PHYSICAL LAND EVALUATION OF CHONYI-KALOLENI AREA, KILIFI DISTRICT, - WITH EMPHASIS ON THE SUITABILITY FOR CASHEWNUTS AND COCONUTS

by

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DECLARATION

This Thesis is my original work and has not been presented for a degree in any other University

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This Thesis has been submitted for examination with my approval as University Supervisor

Signed: ....
R.G. BARBER

DEDICATION FOR MZEE GATAHI, MY PARENTS AND MINNIE M. MAINA.

For your very special and invaluable contributions and love, before and during this study, the need to be thankful increases each day.

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PREFACE

A 'complete' or 'integral' land evaluation involves not only the analysis of the physical environmental factors but an analysis of the social, cultural and economic factors. However, because of lack of time, this study was primarily limited to a physical land evaluation in which the consideration of cultural, social-economic factor was limited to the extent of defining the present and alternative land utilization types and in the choice of alternative LUTs and in prescribing the tentative land use recommendations of the study area. Moreover, because of this lack of time it was not possible to conduct a physical land evaluation for all the possible and relevant LUTs, therefore attention was focussed on land suitability for coconuts and cashewnuts - the main existing crops in this area. For completeness, the suitability of land for other LUTs (simple and compound) such as maize and grass for both dairy and beef cattle was also studied but in less detail.

Although standardised (FAO) methods of describing, analysing and classifying soils as used by Kenya Soil Survey (KSS) were adopted in this study, the mode and format of presentation of the data, e.g. the legend construction, description of mapping units, and the approaches used in evaluating the data, e.g. the land qualities 'availability of moisture' and availability of nutrients', are different from those used by the KSS, and will hopefully stimulate discussions on how the existing methods might be improved.

ABSTRACT

A physical land evaluation was carried out on 13,000 ha in the Chonyi-Kaloleni area, Kilifi District, following the guidelines outlined in the framework for land evaluation.

The present land use in the area ranges from ranching to cultivation of both annual and perennial crops. The alternative land utilization types (LUTs) for which the suitability of land was assessed include cashew, coconuts, maize, grass, cashew-dairy cattle, coconut-dairy cattle, maize-dairy cattle, coconut-cashew and beef cattle-cashew associations, all at an intermediate level of technology.

As a basis for the physical land evaluation, a soil survey at a scale of 1:50,000 was carried out. The soils of the study area were delineated into sixteen mapping units. The dominant soils are VERTISOLS, ARENOSOLS, FERRALSOLS, ACRISOLS, LUVISOLS and NITOSOLS. Other soils include GLEYSOLS, LITHOSOLS, FLUVISOLS and CAMBISOLS.

The following land qualities were used as diagnostic criteria to assess the suitability of each mapping unit for the relevant LUTs: availability of moisture, nutrients and oxygen, rootability, susceptibility to erosion, workability of the soil and in addition, the harmful effect of August-December rain-

fall for cashew. The suitability of each unit was determined by matching the requirement of each LUT with the rated land quality through conversion tables.

The well drained soils including FERRALSOLS, ACRISOLS, LUVISOLS, NITOSOLS and ARENOSOLS were, in general, moderately to marginally suitable for cashews, coconuts, maize and grass for dairy cattle and highly to moderately suitable for beef cattle. Poorly and imperfectly drained soils including VERTISOLS, GLEYSOLS, gleyic and vertic LUVISOLS were not suitable for coconuts and cashews.

Finally land use recommendations for each mapping unit were made taking into account social, economic and cultural factors together with present land use, nutritional requirements and the physical suitability of each unit. Coconut-dairy cattle association is recommended for dystric NITOSOLS, chromic LUVISOLS and orthic ACRISOLS; cashew-dairy cattle association for rhodic FERRALSOLS and some orthic ACRISOLS; maize-dairy cattle association for ferric LUVISOLS; beef cattle-cashew association for ARENOSOLS; maize, other food and fodder crops for dairy-beef cattle for gleyic and vertic LUVISOLS, vertic CAMBISOLS, VERTISOLS and dystric GLEYSOLS.

1. INTRODUCTION

The population of Kenya in 1979 was 15 million people with one of the world's highest growth rates of 3.5 to 4.2% per annum. The rapid population growth and the subsequent pressure on the land creates a problem of how to increase and sustain agricultural production while at the same time conserving our natural resources.

To increase agricultural production the government has in Session Paper No. 4 of 1981, outlined a "National Food Policy". The success of this policy depends heavily on identifying new areas for production, which can only be achieved through optimum land use planning. To plan effectively, the quantity and quality of the land resources and their agricultural potential must be well known. Soil survey provides the basic data, but they have to be interpreted and expressed in a manner well understood by planners and farmers. This process, termed land evaluation, indicates the relevant development alternatives and the required management specifications.

The Kenya Soil Survey (KSS) has, since 1972, carried out a systematic inventory of soils and other land resources data in Kenya for multipurpose land use planning at the district, regional and national levels. To assign priority and to select appropriate mapping scales the KSS has divided the country into three areas with different agricultural potentials based on agroclimatic and vegetation zones. These are:

1. High potential areas
2. Medium potential areas
3. Low potential areas

The high and medium potential areas are mapped at a scale of 1:100,000 and the low potential areas at 1:250,000. Medium potential areas are further subdivided into high and low altitude medium potential areas and it is in this latter category that the coastal Kenya belongs.

Although medium in potential, coastal Kenya has not been fully exploited since the present production is based on a low level of technology (traditional); moreover some tracts of land are only extensively used. The production is dominated by small-holder cultivation of coconuts, cashewnuts, mangoes and citrus fruits. Annual crops include maize, cassava and pulses for subsistence, and cotton, simsim and tobacco as cash crops. The tobacco is only sold at the local markets. Livestock is rather scarce and includes zebu cattle, goats and poultry maintained at poor levels of husbandry.

To fully exploit the agricultural potential, resource surveys and subsequent land evaluations are needed. The Kwale area has been surveyed (Michieka et.al., 1978) but Kilifi and Lamu areas in the north have not been surveyed. Recently a survey and land evaluation of the Kilifi area was started by the "Training Project in Pedology" of the Agricultural University, Wageningen, The Netherlands in co-operation with the KSS.

In order to co-operate with this project, the Chonyi-Kaloleni area in the Southern Division of Kilifi district was selected for this study which aimed to:

1. examine, describe and delineate on a map the soils of the Chonyi-Kaloleni area;
2. define the present and alternative simple and compound land utilization types (LUTs), and subsequently study some of the relevant land qualities;
3. assess the suitability of land for simple and compound LUTs at an intermediate level of technology with particular emphasis on coconuts and cashewnuts;
4. make land use recommendations based on the present and suitable alternative land utilization types.

2. REVIEW OF LITERATURE

2.1 BACKGROUND

Throughout his history, man has evaluated land and made decisions about its use. In the past, the results of land evaluation were used mainly for tax assessment but nowadays land evaluation is geared towards better land use. This change in bias has resulted from the need to maximise production while at the same time conserving the land resources. Land evaluation, for better land use, has received more attention lately because it has become clearer that an efficient use that does not degrade the land can only be achieved when the land conditions and all the details germane to the use are well known, (Bennema, 1978).

For land evaluation purposes, the term 'land' is a broader concept than 'soil' and is defined as "an area of the earth's surface; the characteristics of which embrace all stable or predictably cyclic attributes of the atmosphere above and below this area, including those of the atmosphere, the soil, and the underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity to the extent that these exact a significant influence on the present and future use of land by man", (FAO, 1976). This concept of land leads to the definition of land evaluation as "the process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to make a comparison of promising kinds of use in terms applicable to the objectives of the study", (FAO, 1976).

The terms land classification, soil capability classification, land capability classification and land suitability classification are sometimes used to mean land evaluation. Their use merits a clarification.

Land classification includes any method of grouping land or its elements into classes (Young, 1980). The land systems method (Stewart, 1968), in which areas with recurring topography, geology, climate, soils and vegetation are grouped as individual land systems, e.g. the Military Engineers Experimental Establishment (MEXE) system (Webster and Beckett, 1970), of classifying terrain are good examples here. These are not land evaluation systems although land evaluation may be applied to the land units they yield.

The term soil capability or suitability classification suggests the exclusive use of soil characteristics in the evaluation. It is however, very difficult to evaluate the suitability of soil for a particular use without considering slope, topography or climate. Thus the Canadian soil capability classification system considers not only soil but also other land characteristics. The use of the term 'soil' instead of 'land' is probably to emphasise the important role of soil characteristics in the evaluation. The term 'land' is preferred to the term 'soil' when referring to suitability/capability/evaluation systems by the author because the definition correctly implies that other land characteristics besides soil characteristics have also been used in the classification.

The terms 'capability' and 'suitability' are more difficult to distinguish. Capability is viewed by some people as an inherent capacity of land to perform at a given level for a general use, and suitability as a statement of adaptability of a given area for a specific kind of use (FAO, 1976). In the land Resources Division of Foreign and Commonwealth office for Overseas Development, U.K., land capability is commonly regarded as equivalent to Potential Agro-forestal land use, (Murdoch, 1972). To other people the terms are used interchangeably (FAO, 1976). Because of these varying interpretations, coupled with the long standing association of "capability" with the USDA-SCS land capability classification system, the term land suitability classification is preferred by the author in this study.

Two phases are recognised in land evaluation, viz. physical analysis and social-economic analysis (Beek, et.al., 1972; Brinkman and Smyth, 1973; Beek, 1978). In physical land evaluation only a physical analysis is carried out and social-economic analyses are introduced only to the extent of defining land utilization types. The results of the evaluation are expressed in purely physical terms. Integral land evaluation includes both physical and social-economic analysis. The land suitability classification in an integral land evaluation is expressed in economic terms.

Many land evaluation systems have been developed in different parts of the world. Differences between the systems arise from differences in the land use problems to be solved, prevailing physical and social-economic conditions and the constraints encountered. The systems therefore differ in both their purposes and in the degree of generalization required for these purposes (Bennema, 1978). Burrough (1976), cited by Beek (1978), made a distinction between those systems which serve a general purpose and those that serve a specific purpose, viz. general purpose systems and specific purpose systems.

The general purpose systems evaluate all lands for a broadly defined, general use, but the use is not studied and is only defined in general terms in the land evaluation process. The USDA land capability classification, the Canadian Soil Capability Classification for Agriculture, the British land use capability classification are examples of general purpose systems.

