

SOIL AND LAND EVALUATION OF A SECTION
OF KILOMBERO VALLEY

9114

BY

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DECLARATION

I, Abdul Ali Mohamed Sanli Mnikonga hereby declare that this thesis is my original work and that it has never been submitted for a degree in any other University.

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ABSTRACT

A section of Kilombero Sugar Company about 400 hectares in size was chosen for this project. A detailed study with objectives of performing soil survey and land evaluation was carried out. Twenty one pits distributed over the different units were excavated, described for their external and internal features. Samples from the horizons taken and analysed for their physical and chemical characteristics. The soils were classified using the Soil Taxonomy of the USDA, while the FAO framework was used for land evaluation.

Inceptisols were found to be the most dominant in the study area, while Entisols are prominent in areas within active river action. Ultisols occupy areas where the soils are formed in situ and Mollisols appear only in small patches.

In the study area, six mapping units have been identified. They are the well drained Mlimani in the west and Mtoni in the south, the moderately well drained Msolwa and Msolwa-Bwawani complex in central areas and the imperfectly well drained Bwawani and Nyarubungu in very low lying eastern parts of the study area.

Land evaluation of the study area has revealed that Mlimani is highly suitable for sugarcane, some parts of Msolwa and Mtoni as moderately suitable, while Msolwa-Bwawani, and Bwawani are marginally suitable for sugarcane growing. Nyarubungu was found to be currently, not suitable for the growing of sugarcane. Wetness limitation is noted to influence parts of Msolwa, Bwawani and Nyarubungu, while soil fertility limitation influences Msolwa-Bwawani, Msolwa and

Nyarubungu. Soil Physical Limitation mainly due to texture has also been found to influence Mtoni section.

Drainage, flood control, selection and application of fertilizer and irrigation have been recommended as some of the agricultural practices and measures for increased sugarcane production. Rice has been suggested as an alternative crop for Nyarubungu where sugarcane growing is currently not suitable.

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LIST OF ABBREVIATIONS

INEAC	=	Institut National pour l'Etude Agronomique au Congo (National Institute of Agronomic Studies in the Congo).
ORSTOM	=	Office de la Recherche Scientifique et Technique Outremer. (Office of overseas Scientific and Technical Research)
gm	=	gramme
kg	=	kilogramme
m	=	metre
km and km ²	=	kilometre and kilometre squared
meq/100 gm	=	Milliequivalents per one hundred grammes
OEC	=	Cation exchange capacity
B.S.	=	Base saturation
%	=	Percentage
B.D.	=	Bulk density
P.D.	=	Particle density
ppm	=	parts per million
KII	=	Kilombero II

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1. INTRODUCTION

A large percentage of the people of Tanzania earn their living from Agriculture. This will likely remain the quantitatively largest productive sector of the country's economy for the next decades. Development of Tanzania, therefore is not very well possible if adequate attention is not paid to the development of agriculture especially along the river valleys and basins where irrigation is also feasible. Mere improvement of the present conditions in this field is not enough. New areas will have to be opened up to increase agricultural production by means of the transformation approach and receive people from areas where shortage of land and employment is already pressing. One of the potential areas for development considered in the early nineteen fifties and sixties (Loxton, 1953 and 1954 ; Anderson, 1961; Sys and Bell 1964) was the Kilombero valley in Morogoro region. Sys and Bell recommended among others the immediate development of rain-fed farming in the Malinyi and Ifakara - Lupiro areas where a variety of crops including paddy rice, maize and cotton showed prominence. The Northern Kilombero Valley appeared to be suitable for cane, maize, beans, cotton, sunflower and rice production. Sys and Bell also suggested an establishment of a Kilombero Valley Authority to supervise all future agricultural development within the valley.

Other agricultural development potentials within the area that have received some preliminary studies in recent years include the establishment of rubber plantation around the Msolwa valley (Dugeon, 1961; ILACO, 1967), fishing industry on the river Kilombero and to a lesser extent on the lower Msolwa

river and a commercial game hunting in the Selous Game Reserve. Before any large scale production of any of the above crops is undertaken, it was recommended (Sys and Bell, 1964; ILACO, 1967) that a reconnaissance and detailed soil surveys be carried out to characterize the physical and chemical properties of the soils and to establish their suitability for the growth of such crops.

In 1959, prior to the establishment of the Kilombero Sugar Estate, a 1:20,000 soil map of the Ruaha area was prepared by the International Training Centre for the Aerial Survey of the Netherlands (ILACO, 1970). This soil map was extended in 1964 to include also the Trans-Msolwa area which was being developed for sugar cane growing. Both maps were of a reconnaissance type and gave only a general idea about the prevailing soil conditions. They were intended to be used as a basis for the planning of the layout of the estate. In subsequent years, the need for a revised soil map became imminent. It became clear that the soil conditions on the estate were more varied and diverse than shown on the original maps. Furthermore, the original classification scheme for some areas, notably the Trans-Msolwa area, showed little agreement with the experience gained in cane-growing. Detailed soil surveys (ILACO, 1966; 1967 and 1970) were later carried out on Kilombero Valley to cover a large percentage of the area under cane, Kiberege and Ifakara. In 1977, a survey conducted by Tate and Lyle Technical Services and Booker Agriculture International Limited, on the development of the sugar industry in Tanzania, recommended among other things the expansion of the existing sugar estates in order to meet the demand for home

consumption and a surplus for export by the year nineteen ninety. Reconnaissance survey conducted at the same time showed that the Kilombero estate and the outgrowers around the estate had a gross-arable area of 3,900 and 6,500 hectares respectively not under cane presently (Fig.3) mainly around the present estates (Fig.4). In order to enable the management of the Kilombero Sugar Company and the farmers around the estate to make rational decisions required for the expansion, a detailed soil survey and land evaluation of the available area is necessary.

The aim of this project was therefore to make a detailed soil survey and land evaluation (with special reference to sugar cane production) of an estimated area of 400 hectares in one of the areas (Fig.3) considered possible for expansion, in order to examine the suitability or limitation of this area for cane production.

2. LITERATURE REVIEW

Soil Survey has been defined by Young (1976) as one of a group of activities collectively known as natural resource survey. These are studies of the natural environment with special reference to its resource potential. Resource surveys may cover each of the following factors of the physical environment: geology, landforms, climate, hydrology, soils and vegetation. Since all agriculture and all human life depends on soil, soil survey is one of the branches of resource surveys most widely used in development planning. A soil map is one of the primary documents on which land development projects are based.

Land evaluation on the other hand, is the process of estimating the potential of the land for one use or several alternative uses (FAO, 1973). The data employed in land evaluation come from three main sources: natural resource survey, the technology of the resource use, and economics. The results are generally expressed as land evaluation maps with supporting statistical and other information, showing the suitability of various parts of the survey area for different kinds of land use. These will normally include directly productive use, principally arable farming, pastoral use and forestry, together with other forms of use such as water catchments and tourism.

2.1 Soil Classification

Soil cannot be described without a system of classification. The different systems of classification that exist today have been developed by different national soil survey organisations to

suit their own conditions. Although to-date there is no universally accepted system of soil classification and nomenclature, comparable to that which exist, for example, for rock types or biological species, one national and two international systems have some measure of international recognition.

In 1960 the United States Soil Survey produced a comprehensive soil classification system commonly referred to as "the Seventh Approximation". This system attempted to avoid the confusion that had arisen in the 1938, and 1949 systems (Baldwin et al 1938, Marbut, 1935 and Kellogg and Davol, 1949) through redefining the terms used and starting with a new nomenclature (Cline 1979). The principles of this new system, together with the authority of the U.S. Soil Survey, attracted much international interest and some measures of adoption, particularly among the countries that had not developed their own national soil classification systems. This classification is hierarchical, with six categories: orders, suborders, great groups, sub-groups, families and series. The soil type in the earlier systems was dropped as a category, and texture of the surface soil became a phase criterion, like slope and coarse fragments. The use of horizon designation related to those of the Soil Survey Manual (Soil Survey Staff, 1951) was also discontinued with this approximation. For 15 years after the publication of the Seventh Approximation, the system was tested against soil series, revised and retested several times before the publication of the Soil Taxonomy in 1975 (Soil Survey Staff, 1975). To date, 10 orders, 47 suborders, 230 great groups and 1251 subgroups have been identified in the United States.

According to Cline (1979), two attributes of "Soil Taxonomy" merit special emphasis. One is the enormous assemblage of data against which it was tested, and the other is the definition of taxa in terms of quantitative class limits. The system is not however to be considered a final fixed taxonomy and accepted as absolute truth (Cline, 1977). Work on the system continues and a procedure to amend the system is being developed. An international committee has been working on the classification of certain soils having low activity clays, which are classified as Alfisols and Ultisols by criteria of "Soil Taxonomy". Another international committee is studying the classification of Oxisols. Various proposals have also been made and questions have been raised for other parts of the system. A proposal to establish a new order for the Andepts has been raised. All these will require study and testing, for a change that may appear logical and useful for one part of the system may have undesirable consequences for another part.

Disadvantages of the U.S. system, apart from its nomenclature, include the extreme complexity, excessive reliance on laboratory analysis, and dependence on parameters of the annual soil moisture and temperature regimes for which data are rarely available. A further difficulty in field survey is that owing to the rigidity of the class boundaries, natural landscape units commonly contain more than one higher-category class (Webster, 1968a, 1968b).

Problems of adopting the U.S. system to other parts of the world especially the tropics have been observed by many

scientists (Kesseba et al., 1972; Stephens, 1963; Sys, 1969; Cline and Johnson, 1963; Leahey, 1963). Cline and Johnson (1963) emphasizes that the soundness of the principles embodied in the definition of diagnostic horizons controls the validity and effectiveness of the entire system. Working with some soils around Morogoro in Tanzania, Kesseba et al., (1972) encountered some difficulties in identifying (using the criteria of the 7th Approximation) argillic and natric horizons - diagnostic horizons of particular concern when classifying Alfisols, and Ultisols. They noted that although the clay content ratio criteria of 1.2 or more between the eluvial and the underlying argillic horizons may be achieved in most cases, presence of clay coatings (clay skins) on the structural units (peds) of the argillic horizons may not be observed. Under hydromorphic conditions, many of the horizons that qualify as argillic (on the basis of clay content) are both massive and structureless, or weakly structured, and that the lack of peds naturally leads to an absence of clay skins. Where structural peds do exist, Kesseba and others (1972) felt that the comparatively high clay content of the illuvial argillic horizons obscured the clay coating features. Furthermore, most of the sub-surface horizons of the soils examined by them having an argillic horizon contained 2:1 type of clays. It has been noted (Soil Survey Staff, 1967) that soils having this type of mineralogy often may be lacking clay skins.

Difficulties have also been encountered in the classification of suborders, great groups and subgroups which are defined wholly or partly on the basis of moisture regimes

(Kessaba et al. 1972; Sys, 1969). Van Wambake (1967) has also noted a weakness in the American System in Classifying tropical soils, though he believes that it is ~~the best~~ the best available so far. He emphasizes that its way of approach to classification of soils is more important than what the classes are that have been defined.

The work of D'Hoore (1965), through the Commission for Technical Co-operation in Africa (CCTA), is considered as the first international scheme of soil classification in Africa. This scheme, resulted in the production of the soil map of Africa at a scale 1:5,000,000. D'Hoore's system was an attempt to combine the French and the Belgian systems of soil classification that had been operating in Africa. He obtained sixteen main groups, four of which are subdivided to give twenty five sub-groups and sixty three soil types. The classification was a natural one and in large part genetic. The sub-division of groups into soil types was frequently on the basis of parent material. D'Hoore's classification system has since been used in a number of countries in Africa, and by the Land Resources Division of Britain. Young (1968b) noted that there was a major misunderstanding of the system in the placing of ferrisols as an intermediate group between ferruginous and ferrallitic soils. In the French system (ORSTOM), two extensive Latosol groups, ferruginous and ferrallitic soils, had been clearly separated from each other on the basis of the base saturation of the B horizon; ferruginous soils having a B horizon base saturation of over 40 percent and ferrallitic soils under 40 percent. In the Belgian

system (INEAC), a broad group of Kaolisols was divided into less-weathered ferrisols and highly weathered ferralsols, distinguished by the presence and absence respectively of clay skins. The ferrisols in the INEAC classification therefore, have no equivalent on the French system, and considering them as transitional between ferruginous and ferrallitic soils as in the soil map of Africa by D'Hoore, brings about a genetic misunderstanding and results in overlapping definitions. Other limitations of the system noted by Young (1968b) included an overemphasis on climatic zonation and insufficient recognition of the distinctive influence of basic rocks. Furthermore, the use of the silica:sesquioxide and silica:alumina ratio as differentiating criteria is a disadvantage, since these are not routine analytical determinations.

D'Hoore's contribution however, served a particularly valuable purpose in bringing the ORSTOM and INEAC approaches more fully to the attention of Anglophone countries. Its major aim was to serve as a basis for international exchange of pedological and agronomic information. Although considerably dependent upon analytical properties, there are nevertheless sufficient morphological criteria for provisional class identifications to be made on the basis of field data. It remains a viable system for converting local surveys into widely recognized mapping units, and a rich source of information of natural soil properties and genetic factors. As far as identification of natural soil units are concerned, D'Hoore's is believed by some people to be better than the FAO system (Young, 1975). This does not mean however that the system is free from limitations. Its lack of definition, at

all levels of classification and of diagnostic properties has led to confusion and ambiguity. Baker (1970) for example found that D'Hoore's system of classification could not accommodate all soils found in Tanzania.

The FAO-Unesco soil map legend is now widely considered as the second international system of soil classification, although the FAO itself holds that it is a map legend (Dudal, 1968, FAO-Unesco, 1974, Young, 1976). It is used on all FAO soil surveys and is the most authoritative system for international use.

Although it is stated that, the legend of the Soil Map of the World is not intended to replace any of the national classification schemes, among the objectives of the map are to promote the establishment of a generally accepted soil classification and nomenclature (FAO-Unesco 1974). The "group" of soil units in the legend which are claimed to be for convenience of presentation, can all but two (luvisols and Acrisols) be identified with natural soil classes that is based on all properties of a soil as an entity. It is now very convincing to many scientists that the groups are in fact classes at a higher level of classification and that the FAO legend is therefore a classification system with two categories. Currently, twenty six groups (the higher category) and one hundred and six soil units (the lower category or the basic element) have been recognized.

Despite of the fact that many of the soil groups are natural soil types, this system is structurally an artificial classification because it is based on small properties or single

property in differentiating classes. It makes use of the principle of diagnostic horizons together with horizon names and definitions all of which are borrowed from the US 7th Approximation. The names of the soil groups, e.g. rendzina, ranker, andosol, vertisol, solonchak, solonetz, chernozem, podzol and lithosol are widely borrowed from widely-recognized traditional nomenclature. The FAO system therefore has some of the defects of all artificial classifications but reduces its main defects, notably by considerable simplification. Other than possessing the authority of the leading international organisation in soil science, it is a compromise document, incorporating features and nomenclature from various national systems. The map units of the system consists of soil units or association of soil units occurring within the limits of a mappable physiographic entity. The methods of compilation was essentially that of taking national soil maps produced by governments, or in some cases individuals, and interpreting the legends in terms of the FAO system; a consequence of this procedure is that certain soil units are more likely to appear in some countries than others. As would be expected at the 1:5,000,000 scale, most map units are associations, of one dominant and up to three associated soil units, sometimes with up to three inclusions.

National classification systems other than the US, that appear to have gained much prominence include: the French (ORSTOM), the Australian, the INEAC, the Indian, the USSR and the Ghanaian. The ORSTOM classification has been used in virtually all French-speaking African countries, while the

INEAC classification was developed mainly for the former Belgian Congo. Both have their own merits and demerits.

The Ghanaian system was devised by C.F. Charter and used mainly in Ghana and Nigeria. This system was valuable in being one of the few to give prominence to the influence of parent material. It is a natural classification, based on the recognition of two main axes influencing soil genesis, those of rainfall and rock composition. In this respect it is a better basis for understanding the differentiation of this group of soils than the ORSTOM system, which overemphasizes the zonal factor, and that of INEAC which emphasizes stages of weathering rather than the direct influence of parent material.

The Australian classification system is an artificial system based almost entirely on morphological properties identifiable in the field. It is a descending hierarchical structure with five categories, subdivisions in each category being based on single properties. The key of classification is easy to use and profile can be unambiguously and rapidly placed into its class from field survey data only. Although the system has been considered as not suitable for international use (Young, 1976), its key can be very useful as a model for the construction of national system if the approach is favoured.

It is obvious from the divergent views in the literature that soil is inherently difficult, at this stage of our knowledge to classify. At one extreme are those soil scientists who wish to create mutually exclusive classes, and at the other extreme are those not in favour of such classes.

According to Webster (1968a), the first leads to inconsistency or absurdity and the second leads to utter confusion. Up to now, most classifications, especially those of tropical soils (e.g. D'Hoore, 1965), have been of this second type.

A study of the different classification systems reveals that an important diversity exists in the way in which the natural soil individuals are separated, named and described. By applying a morphometric well-defined system, the US classification has attempted to clear away this confusion. The precisely defined morphological and analytical data allow pedologists greater communication, within a country and internationally. It provides the most comprehensive framework from which an assessment of a nation's soil resources and ultimate development of agriculture could be achieved. The FAO-Unesco map legend, although being preferred by many developing countries because of its simplicity, caution must be exercised when using it because of its overlapping definition especially at the lower category. Countries with no strongly-established national classifications could suitably adopt the FAO system as a basis for higher-category grouping.

2.2 Soil Classification in Tanzania

Soil survey of various kinds and various scales have been conducted in Tanzania since Milne's initial work in the early 1930s. Baker (1970) has listed the major soil survey works that have been undertaken in this country as well as providing a fairly comprehensive bibliography of published

and unpublished works on Tanzania soils. From Milne (1935) to the present, three trends in soil classification in Tanzania can be traced:

1. Cartographical classification, that is, the "soil" units depicted do not form taxa of genetic or a morphological classification of soils.
2. Utilitarian classification oriented to specific problem-solving situations especially irrigation.
3. Taxonomic classification in which soil units depicted form taxa of a genetic or a morphological classification of soils.

2.2.1 Cartographical classification

The cartographical unit that has been used in Tanzania is the catena. The idea of the catena is that particular soil sequences are associated with particular slope forms. Mapping is largely dependent upon non-pedological information, although pedological data collected on a broad reconnaissance basis are vital. Moss (1968a) noted that the relationship expressed by the catena concept seemed so "real" that many in the 1940s and 1950s elevated the catena to taxonomic status. However the loss of taxonomic value which the concept appears to have undergone is probably the result of an increasing realization of the complexity of the relationships between soils and slopes (Moss, 1968a). Baker (1970) questioned the emphasis that so far has been placed on the catena as a mapping unit in Tanzania.

Certainly 'no simple catena', except for the classic, Ukiriguru example (Calton, 1952), may exist in many parts of the country. But this is not a sufficient reason to dismiss it outright. Milne (1935) himself recognised that the catena concept could not be applied in all situations.

Outside Tanzania soil/slope units still form a major ~~founda-~~
~~ation~~ for land classification and mapping. Notable among these is the 'Land System' concept of the Australian Organisation CSIRO. Baker (1970) conceded that his maps of the land resources of Tanzania basically follow this concept. But the land system concept is firmly based on the idea that soils and slopes are so intimately interrelated that they can be studied and mapped as integral units (Moss, 1968a). Thus Baker's work fits well into this trend of classifying Tanzania's soils by cartographical rather than taxonomic units as he uses a catena-like mapping unit where physiography and soils are highly correlated. This does not imply that the catenary mapping of soils is a dead issue. Catenary mapping of soils at best gives a broad soil associations in an area. What is more relevant now is the characterization, classification, and mapping of the soils of the individual catenary elements on scales much larger than the present maps. To do this, researchers must place greater emphasis on the use of more strictly pedological classification. Samki (1975) has attempted to do this with the Ukiriguru Catena. He classified the soils of this catena using the US Taxonomy system. Over the years, as more people work in this field and as more data become available, catenary units could be more precisely defined.

2.2.2 Utilitarian Classification

In general, large-scale surveys have been oriented to specific problems-solving situations—especially irrigation. As a result, the classifications employed have been particularly utilitarian in nature. Soils having similar properties, either advantageous or disadvantageous to agriculture, are grouped together. Less emphasis has been placed on non-pedological information, although such data have been found useful in the mapping programme. More emphasis has been placed on specific soil profile data such as drainage, texture and consistency. Two examples of this trend are given by Anderson (1961 and 1963). In the Rufiji Basin Survey (1961), principally a soil irrigability survey, the primary division in the soil classification is into alluvial and non-alluvial soils. The alluvial soils are then subdivided on the basis of their texture. The non-alluvial soils were subdivided on the basis of their colour, texture, presence of cemented horizons, and other pedological data of significance to irrigation. In Anderson soils of Tanganyika (1963) the primary division into well-drained and poorly-drained soils is adopted as being important for agricultural purposes. Although these types of utilitarian classifications are of extremely high value, the classifications employed present two related problems:

Firstly, because the surveys are problem-oriented, the data collected are quite often of specific nature, related to the purpose of the survey. Texture for example, may be of exceeding importance to the irrigation engineer but may not

tell the agronomist much about the fertility of the soils. There is danger that much unnecessary duplication of survey effort will be required in such situations.

Secondly, by localizing the classification system, much valuable information dealing with the nature of the soils and their management may be lost to those workers in other parts of the country that have similar environmental conditions. Conversely, by using localised classification, the Tanzanian worker may not be able to correlate his soils with soils of similar nature and management problems in other countries. To avoid these problems, a more general classification, that could be applied nationally and be correlated internationally, would be useful.

2.2.3 Taxonomic classification

Taxonomic classification soil survey in Tanzania have been used only very recently and covers only isolated parts of the country, covering in most cases areas around research stations and areas of high agricultural potential. Notable among the works already completed is that of Kesseba and others (1972), in which they experimented on the use of the 7th approximation in classifying Tanzanian soils. Apart from the difficulties already raised in the system, they found it to be the best system available. Later on, Samki (1975), successfully characterised the soils of the 'famous' Ukiriguru catena using the US Taxonomy classification. He identified four soil types, Kikungu, Lusenyé, Itogoro and Mbuga occurring from upper most slope to the valley as ~~Ustipsamment~~ ~~Tropaqualf~~ and ~~Palaustent~~ respectively.

The FAO mapping legend has also been used in Tanzania since 1975, although published reports using the legend are rare (Hannemann and Kullaya, 1978). The general trend in the country now is to adopt the FAO legend for the future soil classification (National Soil Service - Personal communication), and has been found to be well suited for mapping soils at reconnaissance level and often adopted in Kenya.

2.3 Land Evaluation

The problems of understanding evaluation principles have often been associated with the controversies in the subject we call land classification (Sys, 1976). In the past, much confusion has resulted from a lack of clear distinction between the terms "soil" and "land" particularly in the context of land classification. According to the frame work for land evaluation (FAO-Unesco, 1974), soil has been defined as "a three-dimensional body occupying the uppermost part of the earth crust and having properties differing from the underlying rock material as a result of interactions between climate, living organisms, parent material and relief over periods of time and which is distinguished from other "soils" in terms of differences in internal characteristics and/or in terms of gradient, slope-complexity, microtopography, stoniness and rockiness of its surface." This concept of soil as mapped in soil survey, although narrower than the concept of land, embraces many surface as well as sub-surface characteristics.

Land on the other hand, has been defined by the FAO frame work of land evaluation (1974) as follows: "A tract of

land is defined geographically as a specific area of the earth's surface: its characteristics embrace all reasonably stable, or predictable cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the topography, the hydrology, the plant and animal populations and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by man." "The following conclusions can be drawn from the definition of land:

1. As defined above, the term land embraces all but the purely socio-economic (human) attributes of the environment. It is assumed that all approaches to interpretive land classification would, to a varying extent, take additionally socio-economic factors into account but these are not considered to be attributes of the land itself.
2. Land is a broader concept than soil. Thus, in developing interpretive land classification from soil survey data, additional aspects of natural environment, notably macro-topography, vegetation, surface and ground hydrology, and climate as well as certain stable man-made features, need investigation in an integral interpretation.
3. The range of indirect related attributes of land is very great. These individual tracts of land defined in terms of specific combined expressions of these attributes tend to be unique.

Although land classification is sometimes used as a synonym for land evaluation, more properly, land classification includes any method of grouping land or elements of land into classes. The land systems method of resource survey (Brink et al. 1966; Christian and Stewart 1953 and 1968) is a form of land classification but not land evaluation (although evaluation may be applied to the mapping units which it yields). Stewart (1968), Gibbons et al. (1968) and Young (1976) have defined land evaluation as the process of estimating the potential of land for one use or several alternative uses. From this definition land evaluation is evidently a branch of land classification, in which basis for classification is suitability for land use.

Vink (1975) defined land use as any kind of permanent or cyclic human intervention to satisfy human needs, from the complex of natural and artificial resources which together are called "land". Sys (1976) concludes from Vink's definition that land use is the application of human control on natural ecosystems, in relatively systematic manner, in order to derive benefit from it. Land suitability in land classification systems is therefore the fitness of a given tract of land for a defined use. Differences in the degree of suitability are determined by the relationship, actual and anticipated, between benefits and required inputs associated with the use of the tract of land in question.

