-forestry and mixed farming
   - intermediate, improved systems which include the turning in of organic matter and green manures.

The most intractable problems are on the grazing lands and low rainfall areas.
3. REQUIREMENTS AND RECOMMENDATIONS

1. Need for clearer thinking and working out the processes. We need to attempt much more specific diagnosis, working out causes and effects. Especially, we need to know how soil changes consequent on erosion are affecting the yield.

2. Big need for multi-disciplinary research, "knocking people's heads together". Some possibilities are
   - more multi-disciplinary meetings
   - adopting multi-disciplinary approaches to scientific investigation.
     Case quoted where erosion trials and
   - agricultural trials were carried out quite independently on adjacent plots.
   - development of integrated packages where, most importantly, the farmers are involved in designing the package.

3. Research is required on soil loss rates and the most effective ways to control them under different farming conditions - especially on-farm research. To be included here is the impact on productivity.

4. Examination of the relationship between soil conservation and water conservation. Much of the immediate benefit of mechanical soil conservation is through better infiltration of water.

5. A far greater emphasis on rangeland and the interactions between arable cultivation and pastoralism. It was noted that pastoralists are getting increasingly marginalized into poorer and more degraded land. The greatest challenge in Southern and East Africa is clearly on the rangelands.

Finally we were concerned with both the general commitment to conservation and the recognition that conservation's true objective is to sustain levels of production without creating additional costs (economically and socially). We believe that there should be a far greater political commitment by national governments and international aid agencies. Many make a lot of noise about conservation but fail to take effective action.
In the meantime, while research continues, we wish to stress the importance of encouraging farming systems on red soils that maintain vegetation cover, keep up organic matter levels, and that provide real benefits (and not increased risks) to farmers.
GROUP 4: RECOMMENDATIONS AND COMMENDATIONS ON COLLABORATION, REGIONAL LINKAGES AND FOLLOW-UP OF THE RED SOILS SYMPOSIUM

Prof J Lenvain - Chairman (Zambia)
Dr S Mughogho - Rapporteur (Zimbabwe)

INTRODUCTION

Red soils occupy the greater part of East and Southern Africa, and have a range of constraints to sustain food and fibre production. The most important constraints as discussed during this Red Soils Symposium are:

1. Moisture stress;
2. Soil Conservation;
3. Correcting chemical soil conditions; and
4. Physical attributes of the top soil.

Different constraints can be controlled by:

a. Conservation and management of soil moisture
b. Reducing soil erosion and reclamation of eroded land;
c. Correcting (i) soil acidity
   (ii) nutrient deficiencies and imbalances;
   (iii) leaching and/or fixation (phosphate specifically)
d. Reversing hard setting soils through proper organic management and tillage.

The problem areas which prevent an immediate solution to the constraints are:

1. Geography: That is (a) lack of detailed soil resource inventories and lack of site-specific information
2. Quality of soils information:
   (a) lack of laboratory facilities;
   (b) lack of trained personnel and
   (c) lack of funds.
3. Inadequate knowledge of how to utilize soil survey information; and
4. Dissemination of information with respect to both vertical and horizontal transfer.
RECOMMENDATIONS

1. Lack of facilities for research and, in some instances, an absence of qualified personnel, are common constraints of the institutions in the region. The participants urge governments, and regional and international organisations to invest in strengthening of agricultural institutions, particularly in the area of soil management.

2. The participants recommend greater coordination in soil-related research activities in the region. For advancement of research, linkage with other national, regional and international institutions is essential. Further, there is an urgent need for a central co-ordinating, professional body and recommend the formation of an ad hoc committee to investigate the formation of this body.

3. Appreciating the beneficial results of network activities, the participants request the ad hoc committee (identified in (2) to,):
   a. establish contact with the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and to examine the possibility of developing a regional network for the East and Southern African Region.
   b. request collaboration with FAO with a view to participating in its East and Southern African Regional Soil Correlation meetings and to use the occasion of these meetings to discuss the committee affairs.
   c. participate in and assist the Soil Management Support Services (SMSS) in its workshops and training activities in the region.
   d. establish contact with the Soil Management Collaborative Research Programme (TROPSOILS) to investigate the possibilities of developing a network in the region.
   e. establish linkages with International Board for Soil Research and Management (IBSRAM) to collaborate as a regional group in its activities.
Appreciating the extent of Red Soils in Africa and realizing the need for coordinated research on such soils to increase food and fiber production, the participants of the Symposium on 

"The properties and Management of Red Soils of East and Southern Africa" wish to thank the University of Zimbabwe and in particular, 

the Land Management Department for initiating and organizing the symposium.

The success of the meeting is also due to the sponsors (of the meeting) for their generous funding and logistical support. They include:

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The participants also wish to record their thanks to their respective governments and organizations for permitting them to attend the Symposium.

Other members of the group were:

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