Specific purpose systems evaluate land for competing and relevant uses. The uses are specifically defined in terms of key attributes, e.g. produce, capital intensity and applied level of technology. These uses are explicitly studied in the land evaluation process and are selected on the basis of the prevailing social-economic conditions. The framework for land evaluation, the ecological method of land evaluation of Beek and Bennema (1972), and the USBR system for irrigated land use are examples of specific purpose land evaluation systems.

However, Burrough's distinction is not clear at either extremes of the mapping scales. At small scales the definition of a land utilization type is broad, and consequently a major kind of use in the specific purpose systems may merge into the broad standardized use in the general purpose systems, e.g. arable rainfed agriculture. At large scales the capability unit with its management specifications appears to merge into a land utilization type.

At intermediate scales the distinction is clearer. For example in specific purpose systems, although the definition of a given use may be broad in terms of one key attribute, e.g. agriculture or forestry, it is more specifically defined in terms of another key attribute, e.g. capital intensity.

Both specific purpose and general purpose classification systems may be applied at any scale of mapping. Thus, specific purpose systems should not be taken to mean a more detailed land evaluation. Both types of systems have some merits and some disadvantages, and are discussed below.

The general purpose systems evaluate all lands for a broadly defined general use. Consequently, this group of systems is very useful for ranking lands according to their suitability for such a use. The suitability classes aim to reflect the degree of flexibility in cropping and yield potentials (Hooper, 1974). Thus land suited for cultivation is rated above that only suited for grazing and forestry because it is more flexible and often more profitable. Ranking of land on the basis of a high yield for a given arable crop is not satisfactory since another crop may give low yields on the same land (Hooper, 1974). Moderately high management levels are assumed to eliminate differences in land performance attributed to individual farmers. Technological and social-economic variables are not considered in the land suitability groupings, hence the classes are valid for long periods (Bennema, 1978; Beek, 1978).

In their places of origin these systems have been successively applied. In the USA, land has been classified into land capability classes based on soil potentialities, limitations in use and management. Furthermore, the classes serve as a basis for a national conservation need inventory. Farm, urban and regional planning also make use of the land capability classification, (Olson, 1974).

Outside their countries of origin, the general purpose systems have to be modified, new suitability classes may be introduced, e.g. in Pakistan (Bramao, H., cited by Olson, 1974) and new guidelines made. Despite the modifications, problems are still encountered which arise from the principles and assumptions of these systems. Some noteworthy difficulties are:-

1. Although the systems are for a general purpose, only the commonly grown crops are considered. Limitations are understood to narrow the choice of crops but the excluded crops are rarely mentioned (Albers et.al., 1975; Bennema, 1978; Beek, 1978).
2. Capability classes are assigned on the basis of increasing limitations. However, the effect of these limitations does not reflect differences in relative suitability but only in the flexibility of cropping and management requirements.
3. In many areas, the applied levels of technology are variable, therefore it is difficult to compare land use performance due to the assumed high level

of management (Beek, 1978).

4. Since all land is evaluated for one general use no comparison between competing uses for the same land is possible.
5. By omitting social-economic variables, some broad development objectives, e.g. labour absorption, improved nutritional status which may be of national importance, despite the limited resources, are not considered (Beek, 1978).

Land evaluation sometimes involves land amelioration. These improvements should also be reflected in the suitability classification. In the general purpose systems, no distinction is made between suitability before or after amelioration. In each case suitability classification is made on the basis of the remaining limitations. Furthermore economics of the amelioration are not a criteria (Olson, 1974).

In view of these problems coupled with the need to exchange information between areas of similar physical conditions there is a trend to shift to specific land evaluation systems discussed below.

Specific land evaluation systems evaluate land for competing and relevant uses. Both the uses and the land are explicitly studied in the land evaluation process. A comparison of the competing uses can therefore be made. For the description of the uses all social-economic, technological and physical variables are considered. Suitability classes are assigned on the basis of required inputs and expected outputs. A separate suitability is made for each relavant use. Finally, specific purpose systems require a multidisciplinary approach to define the uses and to assign the suitability classes after 'matching' of land qualities with the requirements of the uses. In specific purpose systems, a distinction is made between minor and major improvements. "Current suitability" classification is one in which land has not been improved or only minor land improvements have been effected and "potential suitability" classification that in which major land improvements are or assumed to have been effected (FAO, 1976). These systems overcome some disadvantages indicated for the general purpose systems, but new difficulties arise, namely:-

1. The precise information required about fundamental relationships between constraining land qualities and the land utilization types is lacking. This results in suitability classes based on subjective observation and experience (Smyth, 1978; Beek, 1978).
2. Specific purpose evaluation relies heavily on multidisciplinary co-operation. This co-operation so far has not produced guidelines specific enough to evaluate for specific crops (Beek, 1978).

3. Since the systems consider technological and social-economic variables, changes in applied technology or changes in costs and prices of inputs invalidates the suitability classes. Thus the suitability classes must be reviewed, to include the new technological developments.
4. Although all competing uses for the same land are considered a good comparison between them is only possible when the suitabilities are commensurable in monetary terms. This requires an additional economic analysis after the physical land evaluation thus increasing the cost of evaluation.

In the next section land evaluation systems are reviewed against this background with an emphasis on their applicability in developing countries.

2.2 LAND EVALUATION SYSTEMS

Each of the land evaluation systems in use belongs to either the general purpose or the specific purpose group of land evaluation systems as mentioned above. They are therefore reviewed under these two headings.

2.2.1 General purpose systems

This group includes all land capability classifications whose doyen is the USDA capability classification system. The modifications of this system are used in many other countries, for example

Britain, Canada, Israel, the Phillipines, Pakistan and Malawi. The general features of this group have been discussed, and therefore only specific features of individual systems are discussed below.

2.2.1.1 The USDA - land capability classification

This system was developed by the USDA-Soil Conservation Services (SCS) and is summarised by Klingebiel and Montgomery (1961). The system groups land into units with similar kinds and degrees of limitations and assesses the extent to which these physical limitations hinder agricultural use of land (Morgan, 1979; Olson, 1974). The main concept used in capability assessment is that of limitations. Land classification is based on permanent limitations, viz. those which cannot be changed, at least by minor improvements. The level of management assumed is high but based on local norms (Olson, 1974; Young, 1980). In the United States the system is based on detailed soil maps published at scales of about 1:15,840 and 1:20,000 (Olson, 1974).

The basic unit is the "capability unit" which consists of a group of soils with sufficiently similar properties to produce similar kinds of cultivated crops and pasture plants under the same management; require similar conservation measures and management when put to similar uses. They have comparable yield potential. Capability units are combined into "sub-classes" according to kinds of limitations and sub-classes into "classes" depending on the degree of limitations.

Eight classes are recognised ranging from class I to class VIII. The limitations increases progressively from class I to class VIII. Classes I to IV are considered suitable for cultivated crops, however, the latitude of choice of crops decreases from class I to IV. The conservation measures required increase from class I to IV, and physical limitations are to some extent correctable. Classes V to VIII are considered not suitable for cultivated crops and have physical limitations which are not easily correctable (Olson, 1974).

In the United States, the system is geared towards large scale, highly mechanised cereal production, consequently slopes have been emphasised in the class designation. For example, land with more than 12% slope is considered unsuitable for cultivation. At the capability unit level, the system is used for farm planning and management specifications, (Olson, 1974). Edwards et.al., (1970) has successively used the system in the Ventura area, California, where capability units have been identified. Management practices have been specified together with predictions of expected yields for the crops and management practices considered. In the Ventura study, land capability ratings are given using "Storie indices based on four factors, viz. profile characteristics, texture of the surface soil, slope and other conditions (Hurradine, 1970). 'Storie indices' are however not normally applied in the system.

When applied outside the United States, problems are encountered due to the strong influence of slope ratings and agricultural versatility in class determinations and the scale at which management practices are specified. Firstly, due to its bias towards large scale mechanised cereal production it considers lands on more than 12% slope non-arable. However, in tropical countries lands with steeper slopes are cultivated without mechanisation. In this respect slope limits for arable land have to be adjusted to include these lands in the arable group. For example, Carter (1965) in Puerto Rico, cited by Murdoch (1972), included lands with slopes of 13 to 20% in class IV provided the soil was 'good enough'. Secondly, the use of agricultural versatility, viz., latitude of choice of crops, in class designation may be criticized. Poorly drained lands are downgraded because of being limited in the possible choice of crops whereas for some crops which prefer poor drainage the land may be highly suitable. Criticising the use of agricultural versatility in ranking land, Hooper (1974) argued that high yields of a particular arable crop may not be an indicator of high quality land because other crops may yield less satisfactorily. The capability classes are based on rather permanent limitations. The distinction between permanent and temporary limitations is sometimes not clear, e.g. natural soil fertility could fall into both. Moreover, costs of improving soil fertility may be out of reach of some farmers. Thus although it is a major limitation it will not be considered in the system.

Finally the system has been criticized for being too biased towards soil conservation. Morgan (1979) points out that although the inclusion of many soil properties may seem to render it useful for land use planning generally, its bias is towards soil conservation. Hudson (1971), stressing the same bias observed that "what the classification does show (and all it shows) is what intensity of use is best for land, and how carefully its conservation must be managed". These criticisms are, however, not fair to the system. Firstly, the system was designed to curb soil erosion in the United States, secondly, the system must be viewed in relation to the prevailing conditions where it is being applied. For example, currently in Kenya, the need to curb soil erosion is a major national concern therefore if this system was to be applied in Kenya, the criticisms of its conservation bias may not be justified.

In conclusion, although the conceptual framework of this system can be used outside the United States, the details of the system must be sometimes dramatically altered for it to be applicable elsewhere.

2.2.1.2 The British Land use Capability Classification

This system, which is summarized by Bibby and Mackey (1969), is a modification of the USDA land capability classification system to suit British conditions. Like the USDA system it places land into capability classes and sub-classes, however, the USDA class V has been omitted and an extra sub-class (g) has been introduced to assess the effects of gradient and soil pattern on mechanised farming. The slope limits used in this sub-class are:-

1. 0-3°; gently sloping, which presents no obstacles to farm operations;
2. 3-7°; moderately sloping, which may present difficulties with gapping machines or mechanised and precision weeders;
3. 7-11°; strongly sloping, which limits use of combine harvesters;
4. 11-15°; moderately steeply sloping, which limits two way ploughing;
5. 15-25°; steeply sloping, not suitable for normal crop rotations but occasional ploughing for pasture improvements is possible;

6. >25; very steeply sloping, mechanisation not possible.