Generally two kinds of suitability classification are considered in land evaluation studies: actual or current suitability classification and potential suitability classification. Actual or current suitability classification relates

the potential of land units for a specific use in their present conditions, with recurrent inputs and minor land improvements (Sys, 1976; Young, 1976). Minor land improvements may involve bush clearance or simple soil conservation work. Generally they can be financed by the individual farmer from his own resources or short-term loans, and do not in principle cause substantial permanent change on the land. Potential land suitability on the other hand, relates the potential of the land units for the use in question at some future date after major improvement such as drainage, reclamation and irrigation have been carried out. These will require substantial non-recurrent input of capital and will normally cause a significant and reasonably permanent change to the land characteristics. From the foregone discussion, it is clear that land use resource inventory is of prime importance in land evaluation studies.

2.3.1 Land use Resources

The land use resources that are important in land evaluation are generally categorized into three broad groups: physical, human and capital resources (Sys, 1976).

The physical resources important in land evaluation studies include climate, vegetation, water and hydrology, landform and soil. The general study of the climate of a land development unit covers a range of factors of which rainfall, temperature, radiation and evapo-transpiration are the most important. Rainfall and temperature and their distribution over the years are the main factors for the world's differentiation in eco-climatic zones, having each a specific land use pattern and determining the length of the growing season for cultivated plants. The moist

evergreen rainforest and the deciduous forest with a permanent high rainfall pattern and high temperature for instance are an environment of the typical tropical crops like rubber, oil palm, coffee, and cocoa, and a range of food crops. Within this zone each crop may have specific climatic requirements which is considered in a detailed investigation on land utilization types. The total energy input of the world (the solar radiation), is also important as it determines the amount of energy to be converted into heat, energize the processes of evaporation and precipitation and that to be utilized in photosynthesis (Baver et al. 1972; Sys, 1976).

Vegetation influences land use in several ways: (1) Some natural vegetation types represent a direct economical value for land utilization. Forest may represent a utilization type for wood production while savannas and steppes are natural land utilization types for extensive grazing. (2) The amount of nutrients stored in the vegetation are a direct nutrient supply for crop production after cutting the vegetation. The amount of nutrients stored in the vegetation will depend directly on the vegetation type as illustrated on Table 1. The vegetation has, together with the climate, an important influence on cycling of nutrients and as such on some important soil properties which may influence the final output of a land utilization type. Table 2 illustrates this. A clear differentiation of nutrients cycling occurs already with the tropical moist forest zone where the production of dry material by the vegetation is quite uniform. In the soil however we realize that under moist evergreen rainforest the pH is very low and the amount of CaO and K₂O are also low. The C/N ratio is generally above 10.

Table 1: Nutrients stored in some typical vegetation types
(P.H. Nye and D.J. Greenland, 1965) as cited by
Sys (1976).

Vegetation type	Dry material 1,000 lb/acre	Nutrients stored, lb/acre				
		N	P	K	Ca	Mg
Moist evergreen 18 years old Yanganbi	300	499	65	361	501	
Moist semi- deciduous forest, lower Zaire	296	1,103	110	851	1,890	290
Savanna in Southern Ghana	51.7	251	25	248	394	93
Miombo woodland copperbelt, Zambia	90	-	45	153	351	90

Table 2. Average amount of nutrients stored in soils under some typical tropical vegetation types (Sya, 1976)

Vegetation type	C, Tons/ha		N, Tons/ha		C/N		pH		CaO, Kg/ha		K ₂ O, Kg/ha	
	0-20 (cm)	20-100 (cm)	0-20 (cm)	20-100 (cm)	0-20 (cm)	20-100 (cm)	0-20 (cm)	20-100 (cm)	0-20 (cm)	20-100 (cm)	0-20 (cm)	20-100 (cm)
Moist evergreen rain forest	24.90	39.58	2,448	4,664	10.01	8.50	4.36	4.62	634	2,607	110	318
Semi-deciduous forest	31.69	50.35	4,330	7,277	8.70	6.80	6.05	5.40	4,813	6,496	402	911
Moist Guinean savanna	33.51	66.20	2,649	6,599	12.70	10.03	4.92	4.99	834	2,879	198	281
Dry savanna	64.35	94.70	5,735	10,443	11.20	9.07	6.37	6.13	7,672	18,614	1,503	207

Under moist semi-deciduous rainforest, with some dry season, a lower C/N ratio in the top soil suggests a better quality of organic matter. The pH is higher and greater amounts of CaO and K₂O are available. As a result, this appears to represent the best agricultural zone for development within the tropical forest area. (3) Natural vegetation is also often regarded as a hindrance for agricultural land use. A dense tropical forest may make reclamation of land more difficult and may require a serious input for cutting down the trees and preparing the land.

The importance of hydrology in agriculture lies from the fact that water and soil are the stable resources on which all agricultural land use is based. Knowledge of soil and water conditions is indispensable for the understanding of past and present land use as well as for prediction of future uses. The soil constitution will influence the choice of crops, the land use pattern on marginal soils, the management of specific soils, the land improvement works, the type of irrigation and the quantity of fertilizers to be used. On a regional basis, the yield of crops will depend for a great deal on the natural fertility of the soil (Sys, 1976).

Landform is normally considered as an indirect land resource because it helps in the choice of land utilization types, influencing management, accessibility of terrain and development of infrastructural works. These may finally greatly influence the amount of non-recurrent and recurrent inputs.

The main structures of the land are essentially defined by geological formations including tectonic action and erosion processes. They determine the major features of the relief, including altitude, which is an important ecological factor. The dissection of the landscape by a dense river system may also greatly influence the management type. Strong dissection can prevent the installation of a plantation type of farming on suitable soils for a considered crop. Sys (1976) observes that a very dissected landscape of the lower Zaire basin with soils suitable for coffee, oil palm and rubber is not suitable for the large plantation block required by the big companies, but only for the installation of small holdings by individual farmers. The large plateaus with similar soils on the other hand, are widely used for industrial plantation agriculture.

Slope is another important element of landform which plays an important role when mechanization is involved. It is generally accepted that on slopes steeper than 20 per cent mechanization becomes impossible. Cultivation on such slopes requires the establishment of expensive anti-erosion terraces and this complementary capital input can greatly influence the final profit. For slopes less than 20 per cent there are still important variations in productivity according to variations in slope.

The second group of land use resources is the human resource. No land use planning is possible without this resource. The ability of the farmer plays an important part in the profit of a farm. The study of human resources, their ability for cattle

raising or arable land farming is extremely important. People involved with fishery along rivers for instance will be very difficult to reconvert to extensive crop farming.

The population pressure will further help to define the land use pattern. Shifting cultivation for example remains possible as long as enough land is available. It has been estimated (Sys, 1976) that shifting cultivation in the Zaire basin can be supported as long as population density remains under 20 persons per km². Under Miombo woodland of Zambia, this critical density is estimated to be 14 persons per km². In this particular case, the soil fertility, amount of cultivatable soils, and rapidity of the recycling process of the fallow vegetation are the most important factors.

Land use pattern, i.e. the layout of the farm, the selection, distribution and rotation of crops, and the ownership of the land are also important human factors to be considered in land use planning.

The third and final group of land use resource important in land evaluation is the capital resources and economic factors. The first requirement to realize a programme of land use planning for rural purposes is the availability of the necessary funds for the realization of the infra-structural works and the land improvement works. Besides this, the capital input for recurrent practices must also be available. Presence of roads, railway and harbour are important factors to be considered. Very suitable soils for fruits cannot be developed for this land utilization type and are therefore unsuitable land for this

practice if no communication network exists to ferry the products to the consumer in towns. The economic situation of a crop on the world market is also a very important factor in land use planning.

2.3.2 Land Evaluation Systems

Many of the approaches and methods employed in land evaluation originated in the United States although recent advances have been made particularly in the Netherlands, where land is unusually scarce and highly-valued, and in Canada (Young, 1976). The most widely used system is the Land-Capability Classification of the Soil Conservation Service of the US Department of Agriculture (Klingebiel and Montgomery, 1961). Although constructed for the United States it has been widely adopted for use in many other countries especially in the developing ones. The system is mainly intended as a means of grouping soil mapping units. Other features of land, namely slope angle, climate and frequency of flooding are taken into account. The main concept used in this system is that of limitations, land characteristics which adversely affect land use. The criteria used in assessing a land unit are the physical land properties made available after a soil survey and the seriousness of a limitation is a function of the severity with which crop growth is inhibited. The capability of a land unit for crop growth is better when a wider range of crops can be cultivated on it than on other land unit. The system is therefore one of a general appraisal and not related to a specific land utilization type. The preferential utilization type and land use is however reflected in the classes. As such the

arable soils are grouped according to their potentialities and limitations for sustained production of the common cultivated crops that do not require specialized site conditioning or site treatment. Non arable soils are grouped according to their potentialities and limitations for the production of permanent vegetation and according to their risk of soil damage if mismanaged.

The capability classification provides three major categories of soil groupings: (1) capability unit, (2) capability subclass, (3) capability class. These are defined in appendix 1.

Among the advantages of the USDA land-capability classification system is its flexibility, its extreme versatility and simplicity. It places stress on possible adverse effects to the environment and permits interpretation in stages (Young, 1976). The major objections to the system on the other hand are its negative nature, being based on limitations rather than positive potential; that it is considerably biased towards emphasis on the soil erosion hazard; and the fact that it does not take sufficient account of the differing requirements of different types of land use, nor its structure such that it can easily be adapted to do so (Riquier et al. 1970; Sys and Frankart, 1971). The usual manner of applying the land-capability classification system to a local condition (Young, 1976) is to draw a conversion table that shows kinds of limitation down the left-hand column and capability classes across the top. For each kind of limitation, the value of the land characteristic judged appropriate to each degree of severity of limitation is filled in. Thus in table 3 the maximum slope angle permitted

Table 3. A simplified example of a conversion table for the use with USDA Land-Capability Classification. To apply the table to a land unit, examine the columns successively from left to right until a column is found in which the values given are not exceeded for any limitation. Otherwise favorable land with a severe wetness limitation is placed in Class Vw (after Anthony Young, 1976).

Limitation	Arable classes				Non-arable classes				Special class
	I	II	III	IV	VI	VII	VIII	Vw	
Slope angle, degrees	1	3	5	10	18	35	Any		
Outcrops and boulders % surface occupied	0	1	2	5	10	25	Any		2
Wetness, class	Nil	Nil	Slight	Slight	Moderate	Moderate	Severe		Severe
Soil effective depth, cm	150	100	60	30	20	20	0		30
Soil texture	SCL-C	SL-C	SL-C	SL-C	IS-Heavy C	IS-Heavy C	Any		IS-Heavy C
Soil Permeability	Moderate	Rep-Slow	Rep-Slow	Rep-Slow	Any	Any	Any		Rep-Slow
Available H ₂ O capacity, cm	25	20	15	10	5	2	0		10
Cation exchange capacity Subsoil, meq/100 g	20	15	10	5	5	2	0		5
Total soluble salts, percent	0.2	0.2	0.4	0.4	0.8	1.0	Any		0.4

for Class I land is 1° , for Class II 3° , for Class III 5° and so on. Using this system land will belong to the lowest class to which it is allocated; thus level and freely drained land, which would fall into Class I on the basis of slope angle and wetness, would be put into Class IV, Sub-class IVs, if the soil depth were less than 30 cm.

The second system of land evaluation is that developed by the United States Bureau of Reclamation (1953). This system classifies land specifically in terms of its suitability for irrigation. Six classes based on their suitability for irrigation are recognised in this system as shown in the appendix (Systems of land evaluation). The manner of applying the system initially involves a conversion table similar to that of the USDA system (Klingebiel and Montgomery, 1961), in which the permitted values of various land characteristics within each irrigation suitability class are set down. The final allocation of land to a particular class is based on economic considerations, specifically payment capacity. This means the capacity of the land to provide an acceptable income for the farmer and at the same time to pay water charges sufficient to amortize the capital costs of development. This system is thus sometimes referred to as single-purpose economic evaluation system. In the hand book (USBR, 1953) in which the survey procedures are described, emphasis is placed on the need to determine quantitatively, the measures necessary for land development e.g. bush clearance, levelling, ditching, drains, desalinization, and requires that each of these operations be costed. The initial and recurrent costs are set against the value of expected

production, and the payment capacity calculated, necessarily making assumptions about discount rates. Thus class 1 to 3 and 6 have progressively less payment capacity, falling below the accepted level in the case of class 6.

The USBR system is specific, referring only to potential for irrigation and not intended for other forms of land use. It emphasizes on inputs and other costs, and it includes assessment of environment hazards. The system however lacks flexibility; the specified procedures, in particular scale and intensity survey, are rather rigid and often inappropriate for the lower intensity of irrigation development in the developing countries. The survey procedures are also very complex although the system produces final results of simplicity, namely the areas of land in classes 1-3 (irrigable), 4 (special use) and 6 (non-irrigable). The system is not designed for interpretation in stages, but only detailed and intensive survey. The stress which it lays upon costs and payment capacity makes it well suited to irrigation projects, in which recovery of the considerable capital investment is a major consideration. Some of the economic principles of this system, particularly that of payment capacity, can be applied to methods for the economic evaluation of major kinds of land use other than irrigation.

Several attempts (Nelson, 1963; Edwards, 1970; Riquier et al., 1970; Sys and Frankart, 1971; Sys and Verheye, 1973; Borden and Warkentin, 1974) have been made in devising land evaluation systems which provide a productivity index, or rating, by means of parametric methods. In these methods,

the effects of individual land or soil characteristics are assessed individually and then arithmetically combined. Riquier et al. (1970) argue that the limitations in the land capability classification are a negative and complex concept, and that present and future capability are better expressed in terms of productivity. They further claim that the system avoids economic and sociological considerations which tend to lie outside the scope of the soil scientist. Soil productivity, or known yields, they further argue, provides the best grounds for understanding between the soil scientist and the economist.

The system (Riquier et al. 1970) suggests the calculation of a productivity index considering nine factors as determining soil productivity viz.: moisture (H), drainage (D), effective depth (P), texture, structure (T), base saturation (N), soluble salt concentration (S), organic matter content (O), mineral exchange capacity/nature of clay (A) and mineral reserve (M).

$$\text{Productivity index} = H \times D \times P \times T \times N \text{ or } S \times O \times A \times M.$$

Each of the factors are rated on a scale from 0 to 100, the actual percentages being multiplied by each other. The resultant index of productivity, also lying between 0 and 100, is set against a scale placing the soil in one or other of five productivity class.

When calculating the actual productivity index, the value of the ratings refer to the present day situation while the index of potentiality refers to the potential productivity with ratings according to the situation after soil management. In calculating index of potentiality, it is necessary therefore

to first determine which management practices are necessary and then evaluate what their repercussions are on potentiality. The management practices are generally categorized into two broad groups: management imposed by the limiting factors, e.g. dryness, poor drainage, shallowness, etc. and management imposed by physiographic conditions and environment, e.g. wind erosion, water erosion, and forest or bushland.

Disadvantages of the parametric systems are their rigidity and restricted applicability. Most of those so far developed are able to demonstrate good correlations between the Productivity Index and yields of a particular crop within the area for which the index was developed, but as soon as one system is transferred to a substantially different climate, the ratings require substantial alteration if they are not to give results greatly at variance with farming experience. All of them become complex as attempts are made to allow for interaction between factors, which the nature of a multiplicative system is unfitted to take into account. Indices of this type are more suited to assessing the productivity of soil than land, and any one index can only do so within a restricted range of environments. They may have uses for research and possibly fiscal purposes, but are not well fitted to evaluation for the purpose of land development planning.

Although the USDA land-capability classification, the US Bureau of Reclamation land classification and the parametric methods have been used as land evaluation systems, they are strictly land suitability evaluation systems in which separate assessments are made of the suitability of land units for each of a number of different, defined forms of use. They give a

general appraisal of the land with only some reference to general utilization. Among the early types of truly land suitability evaluation is a land classification for use in New Guinea developed by Haantjens (1965). This provides suitability ratings for four types of use: annual crops, tree crops, improved pastures and padi cultivation. The method of deriving these ratings is intermediate between the "limitations" method and the parametric approach. Each of the environmental factors is given a rating from 0 to 6. Every rating is assessed according to its individual suitability for each of the four types of land use. The overall suitability is derived from the individual suitabilities by a modified summation process, in which a single very low rating or a combination of moderately low ratings can have similar effects on the overall suitability.

In 1973 the FAO panel for land evaluation defined the concept of land utilization types and suggested the classification of land for a specific use (Brinkman and Snyth, 1973). This classification was further modified in 1973 and 1975 to yield a standardized frame work for land evaluation (FAO, 1973; 1974; 1975; 1976). Putting together some positive aspects of the early approaches to land evaluation, and adding consideration of the role of evaluation in development planning, Young (1976) has suggested a number of requirements (based in part on Brinkman and Snyth, 1973) for a land evaluation system:

1. The system should evaluate land for specified forms of use, defined as closely as the intensity of the study requires

2. The land use alternatives considered should be those which are not only physically possible but also economically and socially relevant.
3. Evaluation should take into account both the production, or other benefits, from each land use alternative, and the inputs or costs necessary to achieve this production.
4. The effects of the land use alternatives on the environment, particularly possible adverse effects (hazards), should be considered.
5. The evaluation system should permit interpretation in stages, according to different purposes and intensities of survey.
6. The system should be versatile, capable for adaptation to a wide variety of circumstances, both environmental and economic. For example, it should permit adaptation both to smallholder farming and to estate or other large scale forms of agriculture.
7. The results of the evaluation should have a degree of permanence appropriate to its expected application; this means not only the period over which it will be consulted for planning purposes but the anticipated duration of the planned changes in land use to which it refers. The results should not be unduly sensitive to short-term economic fluctuations.

8. At the same time the system itself should be flexible, permitting periodic revision, for example with changing technology or with ~~substantial~~ and reasonably permanent changes in economic conditions.
9. The final results of the evaluation are going to be read by economists, planners and those responsible for administering foreign aid. They should therefore be presented in terms which are simple, capable of being understood by the non-specialist, whatever may have been the complexity of the processes which lead up to them. The presentation should be in terms which inspire confidence in government agencies and investment institutions.

The FAO (1976) framework for land suitability evaluation is not claimed to be a complete evaluation system, but a framework around which national or local systems may be constructed. In this system, the forms of land use which serve as the subject of evaluation are defined as closely as the purposes and intensity of the survey required. In reconnaissance surveys they may be major kinds of land use, e.g. perennial cropping, forestry. In more detailed surveys they may be individual crops or plant species, e.g. oil palm, Pinus patula; farming systems, e.g. smallholder mixed arable and dairy farming; or other land utilization types, e.g. national parks. It is essential that the forms of land use be properly defined in this system.

The FAO system is a classification structure with four categories: orders, classes, subclasses and units. At the origin three orders, suitable (S), conditionally suitable (CS)

and unsuitable were recognized and defined. At a later stage (FAO, 1975), the order "conditionally suitable" which had been a subject of misunderstanding and misuse was removed and remained with only two orders. The order "suitable" refers to land on which sustained use for the defined purpose in the defined manner is expected to yield benefits that will justify required recurrent inputs without unacceptable risk to land resources on the site or in adjacent areas. The "unsuitable" order on the other hand is land having characteristics which appear to preclude its sustained use for the defined purpose in the defined manner or which would create production upkeep and/or conservation problems requiring a level of recurrent inputs unacceptable at the time of the interpretation.

Land suitability classes indicate degrees of suitability within orders. The framework at its origin (FAO, 1973) permits complete freedom in determining the number of classes within each order. It has been recommended (FAO, 1975; 1976) however to use three classes within the suitable order and two classes within the unsuitable order. The classes are indicated by arabic numbers in sequence or decreasing suitability within the order, e.g. S1, S2, S3, indicating respectively suitable, moderately suitable, and marginally suitable for that order and U1 and U2 indicating actually unsuitable but potentially suitable and actually potentially unsuitable respectively. No firm criteria are given for defining the classes. This permits complete freedom in the choice of the criteria in order to elaborate the degrees of suitability within the orders. For each specific case a specific method has to be suggested. Appraisal can be done according to an evaluation of land limitations or even through a parametric method.

Land suitability sub-classes are divisions of classes reflecting kinds of limitations, or main kinds of improvement measures required within classes. They are identified by lower-case letters with mnemonic significance, e.g. w = wetness limitation, t = topographic limitation. Subclasses are written thus: S2w, S2t, S2wt. Recognition of subclasses is only worthwhile in so far as it assists in distinguishing lands that differ in the broad nature of their management requirements. These differences can rarely be expressed conveniently by precise definitions but they require to be explained in the supporting text. The land suitability subclasses that have been defined so far are: c = climatic limitations; t = topographic limitations; w = wetness limitations; n = salinity (and/or alkalinity) limitations; f = soil fertility limitations not readily to be corrected; s = physical soil limitations (influencing soil/water relationship and management) and e = erosion hazard limitation. It should be noted that there is no subclasses in class S1.

Land suitability units in the framework are divisions of the sub-classes which differ in minor aspects of the management requirements. They are identified by arabic numbers in brackets (Young, 1976; Brinkman and Smyth, 1973), e.g. S2w(2) or arabic numbers following a hyphen (FAO, 1976), e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass.

The guidelines for the use of the FAO system is well documented in the framework of land evaluation (1976). This involved four phases (Sys, 1976).

Phase I Requires the characterization of the land development units in pedological terms, mentioning the characteristics having an influence on the limitations used to define the subclasses (topography, wetness, salinity and alkalinity, natural fertility, and soil characteristics). In a regional scale, the data in phase I are best summarized in a table form, listing all land units and their characterizing pedological terms.

Phase II Requires definition of the evaluation criteria for the ~~considered~~ land utilization types. This involves construction of tables for utilization type, taking into consideration the characteristics mentioned in phase I and their degree of limitation.

Phase III Requires characterization of land units in evaluation terms. This can be achieved through transformation of the first table mentioning the land characteristics for each land unit. These land characteristics are replaced by an interpretation expressed as a degree of limitation (0, 1, 2, 3, 4) using the suitability tables or expressed as a numerical rating taken from similar suitability tables as shown in table 4.

Phase IV Requires the criteria for the definition of the classes to be defined as for example in the following case:

S1: land units without limitations or with only slight
limitations

S2: land units with slight and no more than three moderate
limitations

Table 4. Guidelines for depth limitations - an example of evaluating land characteristic parameters (After Sys, 1976).

Land Utilization type	Degree of depth limitation (cm)				
	0	1	2	3	4
Cereals and pastures (rain fed)	+ 90	40-90	20-40	10-20	-10
Annual root crops (rain fed)	+ 90	60-90	40-60	20-40	-20
Deep rooting (perennials)	+ 150	90-150	60-90	30-60	-30
Irrigation (farming)	+ 150	100-150	50-100	20-50	-20

- S3: land units with more than 3 moderate limitations and/or no more than one severe limitation that do not however exclude the use of the land
- U1: land units with one severe limitation that excludes the use of the land or more than one severe limitation that can be corrected
- U2: land units with severe or very severe limitations excluding the use of the land and which cannot be corrected.

Like the FAO map legend for soil classification, the FAO framework for land evaluation borrows quite a number of features from other systems especially from both the USDA and USBR systems. The terms (capability/suitability) class, sub-class and unit have much the same meanings as in the USDA system, and in the two latter cases the same symbols. The framework does not specify how suitability is to be determined, but in practice systems based upon it are likely to use conversion tables which employ, in whole or in part, the concept of limitations. It differs radically from the USDA system in three respects: first, that suitability is assessed separately for each form of use; secondly, in that it makes use of land qualities in place of individual land characteristics; and thirdly, that it places emphasis on economic aspects. In this last respect it has borrowed the concept of payment capacity from the USBR system. When applied to the economic evaluation of a proposed irrigation scheme its approaches and methods become very much similar to those of the USBR system, FAO classes S1, S2, S3 and U2

corresponding to USBR classes 1, 2, 3 and 6. The USBR system therefore appears to be fully compatible with the framework, whereas the USDA system, owing to its general-purpose nature, is not. The most important contribution of the FAO framework however is the emphasis placed on the fact that different forms of land use have different requirements, and that consequently these uses must be defined and land suitability assessed separately for each. It still requires to be tested extensively by application to a wide variety of environments, physical, economic and social conditions, and to a broad range of planning purposes before it could be adopted internationally.

2.3.3 The Role of Land Evaluation in Development Planning

In the conventional approach to land development planning it is regarded as a process consisting of three phases: description, evaluation and development. The phase of description includes natural resource surveys, of which soil survey forms one, along with the collection of information on agriculture, economics and other aspects of existing situation. In the evaluation or appraisal phase information from resource survey is combined with that from technology, such as crop requirements and agricultural methods, and expressed as productive potential. The development phase is concerned with the physical planning necessary to convert this potential into production.

The three phases are to some extent successive in time. Information collected during one phase is passed on to, and serves as a basis for, the next. The completion of each phase is marked inter alia by the production of maps: soil, landform

and other maps showing the physical environment at the conclusion of resource survey, land suitability maps following evaluation, and development plans at the conclusion of the project survey.