Climate is an important consideration in the British adaptation (Bibby et.al., 1969; Olson, 1974), and consequently a sub-class (c) has been introduced to assess climatic limitations on land use. A conventional classification of climate was considered inadequate to assess climatic limitations, therefore three climatic groups (equivalent to a capability unit) were defined. The water balance and temperature during April to September period is used as the criteria for delineating the three climatic groups indicated below:-

Group I where R-PT<100mm and $\bar{\bar{T}}(x) > 15^{o}C$

Group II where R-PT 100-300mm and $\bar{\bar{T}}(x) > 14^{o}C$

Group III where R-PT>300mm or $\bar{\bar{T}}(x) < 14^{o}C$

R is the average rainfall (in mm) and PT is average potential transpiration (in mm) during April to September. $\bar{\bar{T}}(x)$ is the long term average of mean daily maximum temperature. Altitude and rainfall limits have also been introduced as an aid to the recognition of climatic limits to land capability (Bibby et.al; loc.cit.). The limits used are:

1. land over 610 metres;
2. land between 305 to 610 metres with >1520mm rainfall annually;

3. land between 183 to 305 metres with 1270-1520mm annual rainfall;
4. land between 122 to 183 metres with 1016-1270mm annual rainfall.

Although the usefulness of capability units is recognised, capability units have not been defined so far (Bibby and Mackey, 1969).

The system, like the USDA one, assesses land for its capability to support cultivated crops, pasture crops, grazing, forestry and recreation. Since the system is a general purpose one, suitability classes are aimed at reflecting the degree of flexibility in cropping and yield potentials (Hopper, 1974). Arable lands are ranked above non-arable land because it is more flexible (Hopper, 1974). In his justification of this ranking, Hooper (1974), observed that farming operates in the context of changing prices and costs. However, in some places the emphasis on flexibility tends to downgrade less flexible lands irrespective of their possibly high suitability for some few adapted crops. The system assesses the 'potential yields' a land is capable of, this necessitates the assumption of high levels of management. When and where the assumed management levels are not possible to apply the capability classes may not be valid.

The British land use capability classification presents a good example of how the USDA system can be modified to suit local conditions. Inclusion of climatic limitation subclasses (C), the subclass (g) and the revised slope ratings are the main modifications.

Finally, (and the most important contribution of the system, in the author's view) this system introduces the use of a water balance criterion in the capability classification.

2.2.1.3 The Canadian Soil Capability Classification

The Canadian soil capability classification is a part of the Canadian Land Inventory (CLI), a comprehensive survey of land capability and its use, for various purposes, (including agriculture, forestry, recreation, wildlife), and an assessment of the social-economic factors related to land use (CLI, 1969).

In this system, a modification of the USDA system, the soils are ranked according to their general capability to produce common crops based on climatic and soil limitations in a mechanised farming system. The system possesses seven capability classes which are used for grouping the mineral soils. Class V of the USDA system is omitted. Classes 1 to 3 are arable while class 4 is only marginally arable. Class 5 is considered capable of use only for permanent pasture and hay while class 6 is only suitable for wild pasture. Class 7 is for lands incapable of use for arable culture, or permanent pasture. All the classes may be suited for forestry, wildlife and recreation but these uses are not considered in this soil capability classification system (CLI, 1969; Olson, 1974). The capability classifications are then stored in computerized data bank systems (CLI, 1969).

Thirteen kinds of limitations are recognised at the subclass level as follows: adverse climate (C); undesirable soil structure and/or low permeability (D); erosion (E); low fertility (F); inundation by streams or lakes (I); moisture limitation (M); salinity (N); stoniness (P); consolidated bedrock (R); adverse soil characteristics (S); topography (T); excess water (W) and cumulative minor adverse characteristics (X).

The soil capability classification system does not consider the capability unit level. Guidelines given by CLI are of a national scope and may require some modification at regional levels due to the diverse conditions in Canada. Slopes are not emphasised as strongly as in the USDA system. The system unlike the USDA recognises a subclass (F) with low fertility as the limitation.

In its entirety, the CLI program evaluates the suitability for agriculture, forestry, wildlife and recreation and therefore, in this context, it would be considered as a specific purpose system. However, the soil capability classification evaluates land only for agriculture, hence it remains a general purpose system. Due to its computerization the system has the advantage of analysing large volumes of data in a short time.

2.2.1.4 The Zambian Land Capability Classification

This system was adapted from the USDA system through the Federal Department of Conservation and Extension (CONEX), (Mumba et.al., 1978). The system was originally designed to indicate the relative suitability for medium and large scale commercial cultivation of maize and tobacco, but now also includes to a lesser extent soya beans, sunflower and groundnuts using ox or tractor cultivation, and assuming a high level of management (Woode, 1981). The system uses only physical soil characters in class determination, but land may be down-graded on the basis of low chemical fertility. A new land capability class indicating the agroclimatic zone in which the soil is situated is now being considered (Woode, 1981). Economic factors are only considered in very broad terms while the impact of major land improvements on land capability are not considered at all.

Three categories are recognised, viz. types of land, land classes and subclasses (Mumba et.al., 1978). Four types of land are distinguished as follows:-

1. Arable land; which is considered suitable for intensive cultivation;

2. Marginal arable land; which may support intensive cultivation of some crops but with risks of poor yields in unfavourable years;
3. Grazing land; which is incapable of supporting arable cropping but can support grazing.
4. Unsuitable land; which is only capable of supporting wildlife and limited recreation due to severe limitations.

The 'types of land' are subdivided into seven land classes, distinguished on the basis of topsoil (0-20cm) texture. Three of the classes are clayey 'C' and four are sandy 'S'. However, all the land classes are recognised in arable and marginal arable types of land. There is no subdivision of grazing and unsuitable types of land into land classes. Classes C1 and S1 are described as good arable land; classes C2 and S2 as moderately good arable land; classes C3 and S3 as poor arable land and class S4 as very poor arable land. Land classes are further subdivided into sub-classes which reflect the kinds of limitations. The limitations recognised are depth (d), erosion (e), fertility (f), gravel or stones in topsoil (g), large termite mounds (m), rock outcrops (r), slope (s), subsoil texture (t), wetness (w) and gravels or stones in subsoil (z).

The system is not specific to any crop but when the suitability of one crop is needed, reference can be made to conversion tables (Woode, 1981).

The exclusive use of this system creates a problem since only the data relevant to large and medium scale farming are collected (Woode, 1981). Due to its exclusive use the need to conduct comprehensive soil surveys for multipurpose land use is overlooked. Arguments for and against the use of such a system may be presented. Where no changes in land use are expected the system has the advantage that it is rapid, cheap, and thus large areas can be covered quickly. Moreover, many rainfed crops and pasture have similar land quality requirements. On the other hand, where changes in land use are expected, especially those involving heavy investments and/or requiring a consideration of different land qualities to those determined, new soil surveys would be necessary. The choice between conducting comprehensive surveys or less detailed Zambian type surveys will therefore depend on how rapid the latter surveys can be executed and the likelihood of having to repeat the original soil surveys and how often such repetitions may be necessary.

The execution of comprehensive soil surveys in developing countries may be considered a luxury, but this is not the case in the author's view for various reasons. Firstly, in these countries, the optimum uses of the land have not been established, therefore, in the search for the optimum land uses many less detailed surveys may be needed. Secondly, due to increasing populations, the land has to be more intensively used. The risks of degradation of land resources will also increase and the less detailed surveys may lack the data required to establish the necessary inputs and pertinent conservation measures required. Finally, and perhaps most important, there is a need to change the present situation where planners have to make decisions on new land uses without prior knowledge of their suitability in different environments and their environmental impacts. It is desirable therefore, that planners should be provided with possible, relevant land use alternatives from which to choose the best development enterprises. This will ensure that only the promising land use types will be considered and implemented when and where appropriate. Less detailed surveys considering only a few land use types as in the Zambian system, may be lacking in sufficient data to select the most suitable form of land use for a given area.

2.2.2 Specific Purpose Land Evaluation Systems

The specific purpose land evaluation systems, as earlier stated, represents a pragmatic approach in which land is evaluated for specific purposes. This group includes parametric methods, the USBR-land suitability classification for irrigated use and its adaptations, the ecological approach of Beek and Bennema and the FAO 'framework for land evaluation'.

2.2.2.1 Parametric Systems

Parametric methods are those which attempt to include all land qualities influencing the suitability of land for a given use simultaneously in a quantitative analysis (Beek, 1978). In doing this, the parametric methods are limited by difficulties in finding the appropriate relationships between land qualities and land use performance. Due to this difficulty, parametric methods have only been able to include a few land qualities in these equations.

The term 'soil characteristics', 'land characteristics', 'land qualities' and 'factors' have been used interchangeably by authors to refer to the parameters employed in the equations. In this study only the term land quality is used. For example, in the equation

$$A = ax_1 * bx_2 * cx_3,$$

A = performance of a given land use expressed in terms of productivity

x_1, x_2, x_3 = land qualities, viz. the parameter determining performance of a given use.

Originally parametric methods were used only for assessing land for taxation, for example the Storie

Index (Storie, 1937 and 1954 quoted by Olsen, 1974) which was used in California, USA. Nowadays, parametric methods are used to evaluate land for different land uses. For example, the Storie Index has been used for rating the capability of land in the Ventura area, California (Edwards, et.al., 1970).

Riquier (1974) summarized the characteristics of parametric methods as:

1. Evaluating separately the different land qualities and giving them numerical values according to their relative importance in predicting performance;
2. Combining the numerical values of these land qualities in a mathematical expression, taking into account the relationships and interactions between the land qualities to produce a final index of performance for a specified land use;
3. This final index of performance is then used to rank land in order of its suitability for that land use.

Each land quality's influence on performance is considered independently as a mathematical function with the other land qualities being held constant. Then all the land qualities are combined to include their interactions following either (1) an additive, (2) additive and subtractive, (3) multiplicative or (4) more complex, expressions of the form:

$$P = C'x + C''Y + C'''z \quad (1)$$

$$P = C'x + CY - C'''z \quad (2)$$

$$P = (C'x)(C''z)(C'''z) \quad (3)$$

$$P = A(1-(x-b)(y-c)(z+d)) \quad (4)$$

where P = productivity

x,y,z = land qualities, e.g. rootable depth, available water

A,b,c,d = constants

C',C",C‴ = mathematical functions appropriate to each land quality.

Riquier (1974) observed that multiplicative functions appear more realistic and conform to experimental data. Generally productivity is expressed as a percentage of the maximum obtainable productivity when conditions are optimum.

By rating different soils for a particular crop the soil best suited to the crop will be that with highest productivity index. Conversely, if the suitability of a given soil is rated for different crops the crop best suited to that soil can be deduced.