Where this three phases approach is combined with different scales and intensities of survey a cyclic pattern can be envisaged, as illustrated in table 5. At the initial stage, a country or a region conducts a survey at the reconnaissance scale, perhaps a land system survey, for resource inventory purposes. The evaluation map derived from this survey is qualitative and shows suitability for major kinds of land use. If the ~~recon-~~
~~naissance~~ survey is sufficient to identify possible development projects, then the next step is to carry out a feasibility survey of at least one of the projects. The resource surveys for this include a soil survey at the semi-detailed scale. The land evaluation map from such a survey ~~is produced initially in~~ quantitative physical land suitability terms, since the timing of development is unknown and there is hence a substantial degree of uncertainty over costs and market prices; subsequently, but still within the feasibility survey, the physical suitability specifications are translated into current economic terms. If after the feasibility studies the project proves to be technically feasible and economically competitive, a decision to proceed with it may then be made.

The three-phase approach, to the extent that it involves the separation of resource survey evaluation and development planning into separate and largely successive phases, has been

Table 5. The place of land evaluation in an idealized sequence of development planning. Based in part on Brinkman and Smyth (1973) and Young (1976).

Purpose of survey	
Resource/inventory/ Project location	<ol style="list-style-type: none">1. Resource surveys, reconnaissance scale; including soil-landform or land system map.2. Land evaluation: qualitative suitability for major kinds of land use.3. Preparation of regional plan; identification of possible projects.
Feasibility survey of possible projects	<ol style="list-style-type: none">1. Resource surveys, semi-detailed scale; including soil map.2. Land evaluation: (i) quantitative physical suitability for land utilization types; (ii) economic analysis.3. Selection of project; funding and decision to proceed.
Development survey of project	<ol style="list-style-type: none">1. Resource surveys, detailed scale, or supplementary to those of feasibility surveys.2. Land evaluation: suitability for defined land utilization types in economic terms.3. Preparation of project plan.

criticised on several grounds (Moss 1968b, 1969; Young 1976; Davidson, 1965). One of the criticisms lie in the practice of treating evaluation as an office exercise began only after the completion of field survey. Another criticism of the conventional methods (Moss, 1968b, 1969) is an argument that methods of resource survey based upon geomorphology lead to a static approach to environmental resources, and that this needs to be replaced by a dynamic approach based upon ecology. (Moss 1968b, 1969) proposed what he termed contemporary functional relationships, or biocenological approach. He argues that every area of land consists of a geo-ecosystem, components of which include landforms, soil, soil moisture, vegetation, and the cropping pattern over a period of years. Each of these components affects the other; for example there are multiple and reciprocal relations between vegetation/land use, soil moisture, soil organic matter and nutrient levels. Many components of the geo-ecosystem are in a state of change, cyclic or permanent. Soil organic matter and nutrient levels for instance vary cyclically between fallow and cropping periods.

Moss (1968b, 1969) argues further that by taking geomorphology as the basis for natural resource survey, as is done in the land systems method and in much soil mapping, a static approach is engendered since landforms, change only very slowly over time. The result is a picture of the environment which sees it as offering a given, fixed quantity of resources, which may be made use of by man. In reality there is a continuous interaction between land use and resources. A change in the

type of intensity of land use, which is invariably a consequence of development projects, will therefore lead to changes in the resources themselves. The way to take account of this interaction as proposed by Moss (1968b, 1969) is to base resource survey on the ecological approach, viewing land/man relations as functioning systems.

The second challenge to conventional methods was made by Davidson (1965). He suggests that the sequence description - evaluation - development should be reversed. He cited examples from northern and central Australia where large sums of money and time was spent on descriptive account of the environment, with only relatively brief evaluation sections and no economic analysis. Davidson (1965) argued that most of the land surveyed could be shown to have little or no potential for development on an economic basis; any money invested in land development would be more profitably spent on the already settled areas in the southern and eastern parts of the continent. He concluded that the surveys were therefore collecting information which was of no use as a guide to investment, and were therefore a waste of government money.

Davidson (1965) suggested that economics should be tackled first. The crops or other forms of production which give a sufficiently high return from capital to compete with other forms of investment should first be determined, by considering market prices of crops in relation to costs of production. This analysis he argues, should lead to the

conclusion that certain types of land development would repay investment, given the present state of technology and market prices, provided that yields were above a certain figure whilst production costs remained below a corresponding level. The environmental conditions requisite for such levels of output and costs could then be determined; location and transport costs would play an important part in such analysis. The specific conditions required could then be sought in the field, with a great saving of field costs. In theory, nothing but "useful" information would be collected.

Much as Davidson's economics - first approach may appear better than the conventional methods, it has disadvantages at least equal to those of the conventional approach when carried to a similar extreme. Natural scientists would have no constructive contribution to make as to how the complex and varied resource potential of the environment might be put to use. In addition much resource data of relevance to development would be missed. What can be learnt from consideration of the economics-first approach, however, are some disadvantages of proceeding in an equally rigid way with the conventional approach without any feedback from economics to resource description. Natural resource surveys are prone to collecting data which is of very little use in evaluation and almost none in development, such as the detailed differentiation of soil types on land which is clearly non-arable. A solution to the disadvantages of either of these procedures when followed rigidly is that there should be greater communication between natural scientists and economists at all stages of a project survey.

Another alternative to the conventional methods of land development is matching land use types with environment as proposed by Beek and Bennema (1974) and Beek (1974). Their approach is considered as a positive contribution to methods of land evaluation rather than a criticism of existing practices. It is based upon a view of land use types which regards these as something much more than simply a matter of what is done with the land itself, e.g. maize cultivation. A land utilization type is regarded as a "technical organisation unit in a specified socio-institutional setting". The key attributes by which land utilization types can be identified are: the produce e.g. crops, timber, beef; land tenure systems (legal status); size of farm; labour intensity; capital intensity; level of technical knowledge; income level; farm power (power source, implements) and technology.

When one considers land utilization types as organizational units defined in some detail, the process of land evaluation is then regarded as one of "matching" environmental resources with land use types. The results of resource surveys lead to a first provisional description of land utilization types which might be suited to them. The land utilization types so defined are compared in suitability terms with the land mapping units identified from resource survey. The provisional description of land utilization types is then modified in the light of this suitability, in such a way that it becomes more closely matched with the environmental potential. The final result of this matching process should be a series of land utilization types,

defined in some detail, which are the most highly suited to each part of the survey area.

There are thus two inputs to the process of land evaluations: the results of natural resource surveys and the specifications of relevant land utilization types. The match of the two is often systematized by means of a conversion table. From the land mapping units defined by resource survey, land qualities are obtained (e.g. moisture availability, rooting conditions); conversely, from the specifications of the land utilization types, the land qualities required for their successful functioning are derived. The one set of land qualities is compared with the other, resulting not only in land suitability classes but also management specifications for each land mapping unit.

The basic concept behind this approach is that land can only be related according to its suitability for a specified purpose; and therefore the purpose, namely the land utilization type, must be specified just as closely as are the environmental conditions of the land.

3. GENERAL CHARACTERISTICS OF THE KILOMBERO SUGAR ESTATE

3.1 Location and Extent

The Kilombero Sugar Estate is located in the Msolwa and Lower Ruembe Valley between latitudes $7^{\circ} 30'$ and $7^{\circ} 50'$ south, and longitudes $36^{\circ} 50'$ and $37^{\circ} 10'$ east of the Kilombero district of Morogoro Region, Tanzania (Fig.1). To the west it is bounded by the Gologolo and Migomberama mountains which rise steeply to a height of over 2,200 m. above sea level. To the east and south is the hilly low plateau of the Selous Game Reserve and to the north is the Mikumi National Park. The altitude of the estate is around 300 m and most of the land slopes gradually from north west to south east with gradients generally less than 0.5° .

The study area is located to the western side of the Kilombero Estate near the escarpment, between the Msolwa and Sanje rivers (Fig.3). To the north and north-west of the area is the tributary of the Msolwa river and the Gologolo mountains; to the west is the Gologolo mountains; to the south is the Sanje river and to the east is the Nyarybungu stream and Msolwa plains.

3.2 Geology

The valleys of the Ruembe and Msolwa rivers are part of the East African rift valley system. Along the western margin of the Kilombero estate, the hilly and mountainous terrain of Central Tanzania is separated abruptly by a north south fault system (Whittingham, 1963). The raised block to the west constitutes the Gologolo and Migomberama mountains, consists of igneous rocks of the Usagaran System of the basement complex (Fig.2 and 4). These Usagaran rocks are known to be composed of two major stratigraphical groups.

- (a) Migmatic gneiss with biotite and or hornblende together with Usagaran undifferentiated.

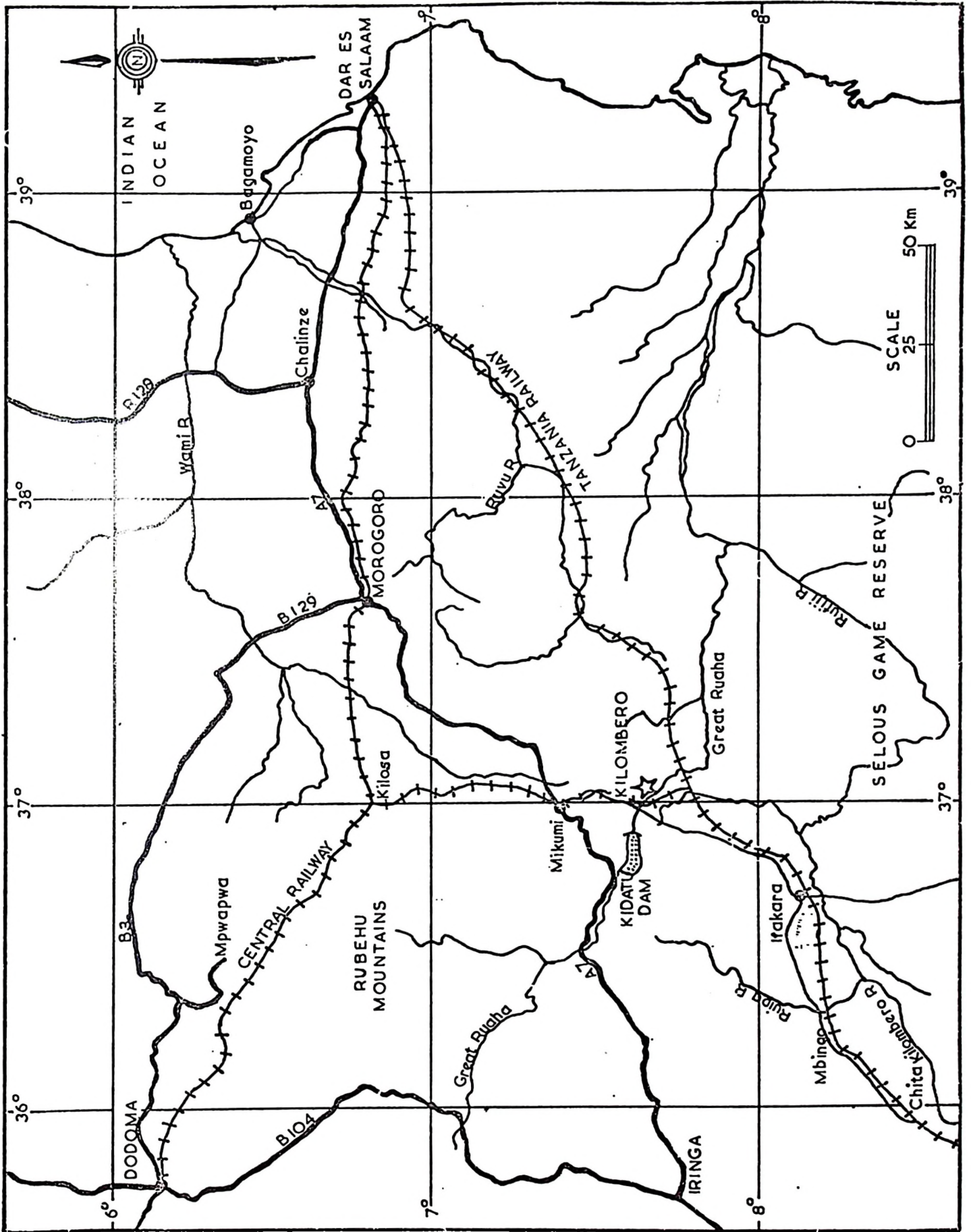


Figure.1. Eastern part of Tanzania showing location of the study area .

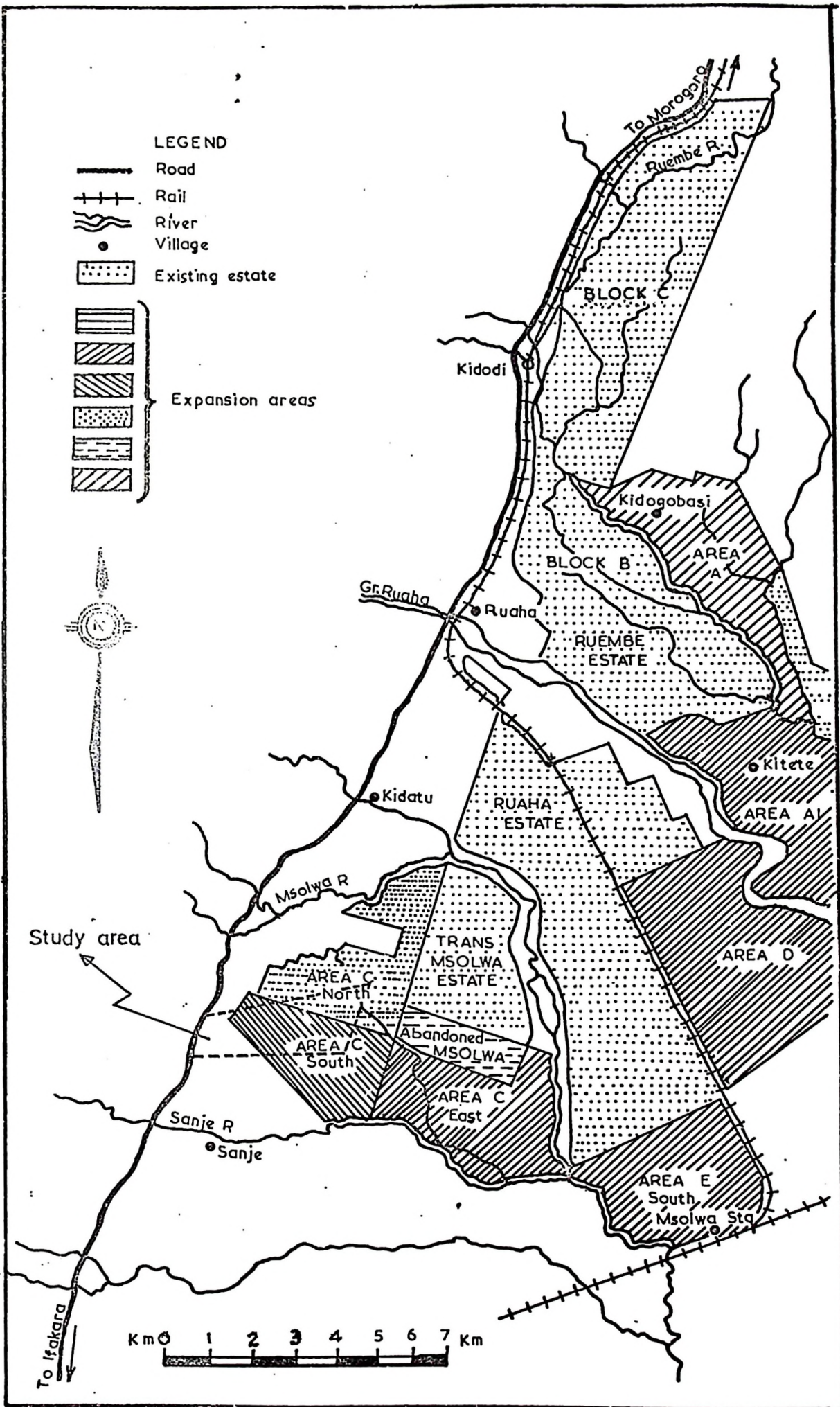


Figure. 3. Potential expansion areas around the existing sugar estate as surveyed-Booker Agriculture International Ltd (1979)

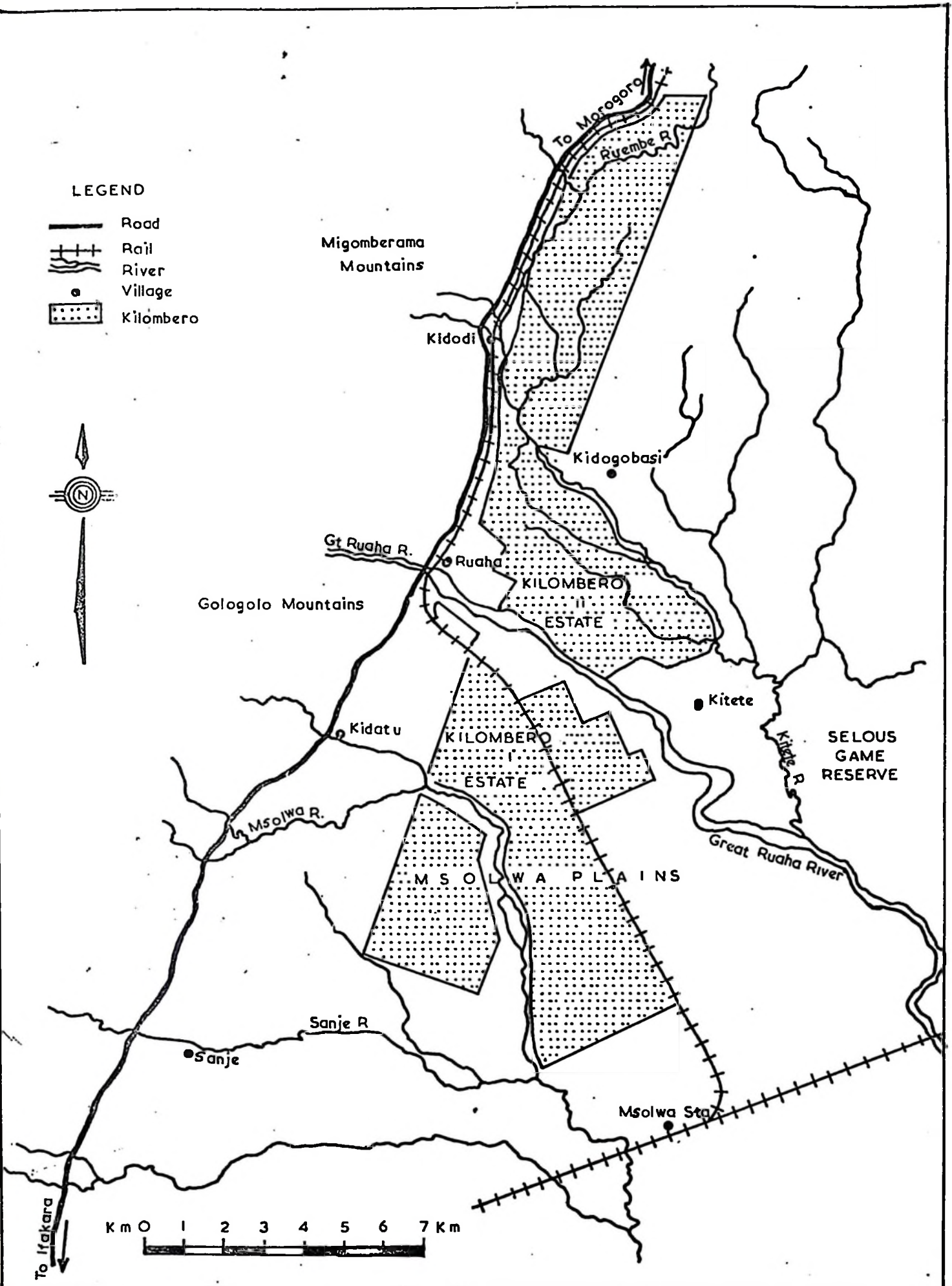


Figure. 4. Existing sugar estates: Kilombero I Estate along the Msolwa plains and Kilombero II Estate along the lower Ruembe valley.

(b) Granulites with migmatitic gneiss

The former group occurs to the north and north/west of Sanje whilst the latter occurs to the south of Sanje.

Overlying the Usagaran rocks in the valley floor are the colluvial and alluvial sediments of Neogene times. These have been differentiated (Whittingham, 1963) into two broad groups: light sandy earths, cemented sand and gravel; and alluvial sands and silts. Both these groups are found extensively within the Kilombero estate area although only the areas of alluvial sands and silts are used for intensive cultivation. At the eastern margin of the estate within the Selous Game Reserve is a relatively small outcrop of Karroo sandstone. It is thought that this formation could extend west of its present outcrop as far as the escarpment underlying the Neogene sediments in the valley floor (Anderson, 1961).

Geologically the study area is dominated by colluvial and alluvial sediments of Neogene times. The colluvial material appear to have originated from the Gologolo mountains while the alluvial sediments appear to have been deposited from the Msolwa river and its tributaries.

3.3 Geomorphology

Within the faulted valley system of the Lower Ruembe and Msolwa valleys, the major land forming agents are the rivers flowing from the elevated lands to the east and south. The Great Ruaha is by far the largest river near the area. This

river flows through a narrow gorge through the Gologolo mountains carrying with it high sediment load during the rainy season which is deposited when the flow rate decreases at the bottom of the scarp as the river enters the Ruembe and Msolwa valley. The pronounced seasonal nature of the flow combined with frequent flooding has resulted in numerous course changes over short time intervals leaving a slightly undulating landscape with sand banks, old channels and levees. Further from the rivers, basins occur in which the finer fractions of the river sediments have been deposited.

The smaller rivers of the valley, with the exception of the Ruembe, show similar features but on a very much smaller scale. The Ruembe flowing from the north is also subject to flash floods, and deposits large amount of alluvial in the area east of Kidodi. It is on these latter deposits that a large fraction of the KII estate has been established. At the foot of the western escarpment, distinct colluvial fans have been formed by the numerous small streams carrying primary weathering products from the mountains. These have slopes of up to 5% and frequently contain layers of very coarse grained sediments. These colluvial fans also act as aquifers for water draining down from the scarp. This water subsequently comes to the surface in a series of springs at the junction between the colluvial deposits and the alluvial sediments.

In the south of the estate is an extensive area of relatively flat, uniform, fine textured sediments which are likely to have been deposited by the Ruaha during an earlier p

period. It is believed (Anderson, 1961) that the Ruaha once followed the present course of the Msolwa river. In the Selous Game Reserve, the Karroo sandstone and basement complex formation have been eroded to form an undulating plain with occasional rock outcrops. Slopes in excess of 5% are not uncommon in this area, and the lower lying depressions are very poorly drained, frequently with swamp features.

3.4 Natural Vegetation and Land Use

Prior to the establishment of the Kilonbero Sugar Estate, a large proportion of the alluvial soils was covered by a tree bush savanna with smaller areas of bush and grass savanna. Substantial areas with natural vegetation still exist around the margins of the estate. These are however rapidly disappearing as the pressure for land in the valley continues to rise.

The dominant grass of the undisturbed and fallow areas is Hyparrhenea rufa which characteristically grows to a height of 2.0m or more. In the more open areas the tree cover is dominated by a variety of Acacia species which give way to Brachystegia dominated woodland where the vegetation thickness. Large areas of land not used for sugar cane cultivation are used to grow subsistence crops. In the imperfectly drained basin areas, rice cultivation is very prominent. On the lower terraces close to the Great Ruaha river which have adequate soil moisture for most of the year, intensive cultivation of maize is practised. The maize is frequently intercropped with tomatoes and other vegetables. In general, the more elevated and better drained

areas support a wide variety of crops including maize, bananas, cassava, pawpaw, beans, sorghum, peppers and vegetables (Booker Agriculture International Ltd., 1979).

3.5 Climate

The climate of the Kilonbero Estate is a tropical rainy climate (in the terms of the Koppen System an "Awa" climate) with pronounced dry and wet seasons (ILACO, 1967). The rainy season lasts from November or December to May with possible dry spells of three weeks or more in the period of January up to and including the first week of March (Table 6). The mean annual rainfall amounts to about 1400 mm around the valley, rising to about 1600 mm in the foothills of the Kilonbero Escarpment. About 40 percent of the total annual precipitation falls in the month of March and April, mainly in the form of downpours of high intensity. The onset of the rains and the rainfall distribution pattern over the years are not very reliable and irregularities in the rainfall very often cause failure of seasonal crops owing to either drought or excessive rainfall. The lower Ruenbe and Msolwa Valleys rainfall (Table 6) is nearly always abundant for one crop in the rainy season, but dry season crops need irrigation. The period from June to October are usually dry, with a mean monthly rainfall of 25 mm.