The parametric methods in use employ varying numbers of land qualities using various mathematical expressions. Harradine (in Edwards, et.al., 1970), using the modified Storie Index, considered four land qualities, viz. profile characteristics, texture of surface soil, slope and one other land quality (i.e.

drainage, water table, depth or erosion susceptibility) combined in a multiplicative expression for the Ventura area. Other methods cited by Riquier (1974) include that by Clark (1950), who considered soil texture, depth and drainage in a simple multiplicative formula to obtain a productivity index. In a new system of soil appraisal, Riquier, Bramao, and Cornet (1970) considered seven land qualities in a multiplicative equation to obtain a general productivity index for crops, pasture and forestry. More elaborate methods which combine land qualities in multiplicative, additive and subtractive functions have been developed in Eastern Europe. Riquier cites the Poushkarov Institute's attempt to set up a comprehensive land evaluation method using an additive equation in which several crops are evaluated for separately.

In the humid tropics, the method of Sys and Frankart (1971) is cited by Riquier. In a multiplicative equation, it considers profile development, parent material, depth, colour, drainage, base saturation, pH and the development of the A horizon for assessing the general soil productivity.

Although this method takes into consideration improvement measures it does not compute their influence on productivity. Furthermore, climatic factors are not taken into account in the equation but are assumed to be uniformly hot and humid.

Parametric methods in land evaluation have several advantages over qualitative methods. Firstly, they reduce the subjectiveness associated with qualitative methods since they are quantitative. However, they do so only to a limited extent since the choice of land qualities and their interactions are still subjective. Secondly, the mathematical nature of parametric methods makes them well suited to use with computers and data banks. There are some difficulties associated with parametric systems. Firstly, the influence of, and the type of interactions between some land qualities are not well documented and consequently the interaction relationships can only be approximated. Secondly, and more important, these mathematical expressions, which are merely models, may hinder the comprehension of the true processes which may otherwise be helpful. The methods cited above have not included climatic factors in their equations.

Beek (1978), concluding a review of parametric methods stated that "once all important factors have been identified, the use of complex modelling techniques should improve the ability of parametric methods to calculate the relationship between all the significant production factors and productivity". In the author's opinion, the parametric approach is the ultimate and best evaluation procedure, once such methods have been established and satisfactorily tested.

The Kenya Soil Survey has not used parametric methods in land evaluation. The influence of individual factors on productivity have been studied to some extent, e.g. rainfall in relation to cashew productivity (van Eijnatten, 1979) and the influence of bird resistance of some varieties of sorghum and millet on yields, Dowker (1963). However, mathematical formulae which combine these influences to yield a final productivity index have not been formulated. In the due course it is hoped that parametric systems will gradually be developed and tested in Kenya.

2.2.2.2 The USBR Land Suitability Classification for Irrigated Use

This system was developed by U.S. Bureau of Reclamation to guide the formulation, planning and subsequently to assist in achieving the objectives of irrigation projects. Details of the system are given in the Bureau of Reclamation Manual (USBR Staff 1953; Maletic, 1966; Maletic and Hatchings, 1967). Olson (1974) and USBR Staff (1974) have given summaries of the system.

Land classification is based on an economic criterion, viz. payment capacity which is used to define the basic classes, and is defined as the residue available to defray the costs of water after all other costs have been met by the farm operator (USBR Staff, 1953 and 1974). The productive capacity and costs of both production and land development are assessed to obtain the payment capacity. Productive capacity is estimated from crop's adaptability to and their yield responses under varying soil, topographic and drainage conditions and with specified management practices. Further, the costs of production and land development are estimated from the specified management practices and anticipated land changes respectively. Finally, using these, the estimated payment capacity is calculated. The ranges of payment capacity are then specified for the time and place under consideration.

The economic definition of land classes is translated into physical mappable classes using land characteristics which are selected to reflect the economic classes. Productive capacity, costs of production and land development in a given agroclimatic zone are dependent on soil, topographic and drainage conditions, therefore they are used to define the classes in physical terms. Soil, topographic and drainage conditions are considered in every project but the specific attributes of each land characteristic that are selected for land class specification will depend on their relevance in predicting the payment capacity. The range of each land characteristic determining the land classes will vary with the economic, climatic, technological and institutional factors prevailing in the project area. The land classes thus reflect the local ranking of land for irrigated use, e.g. best suited, moderately, poorly or not suited (USBR Staff, 1974).

Six suitability classes are defined in physical terms and are designed to reflect the extent of limitations and their influence on the range of suitable crops and on payment capacity. Classes 1 to 3 are arable. The level of suitability decreases from class 1 to 3. Class 4 designates a class suited for special uses, e.g. 4F for fruits, or land with excessive deficiencies which economic or engineering studies have shown to be irrigable. Class 5 is a temporary one into which land is placed pending special studies before final classification. Class 6 is land unsuitable for irrigation. Subclasses are used to specify why land was not placed in class 1 and are based on soil deficiency (s), topographic deficiency (t), and drainage deficiency (d). The seven subclasses recognised are based on deficiencies in s,t,d,st,td and std.

The system provides general principles which can be used to classify land according to the economic and physical conditions prevailing in the project areas. The ranges in payment capacity defining the classes are selected for the local climatic zone and prevailing economic conditions, and hence this system is flexible for use in other areas and reflects the local ranking of land.

The system has one major difficulty that it is based on an economic criterion, yet the data required for economic analysis may often be lacking in a given project area. Moreover, the use of payment capacity criterion may not be appropriate. For example, where a farm operation is not required to meet the costs of land development, the payment capacity defined by the system cannot be used without modification. Secondly, the defined ranges in payment capacity are based on established adaptability and yield responses of crops under varying soil, drainage and topographic conditions. Yet these responses are not available in some developing countries.

The difficulty of applying an economic criterion in Kenya has been illustrated in a proposed classification system (Muchena, 1980). The proposed system was aimed at classifying the semi-arid lands of the Tana River Basin for irrigation. Faced with a lack of yield data, Muchena has used purely physical criteria. Soil characteristics, drainage conditions, topographic features and vegetation density were used as class determining factors. The specific land characteristics considered were texture, depth, alkalinity and salinity as soil characteristics, slope percent, micro and macro relief as topographic characteristics, drainage conditions of profiles and density of woody cover as a vegetation characteristic.

Five suitability classes have been recognised in the proposed system, viz. highly, moderately and marginally suitable, provisionally not suitable and not suitable. For each suitability class, land class specifications have been erected for each land characteristic. Suitability classes for cotton, rice and the commonly grown crops, viz. maize, beans, sugarcane and peanuts have been defined using separate land class specification ranges. The land classes reflect decreasing limitations from highly suitable to not-suitable. They also reflect in a qualitative way the productivity and implied economic constraints of development as influenced by the physical limitations.

2.2.2.3 Land Suitability Classification for Irrigation in Iran

The system was developed by the Soils Institute of Iran to provide a preliminary assessment of lands suitable for irrigation. It was also meant to indicate the present limitations and degradation hazards with respect to soil salinity, alkalinity, topography and erosion, (Soils Institute of Iran, 1970). The system is qualitative and is based on physical criteria although some economic factors are broadly considered. These include the productive capacity, cost of production and cost of required land development.

Four limitation categories are recognised, viz. those of soil, soil salinity and alkalinity, topography and erosion, and drainage. Both correctable and non-correctable limitations are weighted equally. The limitation categories are subdivided into types of limitations. The types of limitations related to the soil include infiltration rates, soil depth, topsoil stoniness and subsoil permeability. Those related to topography and erosion are overall slope, maximum transverse slope, macro relief and present erosion status. Drainage limitations include depth to the ground water, inner drainage, ponding and flooding hazards. The degree of limitations are used in determining the suitability classes of land for irrigation. Four suitability classes are recognised, ranging from class I, most suitable with least limitations to class IV, least suitable. The most severe limitation determines the suitability class. The range of suitable crops or expected yield decreases from class I to class IV.

This system does not however consider:-

(a) the quantity and quality of irrigation water and the location of the water source in relation to the land to be irrigated.

(b) the suitability of land when some land improvements are made

(c) the distance to the market.

Moderately high levels of management are assumed and the classification is developed for the sustained profitable irrigated farming of common cereal and industrial crops under gravity irrigation.

2.2.2.4 Land Suitability Classification - An Ecological Approach

The ecological approach of Beek and Bennema (1972) was developed during, and following, a resource study in Latin America. Its principles and concepts were discussed in the Background Document (Brinkman and Smyth, 1973), and subsequently adopted in the 'framework for land evaluation' (FAO, 1976).

The ecological approach systematically relates the physical land qualities (or attributes) with the ecological, agricultural and other requirements of plants or other land uses. This practical approach results in a technical classification for certain defined agricultural land uses (Beek and Bennema, 1972), and provides:

1. alternative uses of the same land;
2. a flexibility which allows easy revision to include any land uses not previously envisaged and;
3. a multidisciplinary co-operation in solving land use problems.

Basic in this approach is the idea that land should be rated on its value for a specific purpose since there is no absolute and generally accepted value of land (Beek and Bennema, 1972). The land utilization type (LUT) concept, (Beek, 1972) is used to define the uses of the land. A land utilization type is a specific way of using the land, described for the purpose of land evaluation in terms of key attributes. Some key attributes are produce, capital, labour, levels of technology applied and infrastructural requirements. Land qualities are then used to assess the suitability of land for each LUT and only those land qualities relevant to a given LUT are considered. This represents a departure from the USDA Land Capability System which considers all land characteristics for a general use in all places. The land qualities are rated and'conversion tables' are used to assign the land quality ratings to each land suitability class for each LUT in turn. Although the approach appears quantitative, suitability classification is based on conversion tables which are qualitatively constructed.

The evaluation procedure involves three steps, firstly the collation of data on land resources resulting in the delineation of land units. Secondly the data on human requirements and the environmental conditions necessary to define the LUTs are gathered. The latter proceeds together with the former since the data needed for evaluation are better known when the LUTs are defined, (Beek and Bennema, 1972). The third and final step is matching and consequently the grading of land qualities with the requirements of the LUTs.

Assignment of suitability classes depends on how best the land qualities meet the major requirement of LUTs. Land is designated as 'Suitable' when it fully meets the major requirements, and as 'Not-Suitable' when it does not meet one or more major requirements. Intermediate classes are assigned when major requirements are only partially met. When and where major land improvements are required, the land is rated on the basis of potential suitability assuming the improvements have been effected.

Either the "parallel" or the "two stage" approach of integral land evaluation may be followed. In the two stage approach physical land evaluation is followed by an economic analysis while in the parallel approach both the physical land evaluation and the economic analysis proceed concurrently, (Beek and Bennema, 1972).

The major limitation of this approach is that the requirements of LUTs in terms of land qualities are not well known. Therefore matching processes and construction of conversion tables are based on guesses or assumed relationships.

2.2.2.5 The Framework for Land Evaluation

The need to standardize the different methods of land evaluation practised in different countries to allow exchange of information between areas with similar environments led to the initiation of two international committees and the preparation under the auspices of FAO of a 'Background Document' containing proposals for a framework of land evaluation, and papers on the existing land evaluation systems. Subsequent discussions resulted in agreement on most of the principles of the proposed framework for land evaluation (Brinkman and Smyth, 1973) and led to the publication of the 'framework of land evaluation', (FAO, 1976).

In the 'framework' land evaluation is based on 'physical land attributes, in so far as these affect economic and other inputs, outputs and benefits within the context of specific land utilization types, protection and enhancement of environment and social-economic conditions', (Brinkman and Smyth, 1973). Two points about the nature of the framework are emphasised (FAO, 1976; page 7). Firstly, the framework is in itself not a system but a set of principles and concepts on which basis local, regional and national systems can be constructed. Secondly the framework is intended for universal application and covers all aspects of rural land use.

The principles fundamental to the approach and methods employed in the framework are:-

(i) land suitability is assessed and classified with respect to a specified kind of use;

(ii) evaluation requires a comparison of benefits obtained and the inputs needed on different types of land;

(iii) a multidisciplinary co-operation is required;

(iv) evaluation is made in terms relevant to the physical, economic and social context of the area concerned;

(v) suitability only refers to use on a sustained basis and;

(vi) evaluation involves a comparison of more than one use.

The LUT concept (Beek, 1972) is employed to specify the land uses. The degree of specification or refinement of the use depends on the intensity of the evaluation, for example major kinds of use are defined in reconnaissance evaluations and LUTs in detailed and semi-detailed evaluations. Land characteristics are used to delineate land units but due to the interactions between them, they are not employed directly in suitability assessments. Land qualities, which act in a distinct manner in their influence on the suitability of land for a specific use, (Bennema, 1972) are used as the diagnostic criteria. A diagnostic criterion is a variable which has an understood influence upon the output, from, or required input to, a specific use and which serves as a basis for assessing the suitability of an area for that use (FAO, 1976). In the "Matching Process", defined as the process of mutual adaptation and adjustment of the description of LUT and the increasingly known land qualities (FAO, 1976), the physical requirements of LUTs are compared with the land conditions. The matching process results in a prediction of land use performance.

Four suitability categories are recognised, viz. orders, classes, subclasses and units. The orders reflect the kinds of suitability while classes reflect the degree of suitability within the order. Subclasses reflect the major limitations and/or major improvements required within classes, while units, a subdivision of subclasses, reflect minor differences in management requirements.

Two orders are defined, order Suitable (S) and order Not-Suitable (NS). The former consists of land on which beneficial and sustained use is possible without unacceptible risks. The order Not-Suitable consists of lands whose land qualities preclude sustained use of the kind under consideration. Five classes are recognised, three of them, viz. S1, S2, and S3 in the order Suitable (S) which reflect decreasing suitability from S1 to S3 of the lowest suitability. The other two classes, viz. NS1 and NS2 are in the order Not-Suitable. Class NS1 consists of lands whose limitations are surmountable in time, but not correctable with existing knowledge at acceptable costs. Class NS2 consists of lands whose limitations preclude any possibilities of sustained use in the given manner.

The number of subclasses recognised and the limitations chosen to distinguish them depends on the purposes of the classification. However, both the subclasses and their limitations should be restricted to the necessary minimum required to reflect management requirements or their potential for improvement. Class S1 has no subclasses whereas classes in order Not-Suitable may have several subclasses. The number of units recognised depends on the variations in the minor management requirements or production potentials, but these too should be restricted to the necessary minimum. The designation Conditionally-Suitable may be used in certain instances to condense and simplify presentation, and is usually applied in cases where small parts of the survey area may be unsuitable for the specified management practices but suitable when certain conditions are met. This designation is equivalent to class V and class 5 of the USDA-SCS and USBR systems, respectively.

Briefly, the 'framework' recommends the following evaluation procedure:- first, initial consultations are held to establish the objectives, and data and basic assumptions on which the evaluation is to be based. Secondly the possible and relevant LUTs or major kinds of use are described and their requirements established. Land mapping units and the relevant land qualities are described and subsequently a comparison of land uses and the types of land present is made by the process of matching. Social-economic analysis is then carried out (in case of two step integral land evaluation). A land suitability classification is made and finally the results are presented. The results should include:-

- a description of physical and socio-economic context of the study area;
- a description of the 'uses' relevant to the area;
- maps, tables, and textural matter showing the degrees of suitability of the land mapping units for each relevant use together with the diagnostic criteria;
- management and land improvement specifications for each use in each suitable land mapping unit;
- economic and social analysis of the consequences of the uses considered and;
- the basic data and maps on which the evaluation is derived, together with information on the reliability of the evaluation.

The 'framework' is both comprehensive and elaborate. Its flexibility allows for easy revision of outdated evaluations. Moreover, it places a lot of emphasis on social-economic conditions of the area under study. It evaluates land for all the uses which appear socially relevant and physically viable. Its full exploitation however, requires a multi-disciplinary approach which may be difficult to organise, nevertheless it combines the advantages of all the other systems except the quantitative assessments of the parametric methods but which can be incorporated in the framework. Unlike the USRB system, suitability classes in the framework are based on physical criteria which may subsequently be translated into economic terms (in integral land evaluation) provided the data needed for an economic analysis is available.

The degree of suitability of land is based on the benefit/input ratio. Estimation of benefits and inputs is the major constraint in the application of the framework. Three procedures of estimating benefits and inputs are generally used (FAO, 1976) viz:

(a) Direct methods, e.g. from trial sites in the study area;

(b) Simulation methods employing mathematical models which establish relationships between benefits and diagnostic criteria;

(c) Empirical methods based on assumed relationships between benefits and diagnostic criteria.

Direct methods are quantitative and would be preferable, however, they are both expensive and time consuming, especially where trials do not exist previously. Costs are increased where many alternative LUTs are considered. Simulation methods depend heavily on availability of reliable data on which to base the models. This data is often lacking in developing countries. The third method, which involves construction of conversion tables is the one commonly used. Although this method may be quantitative in outlook it is essentially a qualitative one. It also requires some data on trials to indicate which of the possible relationships between benefits and diagnostic criteria is applicable. The major constraint with empirical methods is that so far there is no simple, quick and a cheap method of testing the conversion tables except the qualitative field checks with farmers' experiences. This is also expensive in terms of cost and time required. The flexibility and specifications in the framework however makes it particularly suited for global application.

2.2.3 Land Evaluation in Kenya

Reconnaissance surveys in Kenya are carried out as a systematic inventory of land resources to serve multipurpose land use planning. Detailed and semi-detailed resource surveys are also carried out for specific projects and farm planning.

To evaluate land for these various purposes the KSS follows closely the principles and concepts outlined in the framework for land evaluation.

2.2.3.1 The use of the Framework for Land Evaluation in Kenya

Since its inception, the KSS has used the 'framework' in its land evaluation. Nyandat et.al (1978) observed that the framework as developed by FAO had been modified and adapted to suit Kenyan conditions. However, this observation is incorrect since, as emphasised earlier (section 2.2.2.5), the 'framework' is only a set of principles and concepts on which local systems can be constructed.

In Kenya, the LUT concept is used to specify the uses. Each LUT is defined using the key attributes produce, capital intensity, labour intensity, level of technology applied, farm power, farm size, land tenure, price structure, infrastructural requirements and location of the area. Agroclimatic zones are used to identify land areas with fairly homogeneous social-economic conditions for which given LUTs are relevant.

The land resources surveyed usually include soils, climate, topography, vegetation and present land use. The study of various land characteristics leads to the identification of land qualities relevant in the study area for the uses envisaged. These land qualities are subsequently studied and rated according to 'proposals' which were devised for that purpose (van de Weg, et.al., 1974 and 1977; Muchena, 1980). The land qualities are used as the diagnostic criteria in assessing the suitability of mapping units for particular LUTs.

The proposals for rating land qualities are meant for use in all parts of the country and therefore all ranges of every land quality should be covered by the classes. So far this requirement is broadly fulfilled. However, a few criticisms can be levelled at the 'proposals'. In the rating of the available moisture storage capacity, the proposals require that the final rating classes be downgraded on the basis of 'hindrance to root development'. The downgrading criteria is not defined in terms of measurable properties, furthermore since the effective rootable depth has been considered in the available moisture calculation for the profile, the downgrading may not be necessary.

In the rating of natural fertility some important properties are omitted. For example, although high Al-saturation causes infertility due to both its toxic effect on crops and phosphorus fixation it has not been considered in the 'proposals'.

Although total nutrient content may be useful to indicate the potential soil fertility, it does not indicate how much of the nutrient is available nor its rate of release to the plants. Consequently the total cation content may not deserve the 'weight' it has been accorded in the 'proposals'.

In the rating of resistance to erosion, a few subratings do not seem to conform to reality. For example, the influence of climate on erosion hazard is rated using agroclimatic zones (defined in section 4.3.4) as shown below:

Rating	Agroclimatic zone
0	I and II (most resistant)
1	III
2	IV and V (least resistant)·

The presence of natural vegetation is assumed, however, since some LUTs involve cultivation the natural vegetation cover will be cleared and erosivity becomes the most important factor. Rating of climate then does not seem relevant. Instead the erosivity of rainfall should be rated. To do this Moore's regression equations, which relate soil loss to annual rainfall (Moore, 1979) may be used. These equations show that agroclimatic zones should be rated in the reverse order to that given by the KSS.

The proposal views longer slopes as being more resistant to erosion than shorter ones whereas in practice we reduce slope lengths to reduce the erosion losses. Therefore the rating on slope length needs to be reversed. The 'proposals' gives equal 'weighting' to organic matter, flocculation index, silt/clay ratio and bulk density in the topsoil in the rating for erodibility. In practice the contributions of soil properties to the erodibility of a soil are not equal as reflected by the different correlation coefficients obtained between these properties and soil losses. It therefore seems desirable to establish the contribution of each factor to the erodibility. This would justify the use of more important properties and secondly would accord them the appropriate 'weighting'.

Only the empirical methods have been used in Kenya to estimate the benefits and inputs. Construction of conversion tables has been and still remains the major limitation in the evaluation process. Lack of precise data on the requirements of LUTs coupled with lack of the desired multi-disciplinary approach increases the problem of constructing reliable conversion tables. The existing conversion tables needs to be tested but so far due to the lack of a suitable, cheap and quick method to test them, they have not been tested in Kenya per se.