The average monthly temperature, calculated from daily observations of maximum and minimum temperatures varies between 21° and 25°C during the dry season and between 25° and 28°C during the wet season. An examination of the temperature data

Table 6. Mean Annual distribution of rainfall in the Kilombero Sugar Estates (mm)
(Averaged from eight stations)

YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	TOTAL
1961/62	67	65	65	9	97	211	261	458	248	160	282	325	2199
1962/63	45	16	6	61	12	33	19	120	218	173	515	342	1561
1963/64	44	62	6	1	1	22	387	145	171	178	362	366	1745
1964/65	71	6	2	15	2	20	7	64	227	157	371	345	1358
1965/66	120	1	8	29	34	46	88	167	109	138	203	297	1240
1966/67	235	20	1	3	10	37	79	66	63	144	206	314	1178
1967/68	135	52	56	13	78	52	199	468	172	111	291	652	2279
1968/69	96	68	0	1	10	8	158	121	94	122	165	265	1108
1969/70	23	18	7	4	0	12	88	15	439	280	250	215	1351
1970/71	116	7	6	4	41	9	0	139	116	82	229	384	1133
1971/72	244	23	37	0	3	26	41	102	108	244	325	344	1497
1972/73	117	0	8	5	115	25	303	141	177	168	142	404	1625
1973/74	167	18	2	●	4	0	58	49	183	99	92	535	1217
1974/75	183	76	55	1	18	75	4	34	150	85	150	318	1147
1975/76	77	37	11	5	24	12	17	171	179	102	238	232	1105
1976/77	135	39	4	20	1	4	3	72	182	151	197	282	1090
1977/78	29	1	14	11	44	90	169	165	184	34	255	196	1102
1978/79	28	19	1	2	1	50	247	336	207	353	219	499	2016

(Table 7) reveals that the period from October to May has high temperatures while June to September has low temperatures. The relative humidity also changes with the seasons, being highest during the wet season. During the dry season the fields are sometimes wet in the morning owing to dew. The annual average evaporation (calculated from class "A" pan) is 1899 mm and the coefficient of variation is rather low. This evaporation data gives an indication of the evapotranspiration loss from the area which is normally related to the yield of crops. Moisture deficits calculated using the average evaporation and rainfall data (Table 6 and 7) are significant in June all through to December in most years. The duration of sunshine tends to be low during the month of April to September, with monthly average of between 5.3 and 6.4 hours per day. The annual mean sunshine hours is around 6.4.

The high rainfall intensity of the steep mountains causes flash floods in the small rivers and streams. This does not present serious problems in the mountains and foothills where the rivers have very often a rocky bed and a steep fall. Once these rivers have entered the main valleys (Kilombero, Msolwa and Ruenbe) however, the river beds become shallow and narrow and fail to carry the flash floods. Very often too, the overflow is obstructed by fallen trees and other debris. As a result, the rivers overflow their banks and inundate large areas in the valleys, in addition to the water already on the land due to rainfall. A quick discharge of this inundation water back into the rivers is sometimes

Table 7. Other Meteorological Data for the Kilonbero Sugar Estates (1961 - 1978)

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
Maximum Temp. °C	32.2	32.1	31.3	29.5	28.3	27.5	27.4	28.5	30.1	32.1	33.0	32.9	30.2
Minimum Temp. °C	21.2	21.2	21.2	20.6	18.9	16.5	16.0	17.2	18.5	20.3	21.0	21.5	19.5
Mean Temp. °C	26.7	26.6	26.1	25.1	23.6	21.9	21.1	22.9	24.3	26.2	27.0	27.2	28.9
Mean Evaporation in mm.	173.3	171	168	117	126	122	130	140	159	180	200	199	157
Maximum Relative Humidity %	94	94	94	95	95	94	93	91	91	89	90	93	
Minimum Relative Humidity %	53	53	55	57	54	48	51	50	48	48	44	52	
Mean Sunshine Hours	6.3	7	6.6	5.3	5.8	6.4	6.0	6.1	6.2	6.8	7.7	7.1	6.4

hampered by the dense grass vegetation. As a consequence the water drains very slowly and large areas in the valleys remain inundated for several months during and after the rainy season with what is called the "creeping flood". Parts of the flooded areas never dry up and have become permanent swamps (ILACO, 1967). Observations regarding the shallow groundwater movements (ILACO, 1967), indicate that during the rainy season and some months thereafter the groundwater level reaches up to the soil surface in large parts of the valleys. At the end of the dry season the groundwater level is rather deep below the soil surface except in narrow strips along the perennial rivers where river-water seeps through the soil.

4.0 MATERIALS AND METHODS

4.1 Aerial Photograph Coverage

Three sets of aerial photographs covering the area were obtained:

- (a) 1:40,000 Fair Air Photo Services Ltd. taken in 1956
- (b) 1:10,000 Spartan Air Services Ltd. taken in 1965
- (c) 1:10,000 Geosurvey International Ltd. taken in 1974

The aerial photographs by the Spartan Air Services Ltd. only covered the lower part of the survey area while the Geosurvey International Ltd., though most recent, covered only the north-western part of the area. The Fair Air Photo Services photographs, although covering the whole area, are among the oldest photographs in the country, usually of the poorest technical quality, thus restricting its value for interpretive work (Cook, 1974). The three sets of photographs were however used during the preliminary stage of the survey to differentiate the broad soil associations in the area before the field work began.

4.2 Field Survey Methods

A ~~topographic~~ map of the area on a scale of 1:10,000 prepared by the Kilombero Sugar Company was used as a base map. The base line was placed at about the middle of the survey area in a west-east direction using a dumpy level. The ground was then covered by making parallel traverses, 200 m apart and perpendicular to the base line. Features which were observed along the grid lines were noted and final details traced from the relevant aerial photographs and the base map. Aggerings to a depth of about 120 m and an interval of about 200 m along

all traverses was carried out and the texture of the soil determined by feel. Altogether a total number of ninety four auger holes were made and characterized (Fig.5).

Twenty one soil pits distributed over the different soil units were excavated to a depth of about 150 cm or to a water table. The soil profiles were described in detail according to the FAO Guidelines for Soil Description (FAO, 1967) and the Soil Survey Manual (1951). Colour was determined by the Munsel Colour Chart (Munsel colour company 1954). Samples were then collected from each horizon of each profile for chemical and physical analysis. Before analysis, the samples were air dried, gently crushed and passed through a 2 mm sieve. Sub-samples were further crushed and sieved through a 60-mesh sieve for chemical determination.

4.3 Soil Physical Properties

4.3.1 Particle Density

This was determined by the pycnometer method as described by Blake (1965). The density is the ratio of the mass of the sample obtained by weighing to the volume of the material obtained from mass and density of water displaced by the sample in the pycnometer.

4.3.2 Bulk Density

This was determined by the core method (Blake, 1965). A cylindrical metal sampler of known volume was gently driven into the soil (in order to avoid compaction of the soil) gently

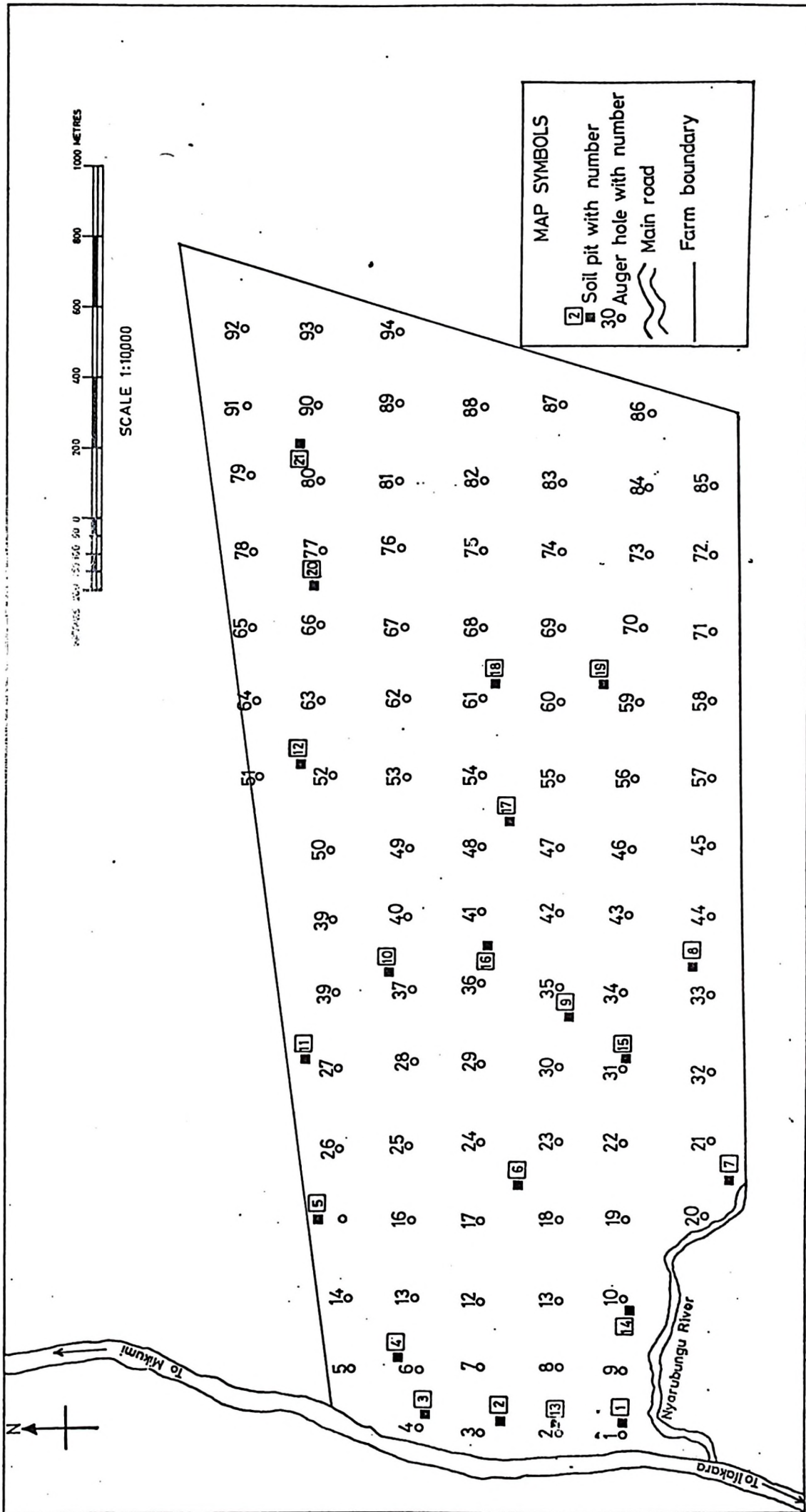


Figure 5 Soil pit and auger hole location map

dug out to remove the protruding soil mass from each end using a sharp knife. The samples were then dried to a constant weight at a temperature of $105 - 110^{\circ}\text{C}$ and weighed. The bulk density was then determined by the ratio of the oven dry mass of soil to the volume of the core.

4.3.3 Particle size distribution

This was determined by the hydrometer method (Day, 1965). The soil was dispersed with sodium hexametaphosphate (Calgon) and subjected to an end to end shaker for about twelve hours. The suspension was then carefully transferred to a one litre sedimentation cylinder and the contents brought to mark with distilled water. The contents in the cylinder was then stirred by a brass metal and left to settle. At exactly five minutes from the time of settling the hydrometer was read to give the contents of silt and clay still in suspension. The temperature of the suspension was also read to allow for corrections. After five hours of settling, the hydrometer was read again to give the content of clay alone in suspension. Temperature was also read for correction purposes. The difference between the value at five minutes and five hours gives the amount of silt alone in the sample. Percentages of silt, clay and sand were then computed. Blank correction was also carried out to remove the error due to the dispersing chemicals used.

4.3.4 Available water

This is theoretically defined as water held between field capacity and the permanent wilting point. The field capacity

4.4.3 Organic Carbon

The organic carbon was estimated by the wet-combustion method of Walkley and Black (Allison, 1965). Normal $K_2Cr_2O_7$ and concentrated H_2SO_4 were used to oxidise the organic carbon in the soil. The amount of $K_2Cr_2O_7$ utilised was taken as a measure of organic carbon content in the soil. A correction factor of 1.33 was used while expressing the final result.

4.4.4 Available phosphorus

Available phosphorus in the soil was extracted with 0.03 normal NH_4F plus 0.07 normal HCl as described by Bray and Kurtz (1945). P in this extract was determined by the chlorostannous reduced molybdophosphoric blue colour method as described by Jackson (1958). The pH of the system was maintained at 3.0 with 4 normal NaOH or 4 normal HCl as required; 2, 4 - dinitrophenol was used as indicator. From the standard phosphorus curve the colour intensity was measured by spectrophotometer at 660 mμ wavelength.

4.4.5 Cation exchange capacity

The cation exchange capacity was determined by ammonium saturation method (Chapman, 1965). The soil was saturated with neutral normal ammonium acetate and then filtered. The residue was washed with methyl alcohol, subsequently shaken with 4 percent KCl solution and filtered. The NH_4-N in the filtrate, which is a measure of the CEC of the soil was determined on a Markham distillation apparatus.

4.4.6 Extractable bases

The determination of the extractable bases was done using the ammonium acetate extract. Flame photometer was used for the determination of extractable potassium and sodium (Pratt 1965) while EDTA method was used for the determination of calcium and magnesium.

4.5 Soil Classification

From the field and laboratory data the soils were classified according to USDA, Soil Taxonomy (1975) system from the category of order up to subgroup level.

4.6 Mapping Units

Identification of the soil mapping units present in the area was carried out with the help of the information obtained from the field survey, following the soil survey manual (Soil Survey Staff, 1951). The slope, texture of topsoil and mottling were mainly used as distinguishing characteristics in compounding mapping units which contain more than one taxonomic class.

4.7 Land Evaluation

The information obtained from field and laboratory data and the suitability table adopted from Sys (1976) were used to evaluate the land with the help of the criteria defined and outlined in the Framework for land evaluation of FAO (1973), up to the subclass level.

5. RESULTS AND DISCUSSION

5.1 Soil Classification

The information on the field observations is presented, followed by tabulated laboratory data for some physico-chemical properties. Soil classification for each profile has been done to the subgroup level using the Soil Taxonomy System (Soil Survey Staff, 1975). However owing to the unavailability of mineralogical data the family level has been omitted. The results of this classification are presented in table 8. Appendix III shows a sketch distribution of the soil orders, found in the study area.

Table 8. Classification of the soils using the Soil Taxonomy System (1975)

Profile number	Ultimate Classification	Order
6	Aquic Ustifluvent	Entisols
7	Typic Ustipsamment	Entisols
8	Vertic Ustiorthent	Entisols
20	Humaqueptic Fluvaquent	Entisols
1, 2, 3, 4, 9, 12, 14	Ustic Humitropept	Inceptisols
15, 17	Aquic Humitropept	Inceptisols
12	Typic Eutropept	Inceptisols
21	Typic Tropaquept	Inceptisols
18, 19	Aeric Tropaquept	Inceptisols
10	Cumulic Haplustoll	Mollisols
5	Ustic Tropohumult	Ultisols
11	Aquic Tropohumult	Ultisols

The most dominant diagnostic surface horizon in the study area is a ochric epipedon followed by an umbric epipedon.

Sub surface horizons are dominated by a cambic horizon and only few had characteristics of an argillic horizon; other profiles studied had no diagnostic subsurface horizons.

5.1.1 Entisols

Profile 6 3/8/79

External features

Located at about 600 metres east of Ifakara - Mikuni road; undulating, linear, about 3 km, south facing minor slope with major slope east facing, approximately 2% gradient, pit site near lower parts of the slope; ustic soil moisture regime, isohyperthermic soil temperature regime; currently under sugar cane, colluvial material, moderately well drained; slightly flooding.

Internal features

Ap 0-18 cm Greyish brown (2.5YR 5/2) dry, very dark greyish brown (2.5YR 3/2) moist; moderately fine sandy clay loam; moderate medium crumbs to sub-angular blocky; slightly sticky and slightly plastic, slightly firm, slightly hard; many fine roots; many fine discontinuous impeded pores with few medium continuous pores; clear smooth boundary.

- AC 18-46 cm Dark yellowish brown (10YR 4/4) dry, dark yellowish brown (10YR 3/4) moist; moderately fine sandy loam; moderate to weak medium sub-angular blocky; slightly sticky and slightly plastic, slightly firm, slightly hard; no outcans; many fine discontinuous inped pores; common fine roots; diffuse irregular boundary.
- C 46-80 cm Dark yellowish brown (10YR 4/4) dry, dark yellowish brown (10YR 4/4) moist; moderately fine sandy clay loam; structureless (single grained); very slightly sticky and very slightly plastic, friable, soft; many fine discontinuous inped pores; few fine roots; clear smooth boundary.
- O_{2g} 80-100 cm Dark brown (10YR 3/3) moist; moderately fine sandy clay loam; structureless; slightly sticky and slightly plastic, friable; many fine discontinuous inped pores; brown mottles (about 15%) present; very few roots; clear smooth boundary.
- IIC_{3g} 100-140⁺ cm Brown (10YR 4/3) moist; moderately fine sandy clay loam; structureless; slightly sticky and slightly plastic, firm; common fine discontinuous inped pores; very few roots; brown mottles (about 20%) present.

Table 9a. Physical Analytical Data
Profile 6

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Sand	Silt Clay		
A _p	0-18	1.30	2.35	35.1	13.2	21.9	60.2	12.8	27.0	Sandy Clay Loam
A _c	18-46	1.46	2.64	27.5	12.1	15.2	71.4	7.8	20.8	Sandy Loam
C ₁	46-80	1.42	2.41	16.8	6.2	10.6	77.8	5.8	16.4	Sandy Clay Loam
C _{2g}	80-100	1.44	2.37	25.4	10.5	14.9	66.4	7.4	26.2	Sandy Clay Loam
III _{3E}	100-140	1.52	-	30.0	13.8	16.4	56.2	16.8	27.0	Sandy Clay Loam

Table 9b. Chemical Analytical Data

Profile 6

Horizon	Depth in cm	pH		% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total extractable bases in meq/100 gm soil	CEC in meq/100 gm soil	Percentage base saturation		
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
A _{1p}	0-18	5.5	5.0	2.81	0.17	9.65	17	5.9	5.0	0.16	0.75	11.8	22.3	82.6	52.9
A _{2c}	18-46	7.4	4.9	1.77	0.10	13.33	12	2.4	4.0	0.14	0.25	6.8	25.0	120.2	27.2
C ₁	46-80	6.2	5.1	0.53	0.04	18.60	12	3.9	2.7	0.10	0.15	9.1	26.6	162.2	34.2
C _{2g}	80-100	5.8	4.7	0.95	0.08	9.30	12	4.9	4.3	0.16	0.20	9.6	25.8	98.5	37.2
II C _{3g}	100-140	5.8	5.1	0.51	0.07	13.16	7	3.4	3.0	0.21	0.17	6.8	24.2	89.6	28.1

Classification

Diagnostic properties

The top 18 cm was an ochric epipedon though the colours are fairly dark thickness does not qualify for an umbric horizon.

There was no diagnostic subsurface horizon.

Order

Entisol: Presence of no other diagnostic horizon than ochric epipedon, and absence of cambic, salic, gypsic, axio, argillic or calcic and clay content less than 30 percent throughout and absence of plinthite.

Suborder

Fluvent: Alluvial deposits with texture finer than fine clay loam, absence of diagnostic horizons below Ap; have slope less than 25 percent (only 2 percent), irregular decrease in organic carbon content and high up to 1.4 m depth, absence of characteristics associated with wetness, higher annual temperatures and absence of lithic and paralithic contact.

Greatgroup

Ustifluent: Has ustic moisture regime and warmer temperature regime.

Subgroup

Aquic Ustifluent: Mottling occurs within 50 cm as evidenced from auger hole 17 (mottling from 20 cm) and hole 24 (near surface) and its seasonal flooding, colour value less than 4 moist and 6 when dry.

Profile 7 4/8/79

External features

Located at about $\frac{1}{2}$ km east of the Ifakara - Mikuni road (Figure 5); undulating, nearly linear, approximately about 2% south - west minor slope in an east facing 3 km slope, pit site lower; ustic soil moisture regime, isohyperthermic soil temperature regime; currently under sugarcane; alluvial material; well drained; slightly flooding.

Internal features

- Ap 0-25 cm Dark yellowish brown (10YR 3/4) dry, very dark brown (10YR 2/2), moist; coarse sand; weak medium crumb to sub-angular blocky; slightly sticky and slightly plastic, friable, soft; many fine and few medium discontinuous inped pores; many fine roots; clear smooth boundary.
- AC 25-46 cm Reddish brown (5YR 4/4) dry, dark reddish brown (5YR 3/4) moist; coarse sand; weak medium sub-angular blocky; slightly sticky and slightly plastic, friable, soft; many fine discontinuous inped pores; common fine roots; clear smooth boundary.
- C₁ 46-68 cm Reddish brown (5YR 4/4) ~~dry~~; dark reddish brown (5YR 3/4) moist; coarse sand and few stones (7%); structureless matrix; non sticky and non plastic, friable soft; many fine discontinuous inped pores; very few fine roots; clear smooth boundary.

C₂ 68-130⁺ on Dark brown (7.5YR 2/2) moist; coarse sand;
structureless; non sticky and non plastic friable, soft;
many fine discontinuous inped pores, very few roots.

Table 10a. Physical Analytical Data

Profile 7

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture Holding Available		Particle size		Textural Class		
				Capacity in %	water %	distribution	distribution			
				pF 2.0	pF 4.2	Sand	Silt	Clay		
A _p	0-25	1.12	2.22	35.4	14.9	20.8	82.4	3.4	14.2	Sand
A _c	25-46	1.32	2.34	12.9	4.5	8.4	86.4	3.4	10.2	Sand
C ₁	68-130	1.32	2.19	29.3	11.1	18.2	86.4	5.4	8.2	Sand

Table 10b. Chemical Analytical Data
Profile 7

Horizon	Depth in cm	pH	1:1 H ₂ O CaCl ₂	pH	%	Organic carbon	%	Total nitrogen	%	Available Phosphorus ppm	O/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100gm soil	CEC in meq/100 gm Soil Clay	Percentage bases saturation
												Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺			
Ap	0-25	6.3	4.9	1.83	0.12	16.32	15	4.9	5.0	0.10	0.70	10.7	26.8	83.0	39.9		
AC	25-46	5.8	5.2	0.51	0.07	10.88	7	9.2	4.0	0.10	0.49	13.7	25.6	251.0	53.9		
C ₁	68-130	6.2	4.9	1.69	0.13	8.42	13	10.6	4.6	0.14	0.60	15.9	28.8	-	55.2		

Classification

Diagnostic properties

The top 25 cm was an ochric epipedon, though colour value moist is less than 3.5 and chroma less than 3.5 it has a thickness of not more than 25 (auger hole 20 had lighter colour of chroma more than 3.5).

There was no diagnostic subsurface horizon.

Order

Entisol: Absence of any other diagnostic horizon other than ochric also absence of conbic, salic, spodic, oxic, argillic gypsic or calcic, less than 30 percent clay throughout the profile and absence of plinthite.

Suborder

Psamment: The texture was sandy throughout the profile and differed from profile 6; absence of fragments of any identifiable subsurface horizon, and absence of hydromorphic properties.

Greatgroup

Ustipsamment: Has warmer iso temperatures and ustic soil moisture regime.

Subgroup

Typic Ustipsamment: Due to the absence of lamellae within 1.5 m from surface, no prominent nodules above 1 m and not saturated with water, had no lithic contact.

Profile 8 4/8/79

External features

Located at about $1\frac{1}{2}$ km east of the Ifakara-Mikumi road; almost flat, linear, approximately 3 km long east facing slope of about 2% gradient, pit site near lower; ustic soil moisture regime, isohyperthermic soil temperature regime; currently under sugarcane; alluvial material, imperfectly drained; moderate flooding.

Internal features

- A_p 0-28 cm Dark greyish brown (10YR 4/2) dry, black (10YR 2/1) moist; fine sandy clay; moderate fine sub-angular blocky; sticky and plastic, firm, hard; common fine with few medium continuous cracks; ant nests (5%) present; many fine and few medium roots; clear smooth boundary.
- C₁ 28-45 cm Dark brown (10YR 3/3) dry, very dark greyish brown (10YR 3/2) moist; moderately fine sandy clay loam; massive; sticky and plastic, firm, hard; common fine discontinuous impeded pores; common fine roots; diffuse irregular boundary.
- C₂₁ 45-60 cm Brown (10YR 4/3) dry, dark brown (10YR 3/3) moist; fine sandy clay; massive; sticky and plastic, firm, hard; common fine discontinuous impeded pores; few fine roots; diffuse irregular boundary.
- C₂₂ 60-108⁺ cm Pale olive (5YR 6/3) moist; fine sandy clay; massive to moderate medium sub-angular blocky; sticky and plastic, firm, slightly hard; very few fine roots; common fine discontinuous impeded pores; brown mottles (about 20%) present.

Table 11a. Physical Analytical Data

Profile 8

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution			Textural Class
				pF 2.0	pF 4.2		Sand	Silt	Clay	
A _P	0-28	1.12	2.22	35.4	14.6	20.8	60.4	7.4	32.2	Sandy Clay
C ₁	28-45	1.17	2.30	36.5	14.9	21.6	72.4	3.4	24.2	Sandy Clay Loam
C ₂₁	45-60	1.66	2.28	20.9	8.5	12.4	66.4	3.4	30.2	Sandy Clay
C ₂₂	60-108	1.56	2.33	25.6	11.3	15.3	-	-	-	-

Table 11b. Chemical analytical Data

Profile 8

Horizon	Depth in cm	pH	1:1 H ₂ O CaCl ₂	Organic carbon	% Total nitrogen	Available Phosphorus ppm	Extractable cations			Total Extractable bases in neg/100gn soil	CEC in neg/100 gn Soil Clay	Percentage base saturation			
							Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺						
Ap	0-28	5.6	4.6	3.70	0.18	21.92	21	9.2	6.0	0.16	1.13	17.1	21.2	65.8	80.7
C ₁	28-45	5.9	5.0	1.36	0.08	20.53	17	4.0	1.0	0.17	0.22	5.4	27.0	111.66	20.0
C ₂₁	45-60	6.9	5.6	0.77	0.07	18.07	11	3.0	3.0	0.12	0.10	6.2	22.2	73.5	27.9
C ₂₂	60-108	6.2	5.1	0.55	0.07	15.09	8	9.2	2.6	0.12	0.10	12.0	23.0	-	52.2

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8
4
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Classification

Diagnostic properties

The top 28 cm have characteristics of an Ochric epipedon however the characteristics of colour, base saturation and organic carbon suggest a mollic but they have hard and massive structures.