Despite the difficulties outlined above, in the author's opinion, the use of the framework has been successful to some extent but there is a need to revise some of the land quality ratings and to check the suitability classes obtained from conversion tables against the farmer's experiences in the field.

Urban

2.2.3.2 Land Evaluation Studies in Coastal Kenya

Land evaluation studies carried out in the coastal area of Kenya up to the early 1970's were aimed mainly at assessing soil suitability for arable settlement schemes. They include the surveys carried out by Edward and Bellis (1952), Nyandat (1969), Averley (1970) and others. Makin (1968) and Nyandat (1975) assessed the suitability of soils for cash crop development with special reference to tobacco, coconut, and sugarcane. In these studies the suitability was descriptive and no suitability classes were assigned. Only soil characteristics were considered. Previously, evaluation of the problems facing the coconut and cashewnut industries were the subject of several commissions, but these were mainly social-economic in nature and placed little or no emphasis on the physical suitability of the soils.

The KSS, as a part of its long term reconnaissance survey program aimed at multipurpose land use planning, carried out a land evaluation of the Kwale-Lungalunga area (Michieka et.al., 1978). The principles and concepts of the framework as described in section 2.2.3.1 was employed in the evaluation. Agroclimatic zones were used as land units with fairly homogeneous social-economic conditions for which the defined LUTs were relevant. The LUTs considered in this evaluation were described in a consultancy report by de Jong (1977) and are listed below:

1. Small-holder rainfed arable farming - traditional technology
2. Small-holder rainfed arable farming - intermediate technology
3. Small-holder rainfed mixed farming - traditional technology
4. Small-holder rainfed mixed farming - intermediate technology
5. Extensive range management
6. Large scale rainfed sugar cane production - intermediate technology
7. Large scale rainfed tree crop growing - intermediate technology
8. Small-holder irrigation
9. Forestry
10. Tourism

However, since the traditional level of technology at the Coast is gradually being replaced by an intermediate level the LUTs described at the traditional level of technology were not considered in the evaluation (Michieka et.al., 1978). Land fragmentation, small farm sizes and the lack of irrigation water also excluded large scale enterprises and irrigation LUTs respectively from the evaluation (Michieka et.al., 1978).

Problems encountered in the evaluation for LUTs 2 and 4 were given by Michieka et.al (1978) as:

1. Crops in the same LUT may have different soil and climatic requirements therefore the most demanding crop will dictate the suitability for the LUT. This downgrades the suitability for the less demanding crops.
2. The presence of complicated soil patterns in the Kwale survey area allows for certain degree of adjustment of crops to soil patterns, e.g. cashew on well drained, deep sands and maize on well drained sandy clay soils.

Due to these problems the LUTs were simplified into individual crops, i.e. simple LUT's, namely coconuts, cashewnuts and maize for evaluation purposes.

The Chonyi-Kaloleni area borders the Kwale area and the social-economic conditions are similar in both areas. Consequently the LUTs and some of the limiting land qualities in the Kwale area are relevant in the Chonyi-Kaloleni area. It is therefore worthwhile considering the definition of the intermediate technology, LUT's, the land qualities considered and the most limiting land qualities in the Kwale area.

Intermediate level of technology implied

a) for maize - the use of selected, possibly hybrid seeds
- full plant population density
- timely planting with adequate weeding

- modest fertilizer application and crop rotation

b) for cashewnuts
- the use of selected planting material
- correct spacing and bush control
- some measure of pest and disease control
- timely harvest

c) for coconuts
- the use of selected planting material
- correct spacing and bush control
- some measure of pest and disease control
- some modest fertilization

In the above specifications for the intermediate level of technology the selected planting materials are not specified. These should be specified using any present or future research findings at the Coast Agricultural Research Station.

The land qualities used as diagnostic criteria in the Kwale area were climate-agroclimatic zones, soil moisture storage capacity, soil chemical fertility, possibility for use of agricultural implements, resistance to erosion, hindrance by vegetation, presence of overgrazing, soil depth (for foothold of plants) and presence or hazard of waterlogging. Some of the land qualities are difficult to quantify and interpret. For example, it is difficult to interpret climate (in terms of agroclimatic zones) per se but if the climatic characteristic, rainfall and available soil moisture storage capacity are considered together, the land quality available moisture (or moisture deficits) can be used to evaluate the suitability for a given crop through a water balance approach.

A detailed land evaluation study (scale 1:12,500) was carried out for Kaloleni-East area (Bouwman, 1980), which borders the present study area. The evaluation procedure used in Kwale was employed here, but at the large scales employed the LUTs in this detailed study merged into 'farming systems'. In the LUT descriptions the attribute produce was defined in terms of the relative importance of crops expressed as percentages occupied by the crops. The market orientation was considered in broad terms, e.g. subsistence or industrial crops. The labour criteria placed more emphasis on the source rather than the quantity, capital intensity was given in terms of current and recurrent inputs, e.g. seeds, and types of tools for the former and latter respectively. The technical knowledge and land tenure were also described. The latter was grouped into the categories privately owned, rented land, borrowed land or communal land. In all, thirteen LUTs were described and the suitability of land for these 13 LUTs was assessed using the following land qualities, viz. availability of water, nutrients, and oxygen, possibilities for mechanisation and animal traction, soil resistance to degradation and erosion and the availability of drinking water.

In this detailed study no mention was made of any problems associated with evaluating land for a compound LUT consisting of several crops as was the case in Kwale. Furthermore, the suitability class determining crop was not specified. Since in many parts of Kenya (including the Coast) 'inter-cropping' is the rule rather than the exception, problems similar to those encountered by Michieka et.al (1978) are likely to occur in all areas where land evaluation is carried out for compound LUTs consisting of several crops. To overcome this difficulty, it would be preferable to assess the physical suitability of land for individual crops - simple LUTs. Crop combinations may then be selected taking into consideration their physical suitability, the interaction between the crops, social-economic needs and the type of conservation measures they require. The selected crop combinations would then constitute a compound LUT which may then be evaluated for in economic terms.

2.3 CHARACTERISTICS AND REQUIREMENTS OF SELECTED SIMPLE LUTs

In this review only the characteristics and requirements of the 'simple' land utilization types *anacardium occidentale L.* (cashew), *cocos nucifera* (coconut) and *zea mays* (maize) are considered.

2.3.1 *anacardium occidentale L.* (cashew)

The requirements of cashew, especially soil conditions and rainfall are scarce in the literature and when they are found they are often vague.

2.3.1.1 Plant Characteristics

The cashew tree is an evergreen perennial which when growing under favourable conditions, and unharmed by pests has an erect stem, symmetrical and umbrella shaped canopy (Ohler, 1979). The tree attains a height of about 15 metres and a canopy diameter of 12 metres (Acland, 1971; Ohler, 1979). Under less favourable conditions the trees are much smaller. Where the shoots are destroyed by insects the trees may only have short stems and be heavily branched. The conditions of growth therefore influence the appearance of the tree.

The root system is very extensive with a tap-root which penetrates deeply into the soil. In mature trees, the lateral spread of roots may be twice the diameter of the canopy. Adams (1975, cited by Ohler, 1979) observed that the lateral roots grow quickly in a young seedling and are produced progressively lower on the taproot as the latter elongates. Root studies in Nachingwea, Tanzania, Tsakiris and Northwood, (1967) showed that the trees can utilize large volume of soil due to both the vertical and lateral spread of its roots. For trees 3½ and 4½ years old, the taproots had descended 2.5 and more than 5.0 meters, respectively. The lateral spread was 1.2, 5.6 and 7.3 meters for 1½, 3½ and 6 year old trees, respectively. For all the trees the horizontal laterals tended to concentrate and fully exploit the top 12cm of soil, (Tsakiris and Northwood, 1967). The root system was better developed when the trees were not planted in holes.

The growing conditions determined the age at which the trees start to flower, consequently various authors report differing ages but 3 years is generally accepted as the age when trees produce fruits worth harvesting (Ohler, 1979). Flowering occurs after the rainy season. The fruits are produced at the surface of the canopy (Ohler, 1979; van Eijnatten, 1977). The pattern of flowering is determined by the rainfall pattern and varies from year to year and from one location to another. In East Africa flowering is from June to January with a peak in August to October (Acland, 1971). Flowering to nutfall takes 55 days and therefore harvesting is from August to March with a peak in October to December, (Acland, 1971). At the Kenya Coast, flowering is from August to September, maturation from September to October and harvesting in November to December (van Eijnatten, 1979).

2.3.1.2 Ecological Requirements

Although cashew trees are found as far south as 24°S and as far north as 25°N, commercial production is restricted to within 15°N and S (Ohler, 1979). The maximum altitude for cashew growth is latitude dependent (Ohler, 1979). In Songea, Tanzania, it grows at 1000 metres above sea level while in Assam, India (25°N) the maximum altitude is 170 metres above sea level. In Kenya, cashew thrives best from 0 to 600 metres above sea level (Warui, 1979). Flowering and harvesting however are delayed by increase in altitude, (Ohler, 1979).

Cashew requires high temperatures throughout the year. It grows under temperatures ranging from 7° to 40°C. Important cashew growing areas however have daily maximum and minimum temperature ranges of 25 to 35°C and 15 to 25°C, respectively. The optimum average monthly temperature is 27°C (Ohler, 1979). Cold periods reduce the production and commercial production is expected only in areas with average annual temperatures above 20°C.

Cashew is a drought resistant perennial but the degree of resistance depends on the volume of soil available per tree, the available moisture storage capacity and the possibility of roots reaching the phraetic water level. The rainfall requirement of cashew is quoted to range from 500 to

4000mm but the yields under these extreme conditions are not stated. The commonly stated ranges are 1000 to 2000mm with a dry period of 4 to 6 months (Ohler, 1979), 750-900mm (Acland, 1971) and 500-1200mm (Warui, 1979). Van Eijnatten (1979) analysing the relationship between yields at the Kenya Coast and annual rainfall at Mtwapa arrived at a range similar to that of Acland (1971). In his analysis, van Eijnatten found a close negative correlation between cashew productivity and annual rainfall. Monthly, bimonthly and trimonthly rainfall periods could however not be significantly correlated to the yields, although almost significant correlation were found for these periods in the latter part of the year during which flowering and harvesting takes place. Separation of years with more than 1000mm rainfall and those with less than 1000mm rainfall revealed that cashew yields increase with increase in rainfall to a threshold of 1000mm after which the yields then decline . Assuming that the negative correlation with rainfall beyond 1000mm can be established for other stations, then the rainfall requirements of cashews at the Coast would be expected to be in the range of 600 to 1000mm.

Cashew tolerates long periods of low relative humidity but very low values cause the leaves to wither and fruits to dry, resulting in reduced yields. Extremely high humidity cause fungal attacks, for example *colletotrichum glocosporiodes* which is common in humid areas (Ohler, 1979). Cashew also needs a high number of sunshine hours all year round.

The scarcity of data on the soil requirements of cashews in the literature is probably due to its vast adaptability to different soil conditions. It thrives well on soils ranging from poor sands to sandy clay loams (Acland, 1971). Poorly drained soils are not suited to cashewnuts. Heavy clays, compacted, hard pans restrict root development hence reducing resistance to drought. Shallow soils are not suited to cashewnuts. The best soils for cashewnuts are therefore the well drained, sandy soils without hard pans and with a phraetic water level at 5 to 10 metres depths (Ohler, 1979). The cashew trees have a tolerance limit of 12-15 mS/cm but there are variations between trees (Ohler, 1979).

2.3.2 *COCOS NUCIFERA* (coconut)

There are several coconut varieties. At the Kenya Coast the 'Tall type' (Child, 1964) also called 'Kenya Tall' is most predominant but 'dwarf' varieties are also grown, (van Eijnatten et.al., 1977). Only the Kenya Tall is referred to in the following description.

2.3.2.1 Plant Characteristics

The coconut has a normally non-branching trunk which grows to 20 to 25 metres in mature trees (Fre'mond et.al., 1966; Child, 1964). In East Africa, the mature trunks are normally 15 to 20 metres (Acland, 1971), but van Eijnatten (1980, CARS II) observed an average height of 4.55 metres in some fourteen year old trees at Mtwapa. The trunk starts to form 5 years after planting (Child, 1964). At its base the trunk may thicken into 'the bole' a part of which is buried in the soil, while at the apex the terminal 'bud' occurs which is the sole growing point of the trunk. The trunk is generally uniform in diameter but variations may occur, reflecting fluctuations in climate, cultural and nutritional conditions through which the palm has undergone (Fre'mond et.al., 1966; Child, 1964). At the top is a radiating crown of leaves with a bud at the apex surrounded by rolled leaves. The number of un-rolled leaves in a palm varies but numbers 30 on average (Fre'mond et.al., 1966; Child, 1964; Acland, 1971). Van Eijnatten et.al. (1977) found an average of 23 leaves in Tezo Roca and 31.5 leaves in Mtwapa (van Eijnatten et.al., 1980; CARS II). The length of mature leaves ranges from 5 to 6 metres (Menon, 1958; Child, 1964 and Fre'mond et.al., 1966). At the Kenya Coast van Eijnatten (1980; CARS II) confirmed this length. On either side of the midribs, leaflets 0.9 to 1.37 metres long when mature, are borne. The number of leaflets ranges from 200-230 (Fre'mond , et.al, 1966) and a new leaf unrolls every 20 to 33 days and falls within 2½ to 3½ years (Acland, 1971 and van Eijnatten et.al., 1977). The palm begins to flower six years after planting (Menon, 1958; van Eijnatten et.al., 1977) and produces 12 inflorescences annually (Acland, 1971). The duration from pollination to maturity is about 12 months with nut abortions occurring within 3 months of nut formation.

The coconut has no taproot but has adventitious roots of uniform thickness which are continuously produced from the 'bole' (Child, 1964). The number of roots range from 1500 in young trees to 11,000 in old trees with an average of 4,000 (Menon, 1958). Although branching is rare, three root orders are reported, viz. first, second and third orders (Menon, 1958; Fremond et.al., 1966). The lateral spread of roots is commonly 5 to 10 metres (Menon, 1958).

In freely rootable soils, the root penetration depends on the nutritional status and availability of moisture. Normally roots penetrate to 3 to 4 metres depth and in places to the water table 6 metres deep (Menon, 1958). In Chonyi-Kaloleni survey area roots were found to penetrate to 4 metres. The majority of roots concentrate in the top 0.9 to 1.5 metres. The main absorptive power is in the third order and at the root tip since both the second and third order roots are impermeable. Davis (1959) and Pandalai

(1960), cited by Fre'mond et.al (1966) observed that coconut has an extreme capacity for adaptation, which enables it to make a thorough exploitation of the full volume of soil a planting site makes available provided the soil is receptive to roots.

2.3.2.2 Ecological Requirements

In Africa although individual trees are found as far north as 24^{o}N and as far south as 25^{o}S, commercial production is restricted to within latitudes 15^{o}N and 15^{o}S (Child, 1964). The maximum altitude for coconut growth is latitude dependent. Thus in Bangalore, India (13^{o}N) the maximum altitude is 900 metres while in Tabora, Tanzania coconuts are grown at 1220 metres altitude (Child, 1964). Nearness to the sea is not a necessity (Fre'mond et.al., 1966).

The optimum temperature for coconut is 27^{o} to 28^{o}C with a mean maximum and minimum of 30^{o} and 20^{o}C, respectively, and a minimum diurnal variation of 12^{o}C (Fre'mond et.al., 1966; Child, 1964).

Rainfall requirements of coconut have been quoted to range from 1000 to 2300mm, (Acland, 1971; Menon, 1958; Fre'mond et.al., 1966; van Eijnatten, 1977). The monthly requirement is 130mm with a maximum of three dry months with less than 50mm rainfall. Thus coconuts require a minimum of 1320mm well distributed annual rainfall. Coconuts grown north of Mombasa and beyond 10 kilometres inland occur under marginal conditions, van Eijnatten et.al. (1977). The topographic positions where coconuts grow are important in areas where rainfall is short of this minimum requirement.

Other ecological requirements are 2000 insolation hours, a relative humidity of 80 to 90% which should not fall below 60% (Fre'mond et.al., 1966). These requirements are normally satisfied at the Kenya Coast.

Coconuts grow on a wide range of soils. The major soil requirement is that the soils be well drained. Physical soil characteristics are considered more important than chemical properties (Fre'mond et. al., 1966; Child, 1964). A deep, well drained soil is suitable for coconuts and the extent to which a soil approaches this condition determines the volume tapped by roots for nutrients and moisture (Fre'mond et.al., 1966). The minimum depth for good coconut growth is 80 to 100cm. The texture of coconut soils is very variable, ranging from 100% sand to 70% clay in mineral soils. Coconuts are also grown on organic soils with up to 80% organic matter, however due to shrinking in these soils they are not very suitable (Child, 1964). The soil pH of coconut soils is variable. In the Philippines, Coke (1936, cited by Child, 1964) recorded a pH range of 6.2 to 8.3 for a poor and high yielding clay and coral sand, respectively. A high yielding volcanic soil had a pH of 7.0. In India, Menon (1958) recorded a pH range of 5.2 to 8.0. Thus the pH ranges from 5.2 to 8.3 in coconut soils. Low pH soils are more likely to show deficiencies in potassium, calcium and magnesium (Child, 1964).

Presently, soil analyses are of very limited value in forecasting the fertilizer requirements (Child, 1964; De Gaus, 1973). A few cases where mineral deficiencies are most likely have however been identified. Thus, when the exchangeable potassium content is less than 0.02 me/100g soil response to potassium fertilizers can be expected. When phosphorus is less than 40 ppm (Truog method) responses are also expected but not when the soil phosphorus is more than 100 ppm (Truog method) (Child, 1964). Good responses are expected in soils with less than 0.02% nitrogen per year (De Gaus, 1973) and the average removal of nutrients at the Coast per palm per year in grams are 429, 64 and 590 of nitrogen, phosphorus and potassium, respectively (van Eijnatten et.al., 1977). The major nutrients required by palms are potassium, nitrogen, phosphorus, magnesium and calcium in that order.

Authors are generally agreed that foliar analysis is a better tool for determining the coconut nutrient requirements than soil analysis since the nutrient levels in the leaves are better correlated with yields.

2.3.3 Methods of assessing land suitability for coconuts and cashewnuts

Water balance calculations have been used to assess the suitability of land for various crops. The balance between rainfall and potential evapotranspiration is used as a simple index of moisture availability and hence of land suitability for a particular crop. More elaborate water balance calculations take into account the available moisture storage capacity (AMSC) of the soil, decrease in moisture availability as the stored moisture is depleted and estimates of effective rainfall. Four examples of simple water balance calculations for both cashew and coconuts are relevant here.

In West Africa, Fre'mond et al. (1966) compared the suitability of Port Buet and Seme Podji for coconuts through a water balance calculation. Thornthwaite's formula was used to estimate the potential evapotranspiration (PET). In the absence of determined crop factors (ET/PET), values ranging from 0.3 to 1.0 were used to estimate the actual evapotranspiration. The magnitude and duration of moisture deficits were used to assign a higher suitability to Port Buet than to Seme Podji. Port Buet experienced moderate moisture deficits in 5 out of 12 months while Seme Podji experienced severe moisture deficits for 9 out of 12 months. This suitability classification was confirmed by higher yields in Port Buet than in Seme Podji .

In Trinidad, Smith (1968) calculated the integrated moisture deficits for coconuts using Thornthwaite's formula. Correlation coefficients between copra yields and moisture deficits and rainfall were calculated for selected periods before the year of harvest. Over the same periods, copra yields were better correlated to integrated moisture deficits than to rainfall (cf -0.81 and -0.78 for moisture deficits 29 and 24 months preceeding the year of harvest and 0.64 and 0.44 for rainfall over the same periods, respectively).

At the Kenya Coast, van Eijnatten (1980) investigated the cashew productivity in relation to rainfall. He calculated the correlation coefficients between yields (average kg/ha for Coast Province) and total annual, monthly, bimonthly and trimonthly rainfall at Mtwapa. Two conclusions are of interest from this study. Firstly, yields were positively correlated to annual rainfall during the years with less than 1000mm. Secondly, monthly, bimonthly and trimonthly rainfall were not significantly correlated to yields. However a nearly significant negative correlation was obtained for these periods in the latter half of the year. The nearly significant negative correlation in the second half of the year was attributed to the harmful effect of rainfall during this period on flowering, fruit maturing and harvesting. Moisture deficits were not calculated in this study.

At Nachingwea, Tanzania, Dagg et.el. (1967) investigated low yields of cashew nuts when canopies touched, through a water balance approach. Various spacings were taken into account in the moisture deficit calculations. Penman's estimate of open water evaporation and transpiration factor (ET/Eo) values ranging from 0.5 to 0.85 were used to estimate the actual evapotranspiration. Assuming a 10 feet rooting depth, this study showed that when canopies touched trees experienced higher moisture deficits resulting in low yields. This conclusion is likely to be also true for higher moisture deficits arising from low rainfall.