There was no diagnostic subsurface horizon.

Order

Entisol: The presence of no other diagnostic horizon than ochric epipedon and absence of carbonic, salic, gypsic, oxic, argillic or calcic horizon. Absence of gilgai, slickensides and wedge shaped aggregates.

Suborder

Orthent: Absence of fragments of diagnostic horizons, organic carbon decreasing regularly with depth and are not permanently saturated with water.

Great group

Ustorthent: Due to warmer temperatures and ustic moisture regime.

Subgroup

Vertic Ustorthent: They are not saturated with water, absence of durinodes, lithic contact and wormholes, has small cracks and less than 35 percent clay throughout.

Profile 20

19/9/79

External features

Located at about 2½ km east of the road from Ifakara to Mikuni (Fig. 5) almost flat, approximately 3 km long, linear, east facing slope of approximately 2% gradient, pit site lower; aquic soil moisture regime, isohyperthermic soil temperature regime; wooded grassland; currently under fallow; alluvial material; imperfectly drained; severe flooding.

Internal features

- A₁ 0-15 cm Dark grey (10YR 4/1) dry, very dark grey (10YR 3/1) moist; moderately fine sandy clay loam; ~~moderate fine~~ granules; sticky and plastic, firm, hard; common fine discontinuous inped pores; with few medium continuous cracks; many fine roots; clear smooth boundary.
- ACg 15-65 cm Grey (10YR 5/1) dry, very dark grey (10YR 3/1) moist; moderately fine sandy clay loam; ~~moderate fine~~ granules; sticky and plastic, firm, hard; common fine discontinuous inped pores; with few medium continuous cracks; many fine roots; clear smooth boundary.
- Og 65-120⁺ cm Dark brown (10YR 4/3) dry, dark brown (10YR 4/3) moist; fine clay; massive compact columns; sticky and plastic, very firm, very hard; brown mottles (about 10%) present; few fine discontinuous inped pores with few medium cracks; few fine roots.

Table 12a. Physical Analytical Data

Profile 20

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution			Textural Class
				pF 2.0	pF 4.2		Sand	Silt	Clay	
Ap	0-15	1.20	2.28	33.7	16.0	17.7	64.4	10.6	25.0	Sandy Clay Loam
ACg	15-65	1.69	2.32	30.9	14.0	16.9	70.4	6.6	23.0	Sandy Clay Loam
CG	65-120	1.55	2.35	39.0	19.9	19.1	44.4	2.6	53.0	Clay

Table 12b. Chemical analytical Data

Profile 20

Horizon	Depth in cm	pH	1:1 H ₂ O CaCl ₂	% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100 gm soil	CEC in meq/100 gm soil	Percentage base saturation		
								Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
Ap	0-15	5.2	4.4	1.82	0.14	25.4	13	4.65	1.27	0.15	0.14	6.21	41.6	166.4	15
B0g	15-65	5.9	5.0	0.80	0.07	17.6	10	5.12	1.27	0.15	0.06	6.60	31.2	135.7	21
CG	65-120	6.2	5.4	0.38	0.04	24.6	9	5.58	2.60	0.45	0.06	8.68	35.6	67.2	24

Classification

Diagnostic properties

The top 15 cm was an ochric epipedon, the characteristics of colour, base saturation and organic carbon which indicate an umbic are associated with smaller thickness and hard structure.

There was no diagnostic subsurface horizon.

Order

Entisol: There was no other diagnostic horizon other than an ochric and absence of cambic, salic, calcic, gypsic and spodic, absence of gilgai, slickensides and wedge shaped aggregates.

Suborder

Aquent: They are saturated with water for some time of the year, texture finer than loamy fine sand and presence of mottles.

Great group

Fluvaquent: The temperature regime is warmer, texture finer than loamy fine sand, more than 0.2 percent organic carbon up to a depth of 1.2 m, absence of sulfidic material.

Sub group

Humaqueptic fluvaquents: They are mottled, have more than 0.95 g_m³ per cubic centimeter bulk density, absence of cracks more than 1 cm wide, less than 4 colour value moist and less than 6 when dry, absence of buried histosol and sulfidic material.

Entisols as they are seen comprise of profiles 6, 7, 8, and 20. These soils appear to have been formed from transported sediments along the Nyarubungu river and its tributaries. Their similarities is absence of diagnostic subsurface horizon and presence of ochric epipedon and are seen to be associated with irregular decrease in organic carbon, texture, and have moisture regimes which gives rise to the different sub orders, greatgroups and subgroups as noted.

5.1.2 Inceptisols

Profile 9 5/8/79

External features

Located at about $1\frac{1}{2}$ km east of the Ifakara - Mlkani road (Fig.5); approximately 3 km long, almost flat, linear east facing slope of approximately 2% gradient; pit site near lower part of the slope. Ustic soil moisture regime, isohyperthermic soil temperature regime; currently under sugar cane; alluvial material; moderately well drained.

Internal features

Ap 0-25 cm Dark yellowish brown (10YR 3/4) dry, very dark greyish brown (10YR 3/2) moist; moderately fine sandy clay loam; moderate fine sub-angular blocky; sticky; and plastic, firm, hard; abundant fine roots with common medium roots; many fine discontinuous inped pores; insect nests (5%) present clear smooth boundary.

B_(w)2 25-65 cm Dark brown (7.5YR 3/2) dry, yellowish brown (10YR 3/4) moist; moderately fine sandy clay loam; moderate fine sub-angular blocky; slightly sticky and slightly plastic, firm, slightly hard; common fine roots; patchy cutans present; many fine discontinuous inped pores; insect nest and charcoal present at 65 cm in depth; clear smooth boundary.

B₂ 65-110⁺ cm Dark yellowish brown (10YR 4/4) moist;
moderately fine sandy clay loam; moderate fine
sub-angular blocky; sticky and plastic, firm; common
fine discontinuous inped pores; very fine roots.

Table 13a. Physical Analytical Data

Profile 9

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Sand	Silt + Clay		
A _p	0-25	1.27	2.24	31.3	11.1	20.2	62.2	10.8	27.0	Sandy Clay loam
B _(w) 2	25-65	1.48	2.27	26.8	10.6	16.2	62.4	9.4	28.2	Sandy Clay loam
B ₃	65-100	1.40	2.18	27.0	13.7	13.6	56.4	15.4	28.2	Sandy Clay loam

Table 13b. Chemical Analytical Data

Profile 9

Horizon	Depth in cm	pH		% Organic carbon	% Total nitrogen	Available Phosphorus	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100 gm soil	DEC in meq/100 gm Soil	Percentage base saturation		
		1:1 H ₂ O	CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
A _p	0-25	6.3	4.9	2.90	0.15	12.56	19	5.8	4.6	0.19	0.80	11.4	25.8	95.6	44.2
B _{(w)2}	25-65	5.9	5.0	0.95	0.08	14.56	12	9.2	6.3	0.16	0.22	15.9	27.0	95.7	58.9
B ₃	65-110	6.0	5.3	0.62	0.07	8.42	9	5.4	3.3	0.16	0.17	7.6	28.0	99.3	25.0

Classification

Diagnostic properties

The top 25 cm is an ochric epipedon, since they have darker colour value and chroma, organic carbon and base saturation do not have the required thickness of more than 25 cm to be umbric.

The subsurface horizon is cambric as the texture was finer than loamy fine sands, absence of rock structure, argillic or spodic horizon, with enough thickness to place its base below 25 cm depth. Though weak cutans were observed the absence of required ratio of 1.2 between B and A horizon rules out presence of argillic horizon.

Order

Inceptisol: The absence of plinthite, spodic, argillic, natric, oxic, gypsic or salic and had no cracks, and has pedogenic ochric and cambic horizons.

Suborder

Tropepts: They have iso temperature regime, no aquic characteristics, have bulk density more than 0.85 gm per cubic centimeter and have ochric and cambic horizons and do not have a plaggen horizon.

Great group

Humitropepts: They have more than 12 kg. organic carbon in the upper cubic meter of soil, base saturation less than 50 percent in some sub-horizons and do not have a sombric horizon.

Subgroup.

Ustic Humitropept: The bulk density was more than 0.95 gm per cubic centimeter, no mottles and no lithic contact, have more than 24 meq/100 gm clay CEC, regular decrease of the content of organic matter and have an ustic moisture regime.

Profile 1, 2, 3, 4, 12, 13 and 14 in Appendix II are also classified in the ustic Humitropept subgroup. Profile 1, 2, 3 and 14 had an ochric epipedon. Umbric epipedon was noted in profiles 4, 12 and 13, while only profile 2 had characteristics of a mollic epipedon.

The occurrence of a cambic horizon underlying the epipedon in all profiles (though weak clay skins were observed in profile 2) an argillic horizon was not confirmed due to the lack of uniformity in the profile mainly through the influence of colluvial material which makes development of an argillic horizon very unlikely. The warmer iso temperature regime, the organic carbon content and soil moisture regime were characteristic of the Ustic Humitropept.

Profile 15 18/9/79

External features

Located at about 1 km east of the road from Ifakara to Mikuni (Fig. 5), almost flat approximately 3 km long linear east facing slope of approximately 2%; pit site near middle part of slope. aquic soil moisture regime; isohyperthermic soil temperature regime; woodland; currently under sugar cane; alluvial material; moderately well drained; slight flooding.

Internal features

Ap 0-25 cm Greyish brown (2.5YR 5/2) dry, dark greyish brown (2.5Y 4/2) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, hard; many fine discontinuous impeded pores; many fine roots; clear smooth boundary.

B_(w)1 25-37 cm Brown (10YR 4/3) dry, dark brown (10YR 3/3) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, hard; many fine discontinuous impeded pores; few fine roots; diffuse smooth boundary.

B_(w)2g 37-67 cm Dark brown (10YR 3/3) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky, slightly sticky and slightly plastic, firm, hard; mottles (about 10%) present; many fine discontinuous impeded pores; few fine roots.

67-120⁺ cm To wet to be described

Water table at 120 cm depth.

Table 14a. Physical Analytical Data

Profile 15

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle Size distribution		Textural Class
				pF 2.0	pF 4.2		Sand	Silt & Clay	
Ap	0-25	1.28	2.19	34.3	12.3	22.0	66.4	11.2 22.4	Sandy Clay Loam
B _{(w)1}	25-37	1.45	2.19	25.4	10.3	15.1	70.2	7.2 22.4	Sandy Clay Loam
B _{(w)2}	37-67	1.27	2.36	35.8	11.6	14.4	68.4	9.2 28.4	Sandy Clay Loam

Table 14b. Chemical Analytical Data

Profile 15

Horizon	Depth in cm	pH		% Organic carbon	% Total nitro- gen	Total Availa- ble Phospho- rus ppm	C/N	Extractable cations in meq/100 gm soil		Total Extracta- ble bases in meq/100 gm soil	CEC in me/100 gm Soil Clay	Percentage base satura- tion			
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺ Mg ⁺⁺	Na ⁺ K ⁺						
Ap	0-25	5.6	5.1	3.45	0.18	14.03	19	4.64	2.99	0.61	0.74	8.98	32.5	145.1	28
B _(w) 1	25-37	5.5	4.9	1.46	0.09	9.65	16	2.47	1.99	0.53	0.42	5.41	23.9	106.7	23
B _(w) 2 _g	37-67	5.8	5.1	1.07	0.06	7.19	18	2.20	2.49	0.48	0.42	5.59	21.8	76.8	26

Classification

Diagnostic properties

The upper 25 cm was an ochric epipedon as the colour value was more than 3.5 moist with base saturation less than 50 percent and organic carbon more than 0.6 percent.

The subsurface is cambic horizon, since it had finer texture than loamy fine sand, structured, more than 16 meq per 100 gm clay CEC, regular decrease in organic matter, redder hue, no argillic and no cementation; and enough thickness that its base is more than 25 cm below surface.

Order

Inceptisol: A plinthite, spodic, argillic, natric,oxic, gypsic or salic horizons were absent and no cracks noted. Have a pedogenic ochric epipedon and a cambic horizon.

Sub order

Tropept: They had warmer soil temperature regime, higher chroma than aquic limits, bulk density more than 0.85 gm per cubic centimeter and have an ochric and cambic horizons with no plaggan horizon.

Great group

Humitropept: They contain more than 12 kg of organic carbon per cubic meter of soil, have base saturation less than 50 percent between 25 cm and 1 meter depth and has no sombric horizon.

Sub group

Aquic Humitropept: Since they have an aquic moisture regime and the presence of mottles to very shallow depths, it is suggested in this sub-group though not given in the taxonomy system.

Profile 17 in Appendix II which has an umbric epipedon underlain by a cambic horizon, warmer iso temperature regime, the organic carbon content and mottles occurring at very shallow depths has also been suggested as an Aquic Humitropopt.

Profile 12 5/8/79

External features

Located at about 1 km east of the road from Ifakara to Mikumji (Fig. 5); almost flat, approximately about 3 km long linear east facing slope of about 2% gradient, pit site lower part of slope; udic soil moisture regime, isohyperthermic soil temperature regime; currently under sugar cane; alluvial material; moderately well drained; slight flooding.

Internal features

A_p 0-25 cm Dark greyish brown (10YR 4/2) dry, very dark brown (10YR 2/2) moist; moderately fine sandy clay loam; strong moderate medium crumbs; sticky and plastic, firm hard; many fine discontinuous inped pores; many fine roots; brown colour observed along rotting roots; diffuse broken boundary.

A_{1t} 25-40 cm Very dark greyish brown (10YR 2/2) dry, very dark grey (10YR 3/1) moist; moderately fine sandy clay loam; strong moderate medium sub-angular blocky; sticky and plastic, very firm, very hard; many fine discontinuous inped pores with few medium, continuous, exped pores; cutans present; common fine roots; clear smooth boundary.

B₂:G 40-111⁺ cm Yellowish brown (10YR 5/8) dry, yellowish brown (10YR 5/6) moist; moderately fine sandy clay loam; strong to moderate medium sub-angular blocky; very sticky and plastic, very firm, very hard, many fine discontinuous impeded pores with few expeded pores; cutans present; very dark brown (10YR 2/2) concretions (about 5%) present yellow mottles (about 5%) present; few fine roots.

Water table at 111 cm depth.

Table 15a. Physical Analytical Data

Profile 12

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water in %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Sand	Silt Clay		
A _p	0-25	1.56	2.24	31.3	12.6	18.7	71.8	5.8	22.4	Sandy Clay Loam
A _{1t}	25-40	1.64	2.36	27.5	11.8	15.7	68.4	7.3	24.4	Sandy Clay Loam
B _{2c}	40-111	1.48	2.27	38.1	16.9	21.2	59.8	6.0	34.3	Sandy Clay Loam

Table 15b. Chemical Analytical Data

Profile 12

Horizon	Depth in cm	% Organic Carbon		C/N	Extractable cations in meq/100 gm soil			Total Extractable in meq/100 gm soil	CEC in meq/ 100 gm	Percentage base satu- ration					
		1:1 H ₂ O	1:1 CaCl ₂		% Total nitro- gen	Ca ⁺⁺	Mg ⁺⁺				Na ⁺ K ⁺				
A _p	0-25	5.6	4.8	2.87	0.21	10.88	14	3.9	4.3	0.35	0.20	8.8	34.4	153.6	25.6
A _{1t}	25-40	5.6	5.1	1.23	0.13	21.58	9	9.2	6.0	0.23	0.15	15.6	30.8	126.2	50.6
B _{2g}	40-111	6.0	5.1	0.58	0.06	20.70	10	2.9	15.2	0.33	0.20	18.6	25.6	74.6	72.7

Soil Clay

Classification

Diagnostic properties

, The upper 30 cm was an umbric epipedon. The ~~structure was~~ not both massive and hard, colour value lower than 5.5 dry and 3.5 moist with chroma less than 3.5, base saturation less than 50 percent and more than 0.6 organic carbon percent with thickness of more than 18 cm and moist at least three months in a year.

The subsurface horizon is cambic. Although clay skins were noted the ratio of clay content between B and A horizon was not more than 1.2 within 30 cm distance change and not uniform enough to show an argillic horizon. Also ~~has~~ finer texture than loamy sands, CEC more than 16 meq per 100 gm clay, regular decrease in organic carbon, placed more than 25 cm deep and no cementation.

Order

Inceptisol: They have no spodic, argillic ~~retic, omic,~~ plinthite, gypsic, salic, sulfuric or cracks, have a pedogenic umbric and cambic epipedon.

Suborder

Tropepts: Since they have ~~156~~ temperature regime, no ~~agric~~ characteristics, bulk density of more than 0.85 gm per centimeter cubed have an umbric epipedon and no plaggipan.

Great group

Entropepts: They have high base saturation throughout all subhorizons between 25 cm to 1 m. have udic moisture regime and no horizon with secondary powdery lime.

Sub group

Aquic Entropept: Have more than 0.95 gm per cubic centimeter bulk density, no evidence of mottles with stronger chroma, organic carbon decreases regularly with depth, no lithic contact, no cracks and have a cambic horizon.

Profile 21 19/9/79

External features

Located at about 2.7 km east of the road from Ifakara to Mikumi (Fig. 5); almost flat, approximately 3 km long, linear, east facing slope of about 2% slope gradient; pit site at lower part of slope, aquic soil moisture regime; isohyper-thermic soil temperature regime; wooded grassland; currently under fallow; alluvial material; imperfectly drained; severe flooding.

Internal features

- A₁ 0-20 cm Dark greyish brown (10YR 4/2) dry, very dark grey (10YR 3/1) moist; moderately coarse sandy loam; moderate medium crumbs to granules; slightly sticky and slightly plastic, friable soft; common fine discontinuous inped pores, with few medium cracks; many fine roots; diffuse irregular boundary.
- AC 20-65 cm Very dark grey (10YR 3/1) dry, black (10YR 2/1) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; sticky and plastic, firm, hard; common fine discontinuous inped pores, few fine roots; clear smooth boundary.

C₁E 65-95 cm Very dark grey (10YR 3/1) dry, yellowish brown, brown (10YR 5/6) moist; fine sandy clay; moderate medium sub-angular blocky to massive; sticky and plastic, firm, hard; yellowish mottles (about 20%) present; common fine discontinuous inped pores; few fine roots; diffuse smooth boundary.

C₂E 95-130⁺ cm Dark yellowish brown (10YR 4/4) dry, dark grey (10YR 4/1) moist; ~~fine~~ sandy clay loam; moderate medium sub-angular blocky to massive; sticky and plastic, firm, hard; yellowish mottles (about 20%) present; common fine discontinuous inped pores; very few fine roots.

Table 16a. Physical Analytical Data

Profile 21

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture Holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Sand	Silt Clay		
A ₁	0-20	1.19	2.24	36.7	13.7	23.0	74.4	8.6	17.0	Sandy loam
AC	20-65	1.42	2.35	31.5	13.4	18.1	70.4	6.6	23.0	Sandy Clay loam
C _{1s}	65-95	1.49	2.39	32.6	11.4	21.2	62.4	6.6	31.0	Sandy Clay
C _{2s}	95-130	1.60	2.35	29.3	13.5	15.8	70.4	4.6	25.0	Sandy Clay loam

Table 16b. Chemical Analytical Data

Profile 21

Horizon	Depth in cm	pH		% Organic carbon	% Total nitro- gen	% Availa- ble Phospho- rus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extracta- ble bases in meq/100 gm soil	CEC in meq/ 100 gm Soil	Percentage base satura- tion		
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
A ₁	0-20	5.5	4.7	1.90	0.17	18.24	11	6.98	0.95	0.12	0.26	10.32	35.2	207.1	29
AC	20-65	5.6	4.7	0.94	0.10	14.37	9	6.05	2.95	0.15	0.08	9.23	33.2	144	28
C ₁ g	65-95	5.7	4.8	0.52	0.05	25.58	10	5.58	2.60	0.45	0.06	8.68	35.6	115	24
C ₂ g	95-130	5.9	4.8	0.34	0.04	23.01	8	5.12	2.95	0.13	0.66	8.26	40.4	161.6	20

Classification

Diagnostic properties

The top layer was an umbric epipedon since the structure was not both massive and hard, the colour value lower than 5.5 dry and 3.5 moist with chroma less than 3.5, base saturation less than 50 percent, organic carbon content more than 0.6 percent, and thickness more than 25 cm as it extends into the most part of the horizon AC and moist for a least 3 months.

There was no diagnostic subsurface horizon.

Order

Inceptisol: A spodic, argillic, natric, oxic, plinthite, gypsic or salic horizon was absent and no cracks and had an umbric epipedon.

Sub order

Aquept: Due to the aquic moisture regime and an umbric epipedon underlain immediately by a mottled horizon with chroma less than 2.

Great group

Tropaquept: They have warmer iso temperature, do not have plinthite, have bulk density more than 0.85 gm per cubic centimeter, do not have sulfuric horizon.

Sub group

Typic Tropoquet: In more than 60 percent of matrix they have a mottled horizon with moist value less than 5 and chroma of 1; also has no histic epipedon, no lithic contact, no cracks more than one centimeter and no plinthite or jarosite mottles.

Profile 18 18/9/79

External features

Located at about 2 km east of Ifakara - Mikumi road (Fig. 5); almost flat, approximately 3 km long, linear, east facing slope of approximately 2% gradient, pit site at lower part of the slope; aquic soil moisture regime, isohyperthermic soil temperature regime; wooded grassland; at the time of examination the land was under fallow; alluvial material; moderately well drained; slight flooding.

Internal features

Ap 0-20 cm Dark greyish brown (10YR 4/2) dry, very dark grey (10YR 3/1) moist; moderately fine sandy clay loam; moderate medium crumbs; slightly sticky and slightly plastic, firm, hard; many fine discontinuous inped pores; many fine roots; diffuse smooth boundary.

B_(w)1 20-45 cm Very dark greyish brown (10YR 3/2) dry, very dark grey (10YR 3/1) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, hard; many fine discontinuous inped pores; few fine roots; diffuse smooth boundary.

B₂(w)2g on 45-68 cm Dark greyish brown (10YR 4/2) moist; gravelly moderately fine sandy clay loam; moderate medium sub-angular blocky; sticky and plastic, firm; mottles (about 8%) present; concretions of manganese (about 20%) present; common fine discontinuous impeded pores; few fine roots.

Table 17a. Physical Analytical Data

Profile 18

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pH 4.2		Sand	Silt Clay		
Ap	0-20	1.38	2.29	35.6	11.9	23.7	70.4	9.2	20.4	Sandy Clay Loam
E _(w) 1	20-45	1.32	2.51	35.2	14.0	21.2	68.4	7.2	24.4	Sandy Clay Loam
E _(w) 2gen	45-68	1.42	2.36	26.6	11.0	16.6	72.4	5.2	22.4	Sandy Clay Loam

Table 17b. Chemical Analytical Data

Profile 18

Horizon	Depth in cm	pH		% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100 soil	CEC in meq/100 gm Soil	Percentage base saturation		
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
A _p	0-20	6.6	5.4	3.37	0.19	52.63	18	5.13	5.15	0.52	0.32	11.12	27.8	136.3	40
B _(w) 1	20-45	6.3	5.1	2.40	0.13	24.21	18	5.86	3.49	0.54	0.24	10.13	19.5	79.9	25
F _(w) 2	48-68	6.0	5.0	0.87	0.07	12.81	12	3.20	2.99	0.64	0.15	6.98	27.9	124.6	25

Classification

Diagnostic properties

The upper 20 cm was an ochric epipedon, though the structure is not both massive and hard, colour value less than 5.5 dry and 3.5 moist, base saturation less than 50 percent, ~~it is not~~ an umbric because ~~it is~~ not more than 25 cm thick.

The subsurface horizon was a cambic horizon due to the finer texture than loamy ~~fine~~ sand, structured, more than 16 meq per 100gm clay CEC, regular decrease in organic matter, no argillic and no cementation ~~and~~ had enough thickness that its base was more than 25 cm below surface.

Order

Inceptisol: A plinthite, spodic, argillic, natric, oxic, gypsic or salic horizon was absent, also no cracks noted, had an ochric and a cambic horizon.

Suborder

Aquept: Had an aquic moisture regime, an ochric epipedon underlain by a cambic horizon, mottled with matrix colour chroma moist 2.

Great group

Tropaquepts: The temperature regime was of warmer iso characteristics, absence of plinthite, more than 0.85 gm per cubic centimeter in all sub-horizons and no sulfuric horizon.

Subgroup

Aeric Tropaquept: A histic, lithic contact, cracks, plinthite and jarosite mottles were absent. Differs from typic in having colour chroma moist of more than 1 even with colour value less than 5 in more than 60 percent of matrix between Ap and 75 cm depth.

Profile 19 in Appendix II with an ochric and cambic horizons, aquic moisture regime, warmer iso temperatures, higher bulk density than 0.85 gm per cubic centimeter, no plinthite, with in more than 60 percent of matrix colour value less than 5 moist and chroma more than 1 is also classified as Aeric Tropaquept.

Inceptisols occupy the largest portion of the study area. Appendix III shows a sketch distribution of the soil orders. They appear to have been formed from both colluvial and alluvial materials. Inceptisols near the foothill of the escarpment are mainly formed from colluvial material while those around the valley are formed from alluvial material deposited during the flood periods.

5.1.3 Mollisols

Profile 10 5/8/79

External features

Located at about $1\frac{1}{2}$ km east of the Ifakara - Mikumi road (Fig. 5) almost flat, a linear east facing slope of about 2% and 3 km long, pit site near lower part of the slope; ustic soil moisture regime, isohyperthermic soil temperature regime; currently under sugarcane; alluvial material; imperfectly drained; moderate flooding.

Internal features

Ap 0-25 cm Very dark greyish brown (10YR 3/2) dry, black (10YR 2/1) moist; fine sandy clay; moderate fine to medium sub-angular blocky; sticky and plastic, very firm, hard; many fine discontinuous inped pores with continuous medium exped pores; many fine roots and few medium roots; insect nests present (5%); clear smooth boundary.

AC 25-55 cm Very dark greyish brown (2.5YR 3/2) moist; moderately fine sandy clay loam; moderate fine to medium sub-angular blocky; sticky and plastic, firm; many fine discontinuous inped with few medium continuous exped pores; common fine roots; clear smooth boundary.

G_{cn} 55-130⁺ cm Yellowish brown (10YR 5/4) moist; fine sandy clay; moderate fine to medium sub-angular blocky; sticky and plastic, firm; black manganese concretions (about 25%) with yellowish mottles (about 5%) present; common fine discontinuous impeded pores; very few fine roots.

Table 18a. Physical Analytical Data

Profile 10

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in % pF 2.0	Available water % pF 4.2	Particle size distribution			Textural Class	
						Sand	Silt	Clay		
Ap	0-25	1.38	2.07	37.5	16.5	21.0	56.4	9.4	34.2	Sandy Clay
AC	25-55	1.55	2.19	33.1	14.9	18.2	63.8	8.0	28.2	Sandy Clay Loam
C _{cn}	55-130	1.50	2.34	32.2	14.4	17.8	60.2	4.8	35.0	Sandy Clay

Table 18b. Chemical Analytical Data
Profile 10

Horizon	Depth in cm	pH		% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100gm soil			Total Extractable bases in meq/100gm soil	CEC in meq/100 gm Soil	Percentage base saturation	
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺				K ⁺
Ap	0-25	5.8	5.1	3.70	0.22	7.19	17	9.8	6.6	0.21	0.40	17.0	25.4	69.9
AC	25-55	6.0	5.1	0.96	0.09	14.26	10	9.2	6.0	0.23	0.15	15.6	30.8	50.6
C _{cn}	55-130	6.2	5.0	0.36	0.07	20.88	5	3.9	6.0	0.26	0.17	10.33	24.2	46.7

Classification

Diagnostic properties

The top 25 cm was a mollic epipedon, the ~~structure~~ was not both massive and hard, the colour value less than 5.5 when dry and 3.5 when moist with chroma less than 3.5; base saturation more than 50 percent, more than 0.6 percent organic carbon, the epipedon more than 18 cm thick and moist at least for 3 months a year.

There was no diagnostic sub surface horizon noted.

Order

Mollisol: A mollic epipedon was present, with higher bulk density values than 0.85 gm per cubic centimeter and absence of amorphous materials, warmer iso soil temperatures, absence of gilgai, slickensides or wedge-shaped aggregates and also no oxic or spodic horizon.

Suborder

Ustoll: The temperature regime was warmer than frigid, absence of albic horizon and had ustic moisture regime.

Great group

Haplustoll: There was no duripan or natric horizon, no petrocalcic, calcic or argillic horizon and no wormholes.

Sub group

Cumlic Haplustolls: A cambic horizon was absent, no brittle horizon, regular decrease in organic carbon content with depth, do not have lithic contact, no calcic or salic horizon, have warmer temperature regime and CEC more than 24 meq per 100 gm clay.

Mollisols have only been expressed by one profile (number 10). Their characteristic colour, thickness temperature and moisture regimes, organic matter, base saturation seem to be formed in an area which is influenced by flooding. The soils of this place are most probably formed from the weathered alluvial material.

5.1.4 Ultisols

Profile 5 3/8/79

External features

Located at about 300 metres east of Ifakara - Mikumi road (Fig. 5); undulating, convex, about 3 km, east facing slope of approximately 3% gradient, pit site near middle; ustic soil moisture regime, isohyperthermic soil temperature regime; currently under sugarcane; colluvial material; moderately well drained;

Internal features

- Ap 0-25 cm Dark brown (10YR 3/3) dry, very dark greyish brown (10YR 3/2) moist; moderately fine sandy clay loam; strong medium sub-angular blocky; sticky and plastic, firm, hard; many fine discontinuous impeded pores and few continuous pores; many fine and few medium roots; clear smooth boundary.
- B₂₁^t 25-60 cm Dark yellowish brown (10YR 4/4) dry, dark yellowish brown (10YR 4/4) moist; fine sandy clay; strong ~~medium~~ sub-angular and plastic, firm, hard; common fine discontinuous impeded pores and few continuous medium pores; common fine roots; weak cutans present diffuse smooth boundary.

B₂₂t 60-120 cm Yellowish brown (10YR 5/6) moist; fine sandy clay; moderate sub-angular blocky; sticky and plastic, firm, slightly hard; cutans present; common fine discontinuous inped pores; very few roots.

Table 19a. Physical Analytical Data

Profile 5

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution			Textural Class
				pF 2.0	pF 4.2		Sand	Silt	Clay	
Ap	0-25	1.50	2.33	26.7	11.1	15.6	61.8	9.8	28.4	Sandy Clay Loam
B ₂₁ t	25-60	1.56	2.37	31.2	12.4	18.8	58.4	7.4	34.2	Sandy Clay
B ₂₂ t	60-120	1.55	2.56	29.2	13.3	15.9	56.4	7.4	36.2	Sandy Clay

Table 19b. Chemical Analytical Data

Profile 5

Horizon	Depth in cm	pH 1:1 H ₂ O CaCl ₂	% Organic carbon	% Total nitro- gen	Abaila- lable Phospho- rus ppm	C/N	Extractable cations			Total Extracta- ble bases in meq/ 100gm soil	CEC in me/ 100 gm Soil, Clay	Percentage base satu- ration		
							Ca ⁺⁺ in meq/100gm soil	Mg ⁺⁺	Na ⁺ K ⁺					
Ap	0-25	5.5	2.38	0.19	18.07	12	6.3	8.3	0.16	0.45	15.2	22.4	78.9	67.8
B ₂₁ t	15-60	6.0	0.97	0.09	12.81	11	9.2	8.0	0.17	0.20	17.4	29.2	85.4	59.6
B ₂₂ t	60-120	6.8	0.39	0.05	19.30	8	9.2	6.3	0.24	0.14	15.9	46.4	128	34.3

Table 19b. Chemical Analytical Data

Profile 5

Horizon	Depth in cm	pH		% Organic carbon	% Total nitro- gen	Abaila- lable Phospho- rus ppm	C/N	Extractable cations in meq/100gm soil			Total Extracta- ble bases in meq/ 100gm soil	CEC in me/ 100 gm Soil ₁ Clay ₁	Percentage base satu- ration		
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
Ap	0-25	5.5	5.0	2.38	0.19	18.07	12	6.3	8.3	0.16	0.45	15.2	22.4	78.9	67.8
B ₂₁ t	15-60	6.0	4.9	0.97	0.09	12.81	11	9.2	8.0	0.17	0.20	17.4	29.2	85.4	59.6
B ₂₂ t	60-120	6.8	5.3	0.39	0.05	19.30	8	9.2	6.3	0.24	0.14	15.9	46.4	128	34.3

Classification

Diagnostic properties

The top 25 cm is an ochric epipedon, though the colours are darker, they have hard structure for any other epipedon, and auger hole 15 had lighter colours with value more than 5.5 dry and more than 3.5 moist.

There was an argillic sub surface horizon, since the clay ratio between B and A is more than 1.2, it is more than 15 cm thick, and presence of cutans though weak due to varying stability of peds and their consolidation rate which alters their appearance, and formed in situ at the crest where runoff loss deprives the area of water.

Order

Ultisol: They do not have tongues of material, have an argillic horizon, a warmer temperature regime, do not have spodic, oxic horizon or plinthite, base saturation less than 35% at lower depths (below 60 cm)

Sub order

Humult: More than 0.9 percent organic carbon in upper argillic horizon was present and more than 12 kg of organic carbon in the upper meter cubed.

Great group

Tropohumult: The temperature regime had warmer iso characteristics, presence of argillic horizon and absence of fragipan or plinthite and absence of sombric horizon.

Sub group

Ustic Tropohumult: The CEC is more than 24 meq per 100 gm clay, absence of mottles, lithic contact or bedrock, not saturated with water, the bulk density more than 0.95 gm per cubic centimeter, redder hues and no anthropic epipedon.

Profile 11 5/8/79

External features

Located at about 1 km east of the Ifakara - Mikumi road (Fig. 5), almost flat, approximately 3 km long, linear east facing slope of approximately 2%, pit site near lowest part of the slope; equio soil moisture regime, isohyperthermic soil temperature regime; currently under sugarcane; residual material; moderately well drained; slight flooding.

Internal features

A_p 0-30 cm Dark greyish brown (2.5Y 4/2) dry, very dark greyish brown (2.5Y 3/2) moist; moderately fine sandy clay loam; moderate fine crumbs; slightly sticky and slightly plastic, slightly firm, slightly hard; many fine discontinuous inped pores; many fine roots; clear smooth boundary.

B₂₁t 30-52 cm Dark brown (10YR 3/3) moist; moderately fine sandy clay loam; moderate fine to medium sub-angular blocky; slightly sticky and slightly plastic, slightly firm; common, fine discontinuous inped pores; outans present; common fine roots; diffuse irregular boundary.

B₂₂₅ cm 52-100⁺cm Strong brown (7.5YR 5/8) moist; moderately fine sandy clay loam; moderate medium compact sub-angular blocky; sticky and plastic, firm, hard; common fine discontinuous inped pores; very few fine roots; mottles present (about 10%); concretions present (about 2%).

Water table at 100 cm depth.

Table 20a. Physical Analytical Data

Profile 11

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution			Textural Class
				pF 2.0	pF 4.2		Sand	Silt	Clay	
A ₁ p	0-30	1.43	2.22	33.33	11.5	21.8	71.8	5.8	22.4	Sandy Clay Loam
B ₂ †	30-52	1.68	2.25	25.4	9.2	14.2	62.2	8.8	29.0	Sandy Clay Loam
B _{22g} on	52-100	1.58	2.25	27.8	11.3	16.5	70.2	4.8	25.0	Sandy Clay Loam

Table 20b. Chemical Analytical Data

Profile 11

Horizon	Depth in cm	pH		% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100gm soil			Total Extractable bases in meq/100 gm soil	CEC in meq/100gm Soil	Percentage base saturation		
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
A _p	0-25	6.2	4.7	2.21	0.19	15.09	12	4.9	6.6	0.21	0.37	10.3	27.8	124.1	37.0
B ₂₁ †	30-52	6.3	4.6	0.36	0.04	21.93	9	3.0	8.3	0.21	0.12	11.6	26.4	91.0	43.9

Classification

Diagnostic properties

The top 30 cm was an umbric epipedon, since the structure was not both massive and hard, colour value lower than 5.5 when dry and 3.5 when moist with chroma less than 5.5, base saturation less than 50 percent organic carbon content more than 0.6 percent, thickness more than 18 cm and moist at least 3 months a year.

The subsurface is of an argillic horizon due to the clay ratio between B and A being more than 1.2, is more than 15 cm thick and there are also cutans present.

Order

Ultisol: They do not have tongues of an albic material, have a warmer temperature regime, do not have spodic, oxic horizon or plinthite.

Sub order

Humult: Have more than 12 kg of organic carbon in a square meter to a depth of one meter.

Great group

Tropohumult: The temperatures regime had warmer iso characteristics, presence of argillic horizon, and absence of fragipan, sombric horizon or plinthite.

Sub group

Aquic Tropohumult: The CEC is more than 24 meq per 100 gm of clay, has mottles and aquic moisture regime, absence of a lithic contact, bedrock and anthropic epipedon.

Ultisols occupy the second largest portion of the area. Although the characteristics of depth, colour, organic matter, base saturation and CEC are similar in profiles 5 and 11, the occurrence of ~~sub~~ moisture regime separates profile 5 from 11 which have characteristics associated with wetness. These are formed from a resistant rock weathered in situ.

5.2 Soil Mapping Units

Six soil mapping units were distinguished in the study area. Drainage status, texture of topsoil and the source of the parent material were used to separate the mapping units. The units were then either named after the location to which they appeared predominant (Msolwa and Nyarubungu) or physiographic position in the study area in which they are found (Mlimani, Mtoni and Bwawani). A soil complex almost centrally located between Msolwa and Bwawani (Fig. 6) was named Msolwa-Bwawani. Each mapping unit was further separated into subunits on the basis of slope and texture. Each unit is expressed by a formula with symbols for each of its subdivisions (see legend in fig. 6). They are also grouped into well drained, moderately well drained and imperfectly drained from the information obtained from profiles and auger holes.

5.2.1 Well drained soils

Two mapping units, Mlimani and Mtoni were identified in this group. Mlimani series is a dark brown gravelly sandy clay loam and occurs on a sloping area with the gradient varying from 2% - 12% (profile 1). The soils have moderate medium subangular blocky structure and are friable. These soils are formed from

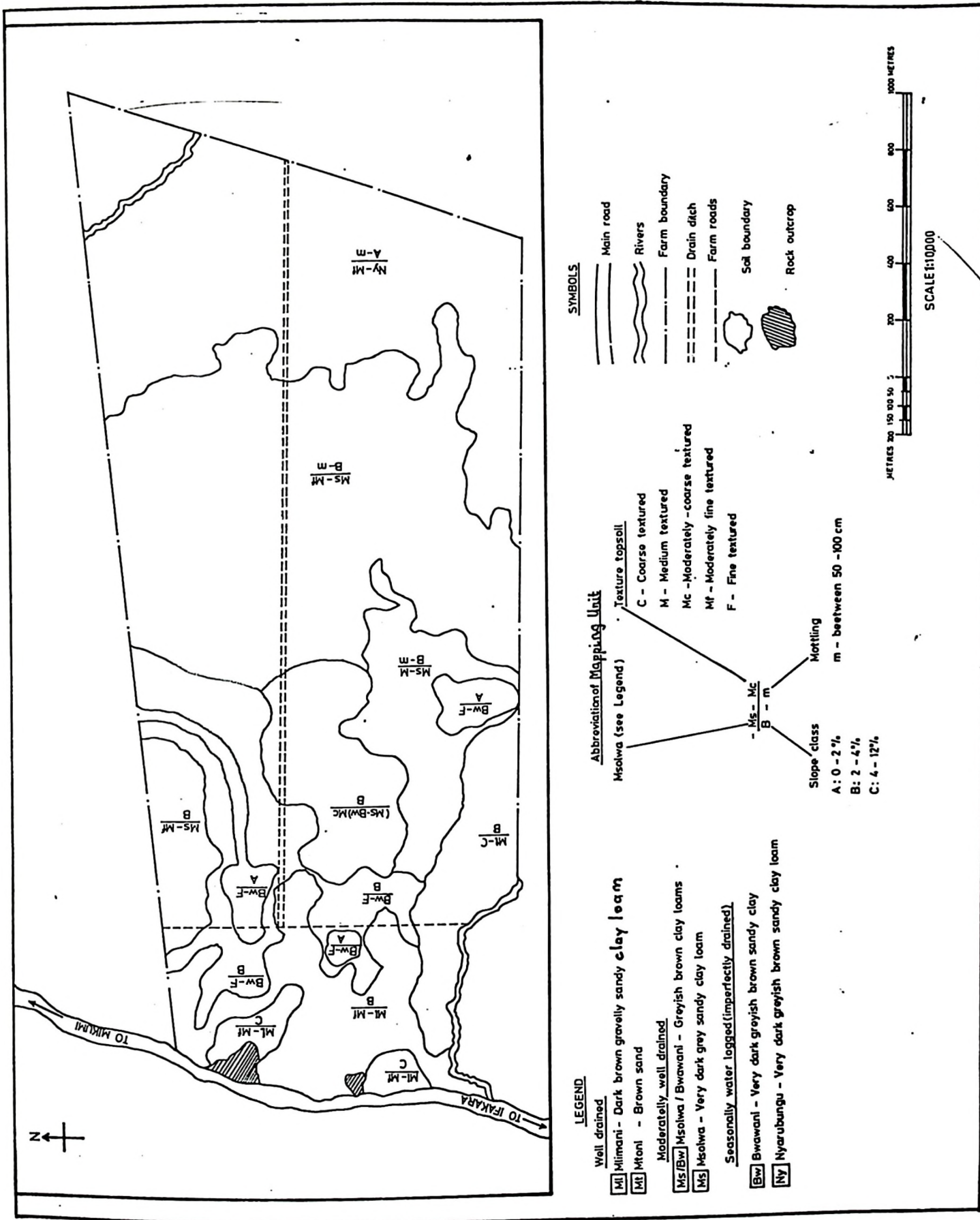


Figure 6. Soil map of the surveyed area

colluvial material originating from the undifferentiated Usagaran geological system of the migmatic gneiss, with biotite and hornblende cemented sands and gravel.

Mtoni unit occurs on gently slopping area adjacent to the Mlimani series (Fig. 6). The soils are well drained moderate-medium sub-angular blocky, brown in colour and sandy in texture as seen in profile 7. The parent material consists of soil material brought in by Nyarubungu river from the Gologolo mountains. This is mainly composed of undifferentiated Usagaran rocks, with migmatic gneiss, biotite and hornblende.

5.2.2 Moderately Well drained soil

The mapping units represented here are Msolwa and Msolwa-Bwawani soil complex. The Msolwa-Bwawani soil complex is represented by profiles 6 and 16 with characteristics similar to both Msolwa and Bwawani but varying drainage condition between moderately well drained and imperfectly drained. The soils are greyish brown loams moderate medium sub-angular blocky and slightly hard. Mottles were observed at relatively shallow depths (70-80 cm). The parent material consists of alluvial material of neogene

times, mainly of the undifferentiated Usagaran rocks with migmatic gneiss, biotite and hornblende which is believed to have been transported by Nyarubungu ~~river~~ from the Gologolo mountains.

Msolwa unit is the most dominant type in the study area. This occurs on gently slopping areas of the middle zone. The soils as seen in profile 17 have moderate medium sub-angular blocky structure; slightly hard and very dark greyish colours, with mottles occurring at shallow depths (70-145 cm). The parent material consists of alluvial sediments of neogene time. The alluvial material is also brought in by Nyarubungu river from the on-looking Gologolo mountains. This consists of the undifferentiated Usagaran rocks with migmatic gneiss, biotite and hornblende.

5.2.3 Imperfectly drained

The Bwawani unit is spread in small patches in different locations. Generally it occupies the low lying areas of the survey area. It appears that from the elevated areas in the west of Ifakara - Mikumi road, there occurs a depression which probably marks the end of the mountain ranges. This is where Bwawani can be located. It comprises of imperfectly

drained, moderate medium sub-angular blocky of very dark greyish brown colour as in profile 8. The parent material consists of the hill wash alluvial sediments of the materials originating from the Gologolo mountains.

The Nyarubungu mapping unit occurs at the lowest part of the survey area in the Eastern part on a very flat area. The soils are imperfectly drained, moderate medium sub-angular blocky and blocky sandy clays. Mottling starts at very shallow depths as in profile 20 and increases with depth, a characteristic of reduced soil conditions. The parent material consists of alluvial material deposited during the flooding wet season and consists mainly of materials from the Gologolo mountains with undifferentiated Usagaran rocks with migmatic gneiss biotite and hornblende.

5.3 Land Evaluation

As mentioned in the introduction, a variety of crops are grown in the Kilombero Valley. Sugarcane is however predominant in the study area. At Kilombero, sugarcane is being grown both at large and small scales. Irrigation is practiced by the large estates where availability of water and

topography permits. In some areas in the floodplain drainage ditches are constructed to remove the excess water. Mechanised cultivation and application of commercial fertilizers mainly sulphate of ammonia is also normally practiced.

5.3.1 Land Suitability

Based on the land characteristics, land qualities and the economics of crop production, the two suitability orders; Suitable and Not suitable were identified in the area. Table 21 drawn from Sys (1976) was used with slight modifications to draw up the suitability ratings. The ratings 0, 1, 2, 3 and 4 are used to indicate no limitation, slight, moderate severe and very severe limitations respectively. The suitability rating and the degree of limitation for each mapping unit, constructed from Sys (1976) table 21 are presented in table 22. Considering the degree of limitation, the suitability of the land into its order, classes and sub-classes has been worked out and mapped (Fig. 7).

5.3.2 Suitability of the individual mapping unit and their features.

Table 21. Suitability table for sugar cane, intensive plantation farming*

Land Characteristics	Range in the degree of limitations				
	0	1	2	3	4
Topography (t)	almost flat 0-2%	undulating 2-8%	rolling 8-15%	hilly 16-30%	Others
Characteristics of the origin of wetness limitation (w)					
Drainage	good	moderate	imperfect	poor	very poor
Flooding	no	no	slight	moderate	others
Characteristics with regard to physical soil conditions(s)					
Texture	sandy clay loam, loam silt, silty loam, clay (blocky), silt clay(blocky)	sandy clay(blocky), silty clay loam	Silty clay, clay sandy clay, loamy sand	sand	-
Surface stoniness	<15% fine gravel <3% others	3-15% coarse gravel 15-40% fine gravel	3-15% boulders, 15-40% coarse gravel, 40-75% fine gravel	15-40% boulders, 40-75% coarse gravel, 75% fine gravel	40-75% boulders, 75% coarse gravel, stones or boulders.
Sub-soil stoniness	<15%	15-40%	40-75%	>75%	-
Soil depth	>100 cm.	80-100 cm	50-80 cm	25-50 cm	<25 cm
Calcium carbonate	3-25%	0-3% 25-50%	>50%	-	-
Gypsum	3-10	0-3	10-25	>25	-

Table 21 (continued)

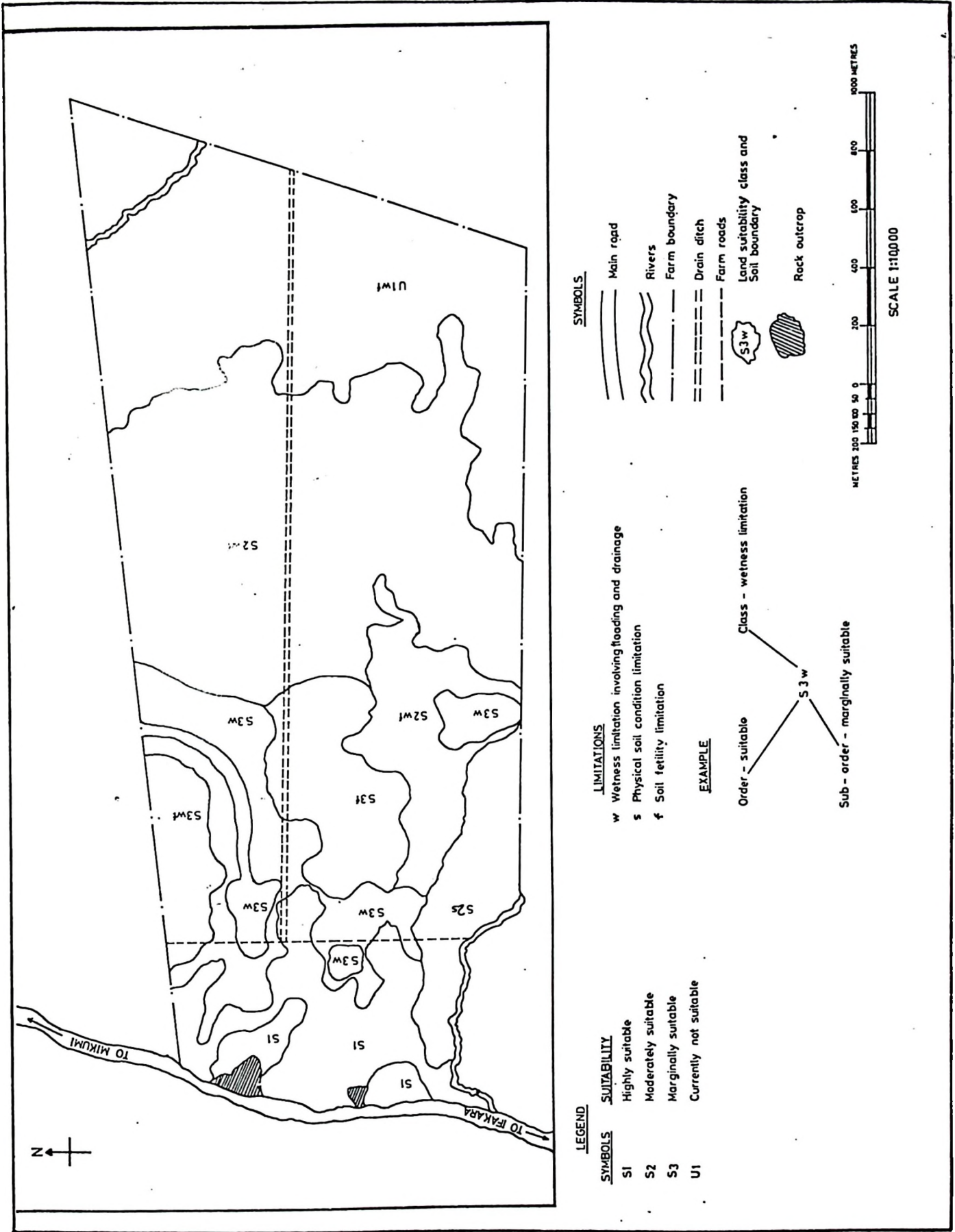
Land Characteristics	Range in the degree of limitations				
	0	1	2	3	4
Characteristics with regard to soil fertility not readily corrected (f)					
Exchange capacity meq/100gm clay	24	16-24	16 with negative charge	>16 with positive charge	
Base saturation	B > 50% A > 80%	B any A > 50%	B any A 35-50%	B < 50% A < 35%	
Organic matter (0-15 cm)	> 3%	1.5-3%	0.8-1.5%	0.8%	
Characteristics with regard to salinity and alkalinity (n)					
Salinity (millimhos/cm)	0-4	4-8	7-10	10-14	>14
Alkalinity (millimhos/cm)	0-8	8-15	15-30	>30	

* From Sys, C. (1966). Land Evaluation, Part I.

> = greater than, < = less than, A and B are horizons.

Table 22. Degree of limitations of land characteristics in the Study area

SOIL UNIT	Topography (w)		Soil Physical conditions (s)			Soil Fertility (f)			Salinity and Alkalinity (n)	
	Drainage	Flooding	Surface stoniness	Sub-soil stoniness	soil depth	Calcium carbonate $CaCO_3$	Gypsum $CaSO_4$	Exchange capacity		Base saturation
Mlimani	0	0	0	0	0	0	0	0	0	0
Mtoni	0	2	3	0	0	0	0	0	2	0
Msolwe-Bwawani	0	1	2	0	0	0	0	0	3	0
Msolwa	0	1	2	0	2	0	0	0	2	0
Bwewani	0	2	3	0	0	0	0	0	1	0
Nyarubungu	0	3	3	0	0	0	0	0	3	0



LEGEND

SYMBOLS

SUITABILITY

S1 Highly suitable

S2 Moderately suitable

S3 Marginally suitable

U1 Currently not suitable

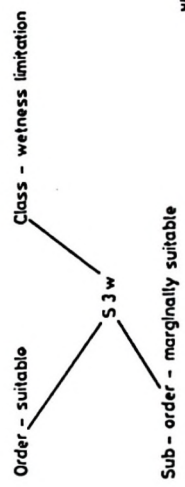
LIMITATIONS

w Wetness limitation involving flooding and drainage

s Physical soil condition limitation

f Soil fertility limitation

EXAMPLE



SYMBOLS

- Main road
- Rivers
- Farm boundary
- Drain ditch
- Farm roads
- Land suitability class and Soil boundary
- Rack outcrop

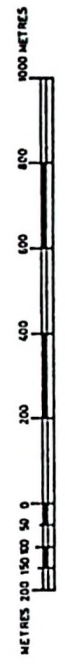


Figure 7. Land suitability map of the surveyed area.

5.3.2.1 Mlimani - S1

Suitable with one slight limitation for sugarcane growing.

The major portion of this area show favourable soil physical condition. The bulk density is fairly low and tend to increase with depth. The low density mainly is due to the influence of large quantities of organic matter in surface horizons as observed in profiles 1, 2, 3 and 4. The topsoil available water holding capacity is higher indicating probably the additional moisture held by the organic matter. The texture with fairly high and evenly distributed clay, low silt and high sand content does not seem problematic to soil management.

The soil reaction of Mlimani is rather slightly acidic. This may probably be due to the climate and parent material. These low pH values (below pH 6) may affect the nitrification and phosphate availability. The nitrifying bacteria require abundance of exchangeable bases, and are seemingly sensitive to low pH values. Ionic form of phosphorus is fixed in the presence of soluble forms of iron and aluminium. However, results from profiles

1, 2, 3 and 4 indicate no special attention necessary at the present time, but avoiding fertilizers with residual hydrogen ion will be more advantageous. The levels of organic matter are high (more than 3.0% organic carbon) and remains relatively high (more than 0.82% organic carbon) up to 65 cm depth. The medium levels of nitrogen (0.25%) indicate a good quality of organic matter. The extractable calcium levels are high (11.2 meq/100gm soil) in the topsoil of profile 2. and decreases with depth, while the levels of magnesium are also high (7.6 meq/100gm soil) and irregularly distributed. This may probably be related to the parent material and might however imbalance the K and Ca availability in sugarcane. Sodium and potassium in the extractable form are low (less than 0.3 meq/100gm soil) and (less than 0.7 meq/100gm soil) respectively. With an exception of profile 3, the general tendency of the extractable potassium decreasing with depth suggests that the contribution of potassium is mainly from the organic matter. The CEC of clay is high (the values have been rather higher than expected). This probably suggests the influences of 2:1 type of clay. With the high values of base saturation as seen in profile 2, Mlimani does not seem to have soil fertility problem. Careful potassium and phosphorus management is suggested within the early years of using the land.

5.3.2.2 Mtoni - S2s

Suitable for sugarcane. The limiting factor is the soil characteristic especially related to soil physical conditions. Other limitations of importance include soil fertility and flooding.

As observed in profile 7, there is no rooting restriction expected from the fairly low bulk density values which tend to decrease with depth. Also the topsoil tends to hold more available water. The high contents of sand, makes soil physical conditions of Mtoni to be a limiting factor. It is not very easy to suggest a solution for this problem under the present working conditions of Kilombero, although the incorporation of organic residues could improve the soil physical conditions greatly. Careful water and fertilizer management could probably bypass the influence of texture though not attempting to solve it.

The soil reaction of Mtoni is slightly acid. The organic matter content is high (1.83% organic carbon) with a C/N ratio of 15, a good quality organic matter is suggested. The extractable calcium levels are high (4.9 meq/100g_msoil) and tend to increase with depth. The magnesium levels are also high and

constant with depth (4.0 meq/100gm soil). The values of extractable sodium are low like those of potassium which are less than (0.7 meq/100gm soil) and tend to decrease with depth similarly are the phosphorus levels (16.32 ppm). The levels of CEC and base saturation are high as seen in profile 7. Therefore the management operations in Mtoni should consider also the levels of potassium and phosphorus.

5.3.2.3 Msolwa - Bwawani = 3Sf

Marginally suitable for sugarcane. The most limiting factor is soil fertility. Other factors which could be of importance include flooding and soil physical conditions especially texture.

The soil physical conditions of Msolwa-Bwawani are characterized by no rooting restriction due to low bulk densities as seen in profile 16 and decrease with depth due to the influence of the organic matter which also makes the available water content of topsoil higher. The soil physical limitation is due to high clay content due to the problems they cause during land preparation especially at high moisture content.

The soil reaction of Msolwa-Bwawani is slightly acidic and as has been suggested, the use of agricultural lime is not very necessary at the

present time. The use of fertilizers with no residual hydrogen ion could reduce further acidification of the soil. The amount of organic matter is very high (more than 4.31%) as seen in profile 16, while the level of nitrogen is low. Thus nitrogen supply has to some extent to be supplemented. Like Mlimani and Mtoni the levels of calcium and magnesium are high while that of potassium is low. The lower base saturation values indicates that Msolwa-Bwawani has soil fertility problem (table 22). Thus supply of fertilizer nutrients should be given a priority in the management of (Msolwa-Bwawani) for agricultural purposes.

5.3.2.4 Msolwa - S2 wf

Moderately suitable for sugarcane. The most limiting factor being internal drainage and slight flooding during the rainy season. Other limitations include soil fertility as reflected by base saturation and to some extent soil depth as limited by shallow water-table.

With an exception of profile 18 the major part of this area has bulk density values which increase with depth as seen in profiles 9, 12, 15, 17 and 19, and have fairly low values such that no

rooting restriction is expected though high water table noted during rainy season. The sandy clay loam textures with moderate clay and low silt are also favourable. The limitations which tend to reduce agricultural production are due to wetness (table 22). Therefore a control of flood and supply of simple drainage structures are here suggested.

Like Msolwa-Bwawani the soil reaction of Msolwa is also slightly acidic. The level of organic matter as indicated by the organic carbon content is high and tend to influence the bulk density and available water holding capacity. The nitrogen content (0.19%) as seen in profile 18 is low and tend to decrease with depth. The calcium content of the soil is high more than (5.0 meq/100gmsoil) in profile 18. Also the value of extractable magnesium is fairly high, this may be due to the parent material. The extractable potassium content is low and tend to decrease with depth suggesting that the contribution is mainly due to the organic matter. The lower base saturation values noted in the subsoils indicate that soil fertility is a limiting factor for Msolwa.

5.3.2.5 Bwawani - 3s w

Marginally suitable for sugarcane. The most limiting factor being drainage and flooding during the rainy season.

Bwawani has high values of bulk density which tend to increase with depth as seen in profile 8 and 10. These values indicate that rooting restriction is a problem. However the available water content is high and tend to increase with depth due to the influence of the organic matter. The high clay content and the high bulk densities aggravates the **poor** drainage condition of the soil. Thus it is suggested that flood control should receive attention and also drainage structures should be constructed if Bwawani is to be productive.

The slight acidic soil reaction may influence the nitrification and the supply of nutrients such as phosphorus. The high content of organic matter as indicated by the values of organic carbon (3.7%) and the values of nitrogen (0.22%) in profile 10 indicate high quality organic matter. There is no limitation as far as the supply of calcium and magnesium is concerned as their extractable values are high (more than 9.0 and 6.0 meq/100gm soil) respectively). The levels of potassium however, are low, so are values of base saturation which are reduced with depth. Supplementary fertilization is suggested.

5.3.2.6 Nyarubungu - U1 wf

Currently not suitable for sugarcane. The most limiting factor being sewer wetness due to restricted internal drainage and flooding during the rainy season. Another factor which may also limit the use of the land is soil fertility.

The bulk density values for Nyarubungu are high, and tend to increase with depth as seen in profile 20 and 21. This aggravates the internal drainage condition. Although the values of the topsoil are lower due to the organic matter content, the much higher values of the subsoil indicate restricted rooting which affects sugarcane. The available water holding capacity values are fairly high and tend to decrease with depth as organic matter decreases. The sandy clay loam texture does not seem to influence the soil properties. Flooding has been noted here as the highest limitation together with internal drainage as expressed by wetness (table 22). This makes Nyarubungu not suitable for sugarcane currently. Thus unless consideration is given on the flood control, say by construction of dykes and a drainage system, which is not very likely at the present time, Nyarubungu will remain not suitable for sugarcane.

Like Bwawani, Nyarubungu has slightly acid soils and high organic matter content. The major problem which is noted in profile 20 is soil fertility as reflected by the base saturation values which are low. Potassium and phosphorus is also very low. If Nyarubungu is to be utilized for agricultural purposes, supplementary fertilization will be necessary.

5.3.3 Comments on Sys (1976) Table.

Although Sys (1976) table was adopted for drawing up the suitability ratings, complete agreement with Sys (1976) table was not possible. Land qualities like texture, base saturation and organic matter can be rectified in some places without having to incur very heavy capital investments. It would therefore be improper to place them under severe (permanent) limitation in some localities.

According to Sys (1976), Mtoni mapping unit would have fallen under suitability class 3, but observations in the field showed that cane performance was just slightly below that in Mlimani - S1. At the early stages of growth (during the rainy season) performance of cane at Mtoni is in fact equally as good as that of Mlimani or Msolwa.

6. SUMMARY AND CONCLUSIONS

The soil and land evaluation has been conducted on soils that are formed from colluvial and alluvial materials from the raised block of the Migomberana and Gologolo mountains, with Usagaran basement complex consisting of migmatitic gneiss, biotite, hornblende, Usagaran undifferentiated and granulites. Rivers form the major land forming agent. Msolwa river and its tributary Nyarumbungu has characteristics of frequent seasonal flooding, resulting to undulating landscape with sand banks, old channel levees and basins in flat areas. The natural vegetation consisted of tree bush savanna with smaller areas of bush and grass savanna. This area has tropical rainy climate. The rainy season lasts from November to May with January dry spells. Moisture deficits are significant in June all through to December. The temperatures are high and varies between 21°C to 25°C in dry season and 25°C to 28°C in rainy season.

Soil classification of each of the 21 soil pits using the Soil Taxonomy System has indicated the most dominant diagnostic epipedon as an ochric followed by umbric. Only profiles 2, 8 and 10 have shown features of a mollic epipedon. The most dominant subsurface horizon is cambic. Among the problems encountered in the study was the identification of an argillic horizon. In some pits weak patchy cutans were observed, however the argillic horizon could not be confirmed due to lack of required clay ratio and non-uniformity of parent material. Also lack of mineralogical and sand fraction separation data made the

classification to the lower category not possible. In this study Inceptisols occupy the largest portion, profiles 1, 2, 3, 4, 9, 12, 13, 14, 15, 16, 17, 18, 19 and 21 which appear to be formed from colluvial and alluvial materials. Others include Entisols, profiles 6, 7, 8 and 20 mostly of transported sediments. Mollisols appear only in small portion, profile 10, while Ultisols which are formed in situ from the residual material, comprises of profiles 5 and 11. The problem of fitting all the information into the Soil Taxonomy System was observed for some pits in the study area, (Profiles 15 and 17). Aquic Humitropept subgroup was suggested though not given in the system.

Broadly six mapping units have been identified and grouped as well drained, moderately well drained and imperfectly drained. For each group two units have been identified and mapped on the basis of their slope, texture of topsoil and mottling. Mlimani and Mtoni are well drained, Msolwa-Bwawani and Msolwa are moderately drained, while Bwawani and Nyarubungu are imperfectly drained. From this it can be seen that the different units observed and mapped are merely associations rather than single soil types.

Land evaluation has been carried out using the F.A.O. System. Mlimani is highly suitable for sugarcane production. Mtoni is suitable with the most limiting factor being the soil physical characteristics related to texture. Msolwa-Bwawani which is marginally suitable has soil fertility limitations. Msolwa the most dominant unit has been noted to be moderately suitable for sugarcane and the factors which tend to be most

limiting include internal drainage and soil fertility. Bwawani which occupies the lowly lying areas has been evaluated as being marginally suitable for sugarcane with the most limiting factor being wetness as indicated by restricted drainage and seasonal flooding. Nyarubungu which occupies the lowest parts of the study area on very flat lands is currently not suitable for sugarcane due to the limitation caused by severe poor internal drainage and severe seasonal flooding. Also the soil fertility of this area is low.

The following conclusions and recommendations can be made in view of the findings in this investigation:-

1. As there is a period of dry spell between June and December when moisture deficits are observed, it is suggested that irrigation be carried out to help close up the moisture demands of most plants including sugarcane. However a careful study on the irrigation, the rate and system should form a separate study.
2. As it has been noted, the soil reaction of most of this area is slightly acidic, amendment measures are therefore necessary. The values however do not call for strong measures such as liming. Fertilizers which have no residual hydrogen ion such as calcium ammonium nitrate should be used instead of those with residual hydrogen ion like sulphate of ammonia.

3. The use of fertilizer is here recommended for the most part of the study area especially Msolwa, Msolwa-Bwawani and Nyarubungu units which have low soil fertility. This will require a careful selection, placement and rating studies before the fertilizers can be safely used.
4. Drainage and flood control measures are also recommended in order to make use of Msolwa, Bwawani and Nyarubungu units.
5. The Nyarubungu area (approximately 110 ha) which is currently not suitable for sugarcane is recommended for small scale rice production, which can be utilized by the labour force working in the estates.

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8. APPENDICES

Appendix 1 - Land evaluation systems.

The U.S.D.A. Land capability classification.

This is a three category classification:-

(i) A capability class - defined as a grouping of subclasses that have the same relative degree of limitation or hazard. Classes are indicated by Roman numerals, the limitation to type of land use and risks of damage to the environment increasing from class I to class VIII. The following are the abbreviated definitions of capability classes.

- Class I Soils with few limitations that restrict their use.
- Class II Soils with some limitations that reduce the choice of plants or require moderate conservation practices.
- Class III Soils with severe limitations that reduce the choice of plants or require special conservation practices or both.
- Class IV Soils with very severe limitations that restrict the choice of plants, require very careful management or both.
- Class V Soils with little or no erosion hazard but with other limitations impractical to remove that limit their use largely to pasture, range, woodland or wild life food or cover.

Class VI Soils with very severe limitations that make them generally unsuitable to cultivation and limit their use largely to pasture or range, woodland or wildlife.

Class VII Soils with very severe limitations that make them not suitable for cultivation and restrict their use largely for grazing, woodland or wildlife.

Class VIII Soils and landforms with limitations that preclude their use for commercial plants production and restrict it to recreation, wildlife, water supply or esthetic purposes.

(ii) A capability sub-class - is a grouping of capability units that have same kinds of limitations of hazard. These kinds are indicated by lower-case later subscripts, of which the original system gives four: erosion hazard (e), excess water (w), soil rootzone limitations (s) and climatic limitations (c). Later adaptations of the system employ additional kinds of limitations e.g. stoniness, salinity. The meaning of sub-class letters changes according to the class to which they are attached; thus the "e" in sub-class III e indicates a more severe erosion hazard than that in II e.

(iii) A capability unit is a grouping of soil mapping units that have the same potential, limitations and management responses. Units are shown by Arabic numbers, as IIIe-1, IIIe-2. All soils within a capability unit can be used for similar crops, require similar management practices and soil conservation measures, and

have a comparable productive potential. With equal management, the yield range within a unit is not expected to exceed 25 percent.

The U.S. Bureau of Reclamation Land Classification for Irrigation:

This system classifies land in terms of its suitability for irrigation. There are six land classes, abbreviated definitions of which are as follows (note that "arable" is used with the meaning "irrigable").

- Class I Arable. Lands that are highly suitable for irrigation, being capable of producing sustained and relatively high yields of wide range of crops at reasonable cost. They are smooth lying with deep soils, open soil structure allowing easy penetration of roots yet good available moisture capacity and free from harmful qualities of soils. These have potentially high payment capacity.
- Class II Arable. Lands of moderate suitability for irrigation, being lower than class I in productive capacity, adapted to a somewhat narrower range of crops, more expensive to prepare for irrigation or more costly to farm. These lands have an intermediate payment capacity.

- Class III Arable. Lands that are suitable but approaching marginality for irrigation. They have substantial soil topographic or drainage limitations. A greater risk is involved in farming these lands than class I and II, but under proper management they are expected to have adequate payment capacity.
- Class IV Limited arable or special use. These lands may either have excessive deficiencies susceptible of correction at high cost, but are suitable for irrigation of high value crops such as vegetables, fruits; or they have excessive non-correctible deficiencies precluding arable use but permitting use as irrigated pasture or orchard.
- Class V Non-arable. These lands are non-arable under existing conditions but have a potential value sufficient to warrant segregation for special study; or their arability is dependent upon additional project construction. The designation is tentative and must be changed to the proper arable class or to class VI prior to completion of the land classification.
- Class VI Non-arable. These lands do not have sufficient payment capacity to warrant consideration for irrigation.

Appendix II -- Other profile features and analytical data.

1. Profile 1 2/8/79

External features

Located about 10 metres east of the Ifakara - Mikumi road
(. ~~Fig.~~ 5) on a concave, east facing slope of approximately 6%
gradient; pit site near middle of the slope; ustic moisture
regime; isohyperthermic soil temperature regime; currently
under sugarcane; colluvial material; well drained; no flooding.

Internal features

- Ap 0-22 cm Brown (10YR 5/3) dry, dark yellowish brown
 (10YR 3/4), moist; sandy clay loam; moderate medium crumbs
 to moderate medium sub-angular blocky; slightly sticky
 and slightly plastic, firm, slightly hard; many fine and
 few medium pores; common fine roots; clear smooth boundary.
- B₁₁ 22³/₂-60 cm Dark brown (7.5YR 4/4) dry, dark brown (7.5YR 3/3)
 moist; fine sandy clay; moderate medium sub-angular blocky;
 sticky and plastic, firm, slightly hard; many fine discontinuous
 inped pores; few fine roots; diffuse smooth boundary.
- B₁₂ 60-80 cm Yellowish red (5YR 4/8) moist, fine sandy clay
 matrix with stones; moderate medium sub-angular blocky;
 sticky and plastic, firm; many fine discontinuous inped
 pores; few fine roots; clear smooth boundary.

B₂ 80-110⁺ cm Yellowish red (5YR 5/6) moist; fine sandy clay; moderate medium sub-angular blocky; sticky and plastic, firm; many fine discontinuous impeded pores; few fine roots.

Table 1a. Physical Analytical data

Profile 1

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution			Textural class
				pF 2.0	pF 4.2		Sand	Silt	Clay	
A _p	0-22	1.49	2.33	23.3	7.9	15.4	69.8	7.8	22.4	Sandy Clay loam
B ₁₁	22-60	1.56	2.31	27.8	12.9	14.9	53.8	9.8	36.4	Sandy Clay
B ₁₂	60-80	1.60	2.31	25.5	13.6	11.9	55.8	5.8	38.4	Sandy Clay
B ₂	80-110	1.62	2.20	28.3	14.1	14.2	54.4	7.4	38.2	Sandy Clay

Table 1b. Chemical Analytical Data

Profile 1

Horizon	Depth in cm	pH		% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100 gm soil	CEC in meq/100 gm Soil Clay	Percentage base saturation	
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺				
Ap	0-22	6.4	5.0	2.02	0.19	10.70	11	3.9	7.6	1.05	12.7	351.2	139.3	40.7
B ₁₁	22-60	7.5	4.8	0.80	0.06	9.30	13	3.4	5.3	0.45	9.3	30.2	83.0	40.8
B ₁₂	60-80	6.5	5.4	0.48	0.07	22.80	7	2.4	6.0	0.51	9.1	28.0	72.9	32.5
B ₂	80-110	6.3	5.4	0.40	0.07	14.56	6	3.0	5.0	0.68	8.8	26.2	68.6	33.6

Profile 2 2/8/79

External features

Located 20 metres east of the Ifakara - Milami road, on a concave east facing slope of approximately 2%; pit site near middle part of the slope; ustic moisture regime, isohyperthermic soil temperature regime; currently under sugar cane; colluvial material; well drained; no flooding.

Internal features

- A_p 0-18 cm Dark brown (10YR 3/3) dry, very dark greyish brown (10YR 3/2) moist; sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, slightly firm, slightly hard; many fine discontinuous inped pores; many fine to medium roots; clear smooth boundary.
- A₁₂ 18-44 cm Very dark brown (10YR 2/2) dry, very dark grey (10YR 3/1) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, hard; many fine discontinuous inped pores; weak clay skins (cutans) present; few fine roots; clear smooth boundary.
- B_w 44-65 cm Dark brown (10YR 4/4) dry, dark brown (10YR 4/2) moist; moderately fine sandy clay loam; weak fine sub-angular blocky; slightly sticky and slightly plastic, friable, soft; many fine discontinuous inped pores; few fine to medium roots; stones 5%, diffuse irregular boundary.

- O 65-85 cm Yellowish red (5YR 4/6) moist; coarse sand with gravel; structureless; non sticky and non plastic, friable, loose; many fine discontinuous inped pores; very few fine roots; diffuse irregular boundary.
- A₁b 85-100 cm ~~Dark~~ reddish brown (5YR 3/4) moist; moderately fine sandy clay loam; weak fine sub-angular blocky; slightly sticky and slightly plastic, slightly firm, slightly hard; many fine discontinuous inped pores; very few fine roots; diffuse irregular boundary.
- B₁₁b 100-122 cm Dark yellowish brown (10YR 3/4) moist; moderately fine sandy clay loam; weak to moderate fine sub-angular blocky; slightly sticky and slightly plastic, firm, hard; many fine discontinuous inped pores; very few fine roots; clear smooth boundary.
- B₁₂b 122-150 cm Dark yellowish brown (10YR 4/4) moist; moderately fine sandy clay; weak to moderate medium sub-angular blocky; sticky and plastic, firm, hard; common fine discontinuous inped pores; very few fine roots.

b indicates a buried profile

Table 2a. Physical Analytical Data

Profile 2

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Sand	Silt Clay		
Ap	0-18	1.22	2.17	38.6	15.8	22.8	56.4	17.4	30.2	Sandy Clay Loam
A ₁₂	18-44	1.38	2.28	43.5	19.4	24.1	54.4	9.4	36.2	Sandy Clay Loam
B _v	44-65	1.59	2.29	22.0	8.8	13.2	71.8	5.8	22.4	Sandy Clay Loam
C	65-85	1.42	2.50	11.9	4.7	7.2	82.4	3.4	14.2	Sandy
A ₁ ^b	85-100	1.40	2.35	31.6	12.9	18.7	60.4	9.4	30.2	Sandy Clay Loam
B ₁ ^b	100-122	1.49	2.34	22.6	9.1	12.5	70.4	3.4	26.2	Sandy Clay Loam
B ₁₂ ^b	122-150	1.66	2.29	26.9	12.8	14.1	58.9	5.4	36.2	Clay Loam

Table 2b. Chemical Analytical Data

Profile 2

Horizon	Depth in cm	pH		%	%	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100 gm soil	CEC in meq/100 gm Soil Clay	Percentage base saturation		
		1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
A _p	0-18	5.6	5.1	3.35	0.25	9.30	13	11.2	7.4	0.30	0.70	20.0	20.6	68.2	97.1
A ₁₂	18-44	6.0	5.0	2.60	0.25	15.61	10	9.2	6.0	0.31	0.35	15.9	21.4	59.3	74.3
B _w	44-65	6.7	5.5	0.82	0.10	18.24	8	3.9	7.3	0.24	0.38	11.8	23.4	104.5	50.4
C	65-85	5.9	5.0	0.35	0.07	17.02	7	6.4	2.0	0.16	0.20	8.8	26.0	180.6	33.8
A _{1b}	85-100	5.9	4.9	0.88	0.08	12.10	11	6.3	9.6	0.16	0.35	14.4	22.0	72.8	74.5
B _{11b}	100-122	6.7	5.0	0.88	0.06	15.79	15	5.4	6.3	0.19	0.22	12.1	30.4	116.0	39.8
B _{12b}	122-150	7.2	5.0	0.60	0.06	10.88	10	3.0	7.3	0.24	0.27	10.8	29.4	81.2	36.7

Profile 3 3/8/79

External features

15 metres east of the Ifakara - Mikumi road, on a convex east facing slope of approximately 8%; pit site near middle part of the slope, ustic soil moisture regime, isohyperthermic soil temperature regime; currently under sugar cane, colluvial material; well drained; no flooding.

Internal features

- Ap 0-22 cm Dark yellowish brown (10YR 3/4) dry, dark brown (7.5YR 3/2) moist; moderately fine sandy clay loam; moderate fine and medium sub-angular blocky; slightly sticky and slightly plastic, slightly firm, slightly hard; many fine discontinuous impeded pores; many fine roots; clear smooth boundary.
- B_(w) 22-60 cm Yellowish red (5YR 4/6) dry, yellowish red (5YR 4/6) moist; fine sandy clay; moderate fine and medium sub-angular blocky; sticky and plastic, firm slightly hard; many fine discontinuous impeded pores; few fine roots; clear smooth boundary.
- CB 60-100⁺ cm Red (2.5YR 4/5) dry, yellowish red (5YR 4/8) moist; fine sandy clay, gravelly and stony; structureless slightly sticky and slightly plastic, friable, soft; many fine discontinuous impeded pores; few fine roots.

Table 3a. Physical Analytical Data

Profile 3

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution			Textural Class
				pF 2.0	pF 4.2		Sand	Silt	Clay	
A _p	0-22	1.20	2.33	24.5	10.1	14.4	66.4	9.4	24.2	Sandy Clay Loam
B _w	22-60	1.50	2.31	23.7	10.9	12.8	62.4	7.4	30.2	Sandy Clay
CB	60-100	1.40	2.34	24.0	11.8	12.3	52.4	3.4	34.2	Sandy Clay

Table 3b. Chemical Analytical Data

Profile 3

Horizon	Depth in cm	pH 1:1 H ₂ O CaCl ₂	% Organic Carbon	Available % Total Nitro- gen	C/N	Extractable cations in meq/100 gm soil			Total Extrac- table bases in. meq/100 gm soil	CEC in meq/100 gm Soil	Clay base satu- ration				
						Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺							
Ap	0-22	5.9	5.1	2.56	0.17	28.77	15	7.3	2.7	0.21	0.95	11.2	26.2	108.3	42.7
B ₁	22-60	5.9	5.2	1.07	0.08	22.80	13	4.9	7.0	0.14	0.65	11.7	23.2	73.2	54.7
Cb	60-100	6.1	5.2	0.41	0.05	18.24	8	3.9	6.0	0.14	0.95	11.0	23.0	67.2	47.8

Profile 4 3/8/79

External features

Located about 200 metres east of the Ifakara to Mikumi road ;
undulating, concave east facing slope of about 2%, pit site
near middle part of the slope; ustic but tending towards udic soil
moisture regime; isohyperthermic soil temperature regime; currently
under sugarcane; colluvial material; well drained; no flooding.

Internal features

- A₁ 0-25 cm Dark greyish brown (10YR 4/2) dry, very dark grey
(10YR 3/1) moist; moderately fine sandy clay loam; weak to
moderate medium sub-angular blocky; sticky and plastic,
slightly firm, slightly hard; many fine discontinuous inped
pores; many fine medium roots; clear smooth boundary.
- B₁ 45-68 cm Dark greyish brown (10YR 4/2) moist; moderately
fine sandy clay loam; weak to moderate medium crumbs;
slightly sticky and slightly plastic, firm; many fine
discontinuous inped pores; few fine roots; clear smooth
boundary.
- CB 68-100⁺ cm Yellowish brown (10YR 5/6) moist; moderately
fine sandy clay loam cemented with gravel; moderate medium
sub-angular blocky; greyish concretions present; slightly
sticky and slightly plastic, firm; common fine discontinuous
inped pores; few fine roots.

Table 4a. Physical Analytical Data

Profile 4

7 Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class
				pF 2.0	pF 4.2		Sand	Silt Clay	
A ₁	0-45	1.14	2.66	24.0	8.3	15.7	64.2	11.6 24.3	Sandy Clay Loam
B ₁	45-68	1.66	2.43	14.9	5.2	9.7	63.8	8.0 28.2	Sandy Clay Loam
CB	68-100	1.80	2.50	12.6	3.5	9.1	62.2	8.8 29.0	Sandy Clay Loam

Table 4b. Chemical Analytical Data

Profile 4

Horizon	Depth in cm	pH		% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100gm soil	CEC in meq/100 gm Soil Clay	Percentage base saturation		
		1:1	1:1 H ₂ O CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺					
A ₁	0-45	5.8	5.3	2.97	0.15	11.58	20	6.3	3.7	0.21	0.55	10.8	28.0	115.2	38.6
B ₁	45-68	6.2	4.8	0.72	0.07	11.58	10	3.0	8.2	0.45	0.12	11.8	29.0	102.9	40.7
CB	68-100	6.2	5.2	0.20	0.04	12.11	5	2.4	1.7	0.76	0.15	5.0	31.2	107.6	16.0

Profile 13 18/9/79

External features

Located at about 10 metres east of the road to Ifakara from Mikumi (Fig. 5); undulating, approximately 3 km long, convex east facing slope of approximately 5%, pit site near middle part of the slope; ~~usitic~~ moisture regime; isohyperthermic soil temperature regime; woodland; currently under sugar cane; colluvial material; well drained; no flooding.

Internal features

A_p 0-15 cm Brown (7.5YR 4/2) dry, dark brown (7.5YR 3/2) moist; medium sandy loam; moderate medium crumbs grading to sub-angular blocky; slightly sticky and slightly plastic, friable, loose; many fine discontinuous inped pores; concretions (about 5%) present many fine roots; clear smooth boundary.

A₁₂ 15-60 cm Brown (7.5YR 4/2) dry, dark brown (7.5YR 3/2) moist; medium sandy loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, friable, loose; many fine discontinuous inped pores; concretions (about 7%) present; ~~few fine roots~~; clear smooth boundary.

B_(w) on 60-95 cm Brown (7.5YR 5/4) dry, dark brown (7.5YR 4/4) moist; medium sandy loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, friable, soft; many fine discontinuous inped pores; concretions (about 7%) present; few fine roots; clear smooth boundary.

O₁ on 95-120 cm Reddish brown (5YR 5/4) dry, reddish brown (5YR 4/4) moist; moderately fine sandy clay loam with gravel; weak fine sub-angular blocky to structureless; non sticky and non plastic, friable, loose; many fine discontinuous inped pores; few fine roots; concretions (about 10%) present; clear smooth boundary.

C₂ on 120-185⁺ cm Yellowish red (5YR 4/8) dry, yellowish red (5YR 4/8) moist; moderately fine sandy clay loam; weak fine sub-angular blocky to structureless; slightly sticky and slightly plastic, slightly firm to friable, L: loose; many fine discontinuous inped pores; concretions (about 10%) present; few fine roots.

Table 56. Physical Analytical Data

Profile 13

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution			Textural Class
				pF 2.0	pF 4.2		Sandy	Silt	Clay	
A ₁ on	0-15	1.27	-	13.5	3.4	10.1	76.2	7.6	16.2	Sandy loam
A ₁₂ on	15-60	1.46	2.26	15.5	4.4	11.1	78.2	5.6	16.2	Sandy loam
B ₍₁₎ on	60-95	1.46	2.32	18.7	8.1	10.6	78.2	5.6	16.2	Sandy loam
C ₂ on	120-185	1.54	2.54	20.0	8.9	11.1	74.2	5.6	20.2	Sandy clay loam

Table 5b. Chemical Analytical Data

Profile 13

Horizon	Depth in cm	pH		% Organic carbon	% Total Nitrogen	Available Phosphorus ppm	C/N	Extractable cations in neg/100 gm soil		Total Extractable bases in neg/100gm soil	CEC in neg/100 gm soil	Percentage base saturation			
		1:1 H ₂ O	1:1 CaCl ₂					Ca++	Mg++ Na+ K+						
A _p en	0-15	5.7	5.8	3.20	0.24	16.32	13	2.93	3.49	0.48	0.84	7.74	22.3	137	33
B ₁₂ en	15-60	5.3	5.4	1.87	0.09	12.10	21	5.12	3.00	0.53	0.50	9.15	28.5	175.9	32
B ₂ en	60-95	6.2	5.4	0.38	0.04	15.79	10	1.33	3.93	0.59	0.36	6.21	27.5	169.7	23
C ₂ en	100-185	6.5	5.1	0.81	0.05	24.21	16	2.71	3.17	0.63	0.27	6.76	26.3	130.2	26

Profile 14. 18/9/79

External features

Located at about 400 metres east of the road to Mikumi from Ifakara (Fig. 5); flat to undulating, approximately 3 km long concave east facing slope of approximately 3%, pit site near middle part of the slope; ustic soil moisture regime, isohyperthermic soil temperature regime; woodland; currently under sugar cane; colluvial material; well drained; slight flooding.

Internal features

- Ap 0-25 cm Brown (10YR 5/3) dry, dark yellowish brown (10YR 3/4) moist; fine sandy clay; moderate medium crumbs; slightly sticky and slightly plastic, firm, slightly hard; many fine discontinuous inped random pores; many fine roots; clear smooth boundary.
- B_(w)1 25-51 cm Brown (7.5YR 5/4) dry, dark brown (7.5YR 3/2) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, slightly hard; many fine discontinuous inped pores; few fine roots; clear smooth boundary.
- B_(w)2 51-61 cm Brown (7.5YR 5/4) dry, dark reddish brown (5YR 3/4) moist; coarse sand; weak to moderate fine sub-angular blocky to structureless; non sticky and non plastic, friable, loose; many fine discontinuous inped pores; few fine roots; clear smooth boundary.

- B_(w)3 61-84 cm Brown (7.5YR 5/4) dry, olive brown (7.5YR 4/4) moist; fine sandy clay; weak to moderate medium sub-angular blocky; sticky and plastic, firm, slightly hard; many fine discontinuous inped pores; few fine roots; diffuse smooth boundary.
- C 84-200⁺ cm Dark brown (7.5YR 4/4) dry, dark brown (7.5YR 4/4) moist; sandy clay; moderate medium sub-angular blocky to massive; sticky and plastic, firm, hard; many fine discontinuous inped pores; few fine roots.

Table 6a. Physical Analytical Data

Profile 14

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Soil	Silt + Clay		
AP	0-25	1.28	2.22	33.6	14.2	19.4	66.2	9.6	24.2	Sandy Clay
B _(w) 1	25-61	1.43	2.39	30.2	12.3	18.9	64.2	11.6	24.2	Sandy Clay
B _(w) 2	61-84	1.46	2.34	26.5	12.5	14.0	62.2	7.6	30.2	Sandy Clay
B _(w) 3	84-200	1.36	2.18	26.4	11.3	15.1	59.8	6.0	34.2	Sandy Clay

Table 6b. Chemical Analytical Data

Profile 14

Horizon	Depth in cm	pH	1:1 H ₂ O CaCl ₂		% Organic carbon	% Total nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100gm soil	CEC in meq/100 gm Soil	Percentage base saturation	
			Ca ⁺⁺	Mg ⁺⁺					Na ⁺	K ⁺					
Ap	0-25	5.6	5.2	2.30	0.18	10.35	13	5.86	3.32	0.56	2.00	10.74	27.7	114.5	39
B(w)1	25-61	5.8	5.3	1.95	0.10	13.35	20	3.90	3.44	0.58	0.35	8.27	28.2	116.5	29
B(w)2	61-84	5.9	5.7	1.31	0.13	9.30	10	4.32	3.42	0.48	0.34	8.56	28.1	93.7	30
B(w)3	84-200	6.0	5.5	0.60	0.14	14.56	4	1.95	2.98	0.52	0.40	5.85	38.9	113.7	15

Profile 16 18/9/79

External features

Located at about $1\frac{1}{2}$ km east of the road from Ifakara to Mikuni (Fig. 5), almost flat, approximately 3 km long, linear, east facing slope of approximately 2% gradient; pit site near middle part of the slope; aquic soil moisture regime, isohyperthermic soil temperature regime; wooded grassland; currently under sugar cane; alluvial material; moderately well drained; slight flooding.

Internal features

Ap 0-30 cm Greyish brown (10YR 5/2) dry, very dark grey (10YR 3/1) moist; moderately fine clay loam; granular; sticky and plastic, firm, hard; common fine discontinuous impeded pores also few medium continuous pores; many fine roots; diffuse irregular boundary.

B_(w)g 30-66 cm Greyish brown (10YR 5/2) dry, very dark greyish brown (10YR 3/2) moist; fine sandy clay; moderate fine sub-angular structure breaking into small prisms; sticky and plastic, firm, hard; common fine discontinuous pores with few medium continuous pores; mottles present; slickensides present; few fine roots; diffuse irregular boundary.

Cg 66-117⁺ on Yellowish brown (10YR 5/6) dry, yellowish brown (10YR 4/4)moist; moderately fine clay loam; massive, breaking into small prisms; sticky and plastic firm, hard; common fine discontinuous inped with few medium continuous pores; mottles present; few fine roots; slickensides present.

Table Va. Physical analytical Data
Profile 16

Horizon	Depth cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Sand	Silt clay		
Ap	0-30	1.09	2.17	54.7	25.3	29.4	42.4	15.2	42.4	Clay Loam
B _(w) g	30-66	1.32	2.10	42.3	21.8	20.5	52.2	7.6	40.2	Sandy Clay
Cg	66-117	1.25	2.37	46.2	25.1	21.1	44.4	9.2	46.4	Clay Loam

Table 7b. Chemical Analytical Data

Profile 16

Horizon	Depth in cm	pH	1:1 H ₂ O CaCl ₂	%	Organic carbon	%	Total nitrogen	Available Phosphorus ppm	Extractable cations in meq/100 gm soil	Na ⁺ Mg ⁺⁺ Na ⁺ K ⁺	Total Extractable bases in meq/100 gm soil	CEC in meq/100 gm Soil	Clay	Percentage base saturation	
															0/N
A _p	0-30	6.4	4.7	4.31	0.22	10.88	20	4.64	3.49	0.62	0.44	9.69	39.5	93.2	24
B _(H) /g	30-66	7.2	5.0	1.93	0.11	14.39	18	5.37	3.00	0.67	0.18	9.22	39.2	97.5	24
C _g	66-117	6.1	5.4	0.67	0.05	12.10	13	1.76	5.81	0.56	0.17	8.30	23.9	51.5	35

Profile 17 18/9/79

External features

Located at about 2 km east of the road from Ifakara to Mikuni (Fig. 5); almost flat, approximately 3 km long linear, east facing slope of approximately 2% gradient, pit site at lower part of the slope; aquic soil moisture regime, isohyperthermic soil temperature regime; wooded grassland; currently under fallow; alluvial material; moderately well drained; slight flooding.

Internal features

Ap 0-38 cm Yellowish brown (10YR 5/4) dry, very dark greyish brown (10YR 3/2) moist; moderately fine sandy clay loam; moderate fine to medium sub-angular blocky; slightly sticky and slightly plastic, friable, slightly hard; many fine discontinuous inped pores; insect nests (4%) present; many fine roots; diffuse irregular boundary.

B_(w) 38-77 cm Yellowish brown (10YR 5/8) dry, dark yellowish brown (10YR 4/4) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, hard; many fine discontinuous inped pores; few fine roots; diffuse smooth boundary.

B₃ 77-145⁺ cm Light olive brown (2.5YR 5/4) dry; yellowish brown (10YR 5/6)moist; moderately fine sandy clay loam; massive to moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, hard; many fine discontinuous inped pores; yellowish and brownish mottles present; few fine roots.

Table 8a. Physical Analytical Data

Profile 17

Horizon	Depth in cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water		Particle size distribution		Textural Class
				pF 2.0	pF 4.2	pF 2.0	pF 4.2	Sand	Silt	
A ₁	0-38	1.32	2.32	30.0	39.0	19.0	70.4	7.2	22.4	Sandy Clay Loam
B ₁ (w)	38-77	1.38	2.29	20.7	7.2	12.8	64.2	7.6	28.2	Sandy Clay Loam
B ₃	77-145	1.31	2.26	27.8	12.7	15.1	65.4	5.2	28.4	Sandy Clay Loam

Table 8b. Chemical Analytical Data

Profile 17

Horizon	Depth in cm	pH.	1:1 H ₂ O	CaCl ₂	1:1	%	Organic carbon	%	Total nitrogen	Available Phosphorus	C/N	Extractable cations in meq/100 gm soil			Total Exchangeable bases in meq/100 gm soil	CEC in meq/100 gm soil	Percentage base saturation
												Ca ⁺⁺	Mg ⁺⁺	Na ⁺ + K ⁺			
A ₁	0-38	6.4	5.4	2.66	0.17	10.70	16	5.37	4.15	0.48	0.43	10.33	23.1	103.1	45		
B ₁ ⁽¹⁷⁾	38-77	6.5	4.9	1.06	0.07	19.47	15	1.95	2.32	0.49	0.27	5.09	24.8	87.9	20		
B ₃	77-145	6.6	5.2	0.50	0.05	21.58	10	2.93	2.32	0.48	0.20	5.95	28.1	101.2	21		

Profile 19 19/9/79

External features

Located at about 2 km east of the road from Ifakara to Milumi (Fig. 5); almost flat, approximately 3 km long, linear, east facing slope of approximately 2% gradient pit site near lower part of the slope; aquic moisture regime; isohyperthermic soil temperature regime; wooded grassland; currently under fallow; alluvial material; moderately well drained; slightly flooding.

Internal features

- Ap 0-20 cm Dark greyish brown (10YR 4/2) dry, very dark grey (10YR 3/1) moist; moderately fine sandy clay loam; moderate medium crumbs; slightly sticky and slightly plastic, friable, soft; many fine discontinuous impeded pores and few medium continuous pores; many fine roots diffuse smooth boundary.
- B_(w)1 20-52 cm Dark brown (10YR 3/3) dry, very dark greyish brown (10YR 3/2) moist; moderately fine sandy clay loam; moderate medium sub-angular blocky; slightly sticky and slightly plastic, firm, slightly hard; many fine discontinuous impeded pores and few medium continuous pores; few fine roots; diffuse smooth boundary.

B_(w)2_g 52-85 cm Dark brown (10YR 4/3) dry, and dark grey
(10YR 4/1) moist; moderately fine sandy clay loam; moderate
medium sub-angular blocky; slightly sticky and slightly
plastic, firm, slightly hard; brown mottles (about 15%)
present; common fine discontinuous impeded pores; few fine
roots.

Water table at 85 cm depth.

Table 9A. Physioal Analytical Data

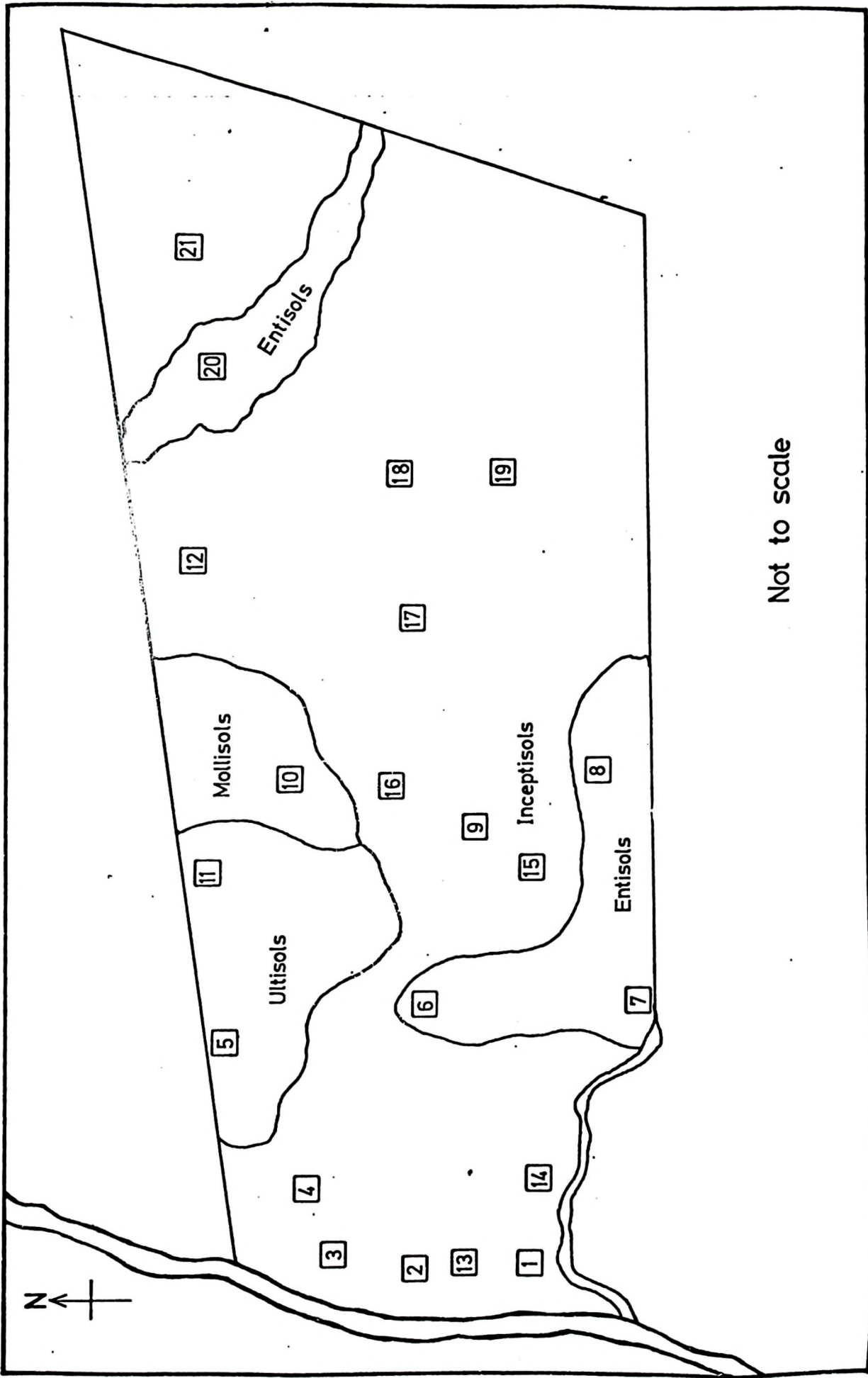
Profile 19

Horizon	Depth in. cm	Bulk Density B.D.	Particle Density P.D.	Moisture holding capacity in %		Available water %	Particle size distribution		Textural Class	
				pF 2.0	pF 4.2		Sand	Silt Clay		
Ap	0-20	1.14	2.39	40.7	15.2	25.5	68.2	9.4	22.4	Sandy Clay Loam
B _(w) 1	20-52	1.36	2.42	29.1	13.0	16.1	68.4	7.2	26.2	Sandy Clay Loam
B _(w) 2B	52-85	1.31	2.45	31.0	16.3	14.7	70.4	9.2	20.4	Sandy Clay Loam

Table 9b. Chemical Analytical Data

Profile 19

Horizon	Depth in cm	pH	pH		% Organic carbon	% Total Nitrogen	Available Phosphorus ppm	C/N	Extractable cations in meq/100 gm soil			Total Extractable bases in meq/100gm soil	CEC in meq/100 gm	Percentage base saturation	
			1:1 H ₂ O	1:1 CaCl ₂					Ca ⁺⁺	Mg ⁺⁺	Na ⁺⁺				K ⁺
A ₁	0-20	5.8	5.1	2.04	0.22	17.54	9	5.37	4.98	0.49	0.66	10.50	38.3	171.0	27
B _{(w)1}	20-52	5.9	5.4	1.47	0.11	18.36	13	5.86	2.32	0.67	0.27	9.12	28.9	110.3	32
B _{(w)2g}	52-85	6.4	5.2	1.08	0.08	16.84	14	6.59	4.32	0.49	0.26	11.66	30.3	148.5	38



Not to scale

Appendix III A sketch showing the distribution of soil orders