In the moisture deficit calculations cited above, no direct reference was made to variations in crop factor through the growing season, however the Et/Eo values used decreased as the moisture stress increased. For example, Dagg and Tapley (1967) used Et/Eo values ranging from 0.85 to 0.5 for cashew and Frémond et.al. (1966) values ranging from 1.0 to 0.3 for coconuts while Smith (1968) assumed that the ratio of actual to potential evapotranspiration varies linearly with soil water deficits. Dagg and Tapley (1967) pointed out the lack of directly determined

Et/Eo values for cashew and the same is true for coconuts, therefore the Et/Eo values used by these authors were guessed. Crop coefficients for use with the modified Penman's formula are also not available for these two crops.

In FAO (1977 and 1979) Derenboos et.al. gives crop coefficients in terms of reference crop potential evapotranspiration for various crops, however those for coconuts and cashewnuts are not included. The author is not aware of any studies which have directly determined the crop factors for these two crops.

The studies cited attempts to relate yields directly to moisture deficits. Although significant correlation coefficients were obtained, recent concepts show that the magnitude and duration of moisture deficits expressed as relative evapotranspiration deficits (1-ETA/ETM) are better correlated to relative yields (1-YA/Ym). This relationship would then be a better index of moisture deficits for assessing suitability. These recent concepts are however based on field crops, for which several high and low yielding varieties are available. Its applicability to tree crops, e.g. coconuts and cashewnuts is yet to be investigated.

The water balance approach, in the author's view is preferable since it affords a means of assessing the land suitability in a quantitative ecological approach including the means of estimating the available moisture over the rootable depth of the crop and determining the actual evapotranspiration of the crop. The available moisture storage capacity may be estimated from the measurement of rootable depth and from the moisture characteristics of each soil horizon. The estimation of the actual crop evapotranspiration is however the main problem as pointed out earlier.

2.3.4 Requirements of *ZEA MAYS* (MAIZE)

There are many maize varieties which makes it adaptable to a wide range of environmental conditions. It is cultivated within the latitudes 50^{o}N and 40^{o}S and altitudes ranging from 0 to 3,300 metres, (Purseglove, 1976). In East Africa, maize is grown from 0 to 2286 metres above sea level (CARS, 1980).

Maize requires warm conditions with temperatures ranging from 20 to 32^{o}C. The optimum temperature for growth is 30^{o}C. Germination is best at temperatures ranging from 18 to 21^{o}C. Below 10^{o}C growth and germination stops (Acland, 1971). Cool temperatures lengthen growth cycles, and above 2400 metres yields are severely affected. The growing season ranges from 100 to 170 days depending on the variety. At the coast planting to harvesting takes an average of 120 days (CARS, 1980).

The amount, distribution and effectiveness of rainfall is very important for maize. The rainfall requirement of maize is quoted to range from 300 to 1800mm annually (Acland, 1971). Authors give varying figures of rainfall requirement during the growing season, for example, 600-900mm for tropical areas (Purseglove, 1976), 375mm (Arnon,1972) at least 125mm during the silking period (CARS, 1980). At the coast the ideal range of annual rainfall is given as 750-1250mm (CARS, 1980).

Maize is highly adaptable to different soil conditions, however it grows best on well drained, aerated, deep loams and silt loams with high organic matter contents, high moisture storage capacities, and well supplied with nutrients. It grows well on soils with pH 5.0 to 8.0 with an optimum at pH 6.0 to 7.0. The bulk of maize roots are concentrated in the top 75cm of the soil, though individual roots may penetrate to 3.6 meter depth (Arnon, 1972). Soils suited to maize must therefore be at least 75cm deep.

The varieties suited to conditions at the Kenya coast are the coast composite, Pioneer X 105A and Katumani composite.

For high yields, high standards of husbandry are necessary, including early planting, adequate weed control, fertilizer application and correct plant densities. A plant density of 36,963 per hectare has been shown to give the highest yields (CARS, 1980).

2.3.5 Requirements of Pastures and Livestock

A detailed review of the requirements of pasture and livestock is beyond the scope of this study. However, since dairy cattle and grazing are a part of the present land use and will be included in the alternative land use recommendations, a general review of the requirements of pasture and livestock suited to the conditions at the coast is worthwhile.

Several projects to evaluate the pasture plants suited to soil conditions and climatic variations in the coast region are in progress. These include the National grass trials, Regional grass trials at Mtwapa, Bana grass management trials and Legume trials at various representative sites. The grasses *P. purpureum, E. Superba, C. ciliaris, C. Gayana, P. maximum, S. spharelata* and *C. dactylon* have given promising yields ranging from 2 to 22 tonnes of dry matter per hectare (CARS, Annual Report, 1978). Though not conclusive, the results of these trials may be used to derive a number of recommendations to farmers (Muturi et.al., 1981). Generalised ecological requirements of some of the grasses are given in table A1. The author assumes that suitable grasses and legumes for the study area can be extended from Mtwapa, in agroclimatic zone III, to farmers in the same zone in the Chonyi-Kaloleni study area.

Livestock research programs are also in progress at the coast. Work on crosses involving Ayrshires, Sahiwals and Freisians has been undertaken at Mariakani (in agroclimatic zone IV) aimed at obtaining a genotype which combines high milk yields, high heat tolerance and high reproductive efficiency. Although not conclusive, the results give the following general trends (Muturi et.al., 1981):

1. Ayrshires X Sahiwal crosses produce more milk than Sahiwals
2. Lactation lengths increased with milk yields; and
3. Ayrshire crosses appear to tolerate heat and poor grazing conditions better than Freisian crosses.

From these general trends it appears that dairy cattle suited to the conditions in the study area can be found.

Generally dairy cattle require adequate amounts of forage of adequate nutritional value, abundant drinking water, dipping or spraying facilities, veterinary services and shade in the grazing pastures. Soil conditions and climate determine the amount and the nutritive value of the pasture available.

Table A1. Generalised requirements of some grass species at the coast

ECOLOGICAL CHARACTERISTICS / GRASS SPECIES	Rainfall (mm)	Suitable soils	Drainage requirements	Rootable depth (qualitative)	Tolerance to Salinity/sodicity
E. superba	500-900	Sandy soils	Well drained	Shallow	-
C. ciliaris	>270	Sandy soils with high exchange-able Ca	Any soils but intole-rant to long durations under water	Very deep	-
P. purpureum	>1000 (in humid areas)	Fertile soils	Well drained	-	-
C. gayana	>600	All soils except heavy clays or acid soils or soils with high Mg contents	Slightly tolerant to flooding	Moderate	High
**Panicum maximum*	680-800 or >1000 (humid areas)	Light textured soils	Well drained	Deep	

* Tolerant to shade and can be grown under tree crops

3. METHODS

Soil survey, soil classification, legend construction, laboratory and land evaluation methods used in this study are described below.

3.1 SOIL SURVEY AND CLASSIFICATION METHODS

The Chonyi-Kaloleni study area is covered by the Survey of Kenya topographic map sheets 198/3 (MAZERAS) and 198/4 (VIPINGO) at a scale of 1:50,000, and the geological map of the Mazeras-Kilifi area at a scale of 1:250,000. These maps and aerial photographs (scale 1:50,000) were all collected prior to the fieldwork. In addition soil and geological reports together with rainfall data of stations within and surrounding the study area were collected and studied.

The element analysis method (FAO, 1967) using relief, drainage patterns and vegetation as elements was used to interpret the aerial photographs. The analysis was rendered difficult by the presence of smoke on some photographs and large variations in photographic tones between adjacent photographs. Nevertheless the photointerpretation was very useful. A photo-interpretation map was made and onto it contours were traced from the topographic maps. The resultant map was used as a base map in the field. Interpretative boundaries were checked in the field and adjusted where necessary. The main interpretative soil boundaries generally coincided with geological boundaries.

Field checking of the interpretative boundaries consisted of routine augering to a depth of 120cm but where necessary they were made to 250cm. On confirmation of the boundaries, representative sites were selected in each mapping unit and profile pits constructed normally to a depth of 160cm. Where relevant, additional profile pits were made at sites reflecting differences in crop performance. Road cuts and sand pits were also used as profiles, the latter being very useful for assessing rootable depths and root distribution of tree crops. All observations were located and marked on the base map.

At each observation site, information on landform, geology, relief, slope, rock outcrops, surface drainage, vegetation, surface cracks, erosion and present land use were described and recorded. For auger samples the following characteristics were examined and recorded: colour, texture, consistence, effervescence with 10% HCl, concretions, pH, stoniness, soil depth and roots. In addition profile pits were examined for structure, cutans, slickensides, mottles, cracks, groundwater table, root and fauna distribution, porosity, hard pans, horizon arrangement and their transitions.

The profiles were described following the

Soil Survey Manual (USDA-Staff, 1952) and 'Guidelines for Soil Profile Description' (FAO, 1977), and the colours according to the Munsell Color Charts. Profile and site information were recorded on the standard KSS profile description forms.

After description, the profiles were sampled per horizon for both physical and chemical analysis. One 'composite' sample was taken around each profile pit to a depth of 30cm for the determination of available nutrients. For selected profiles, undisturbed core samples were taken per horizon using special steel rings for the determination of bulk density and moisture characteristics. Core samples were sampled from previously wetted horizons. Some clayey profiles, notably those of unit $VcTi_1$ were difficult to sample because of the very strong structure and hard consistence and the difficulty in wetting them. Consequently those were sampled after wetting for 48 hours.

The profile pits were classified using the FAO/UNESCO system, (FAO/UNESCO, 1974) and where possible the Soil Taxonomy Classification (USDA, 1975) was also given.

3.2 LEGEND CODES

The physiographic approach to legend construction used by the KSS recognises three levels of entry, followed by a descriptive legend and finally the soil classification is given in parenthesis. The unit code consists of three entries and a slope class code beneath the unit code. The first, second and third entries are physiography, geology and soil characteristic(s) respectively. The third entry, viz. soil characteristic(s) is either colour or soil depth or another unspecified measurable characteristic.

This unit code system is short, quick to formulate, tends to reflect mapping procedure and furthermore one can choose the soil characteristic(s) to enter at this third level. However, the system has some shortcomings. It does not give prominence to the nature of the soil per se, and moreover it describes only one soil characteristic. The chosen soil characteristic, the essence of the soil map, is entered only at the third level and is not constant, sometimes it is colour, or depth, sometimes drainage. Moreover this code system may not be well understood by 'external' users.

In view of the above remarks a few modifications were introduced so that the unit code would emphasise the soil components of the mapping unit and so convey more information on the nature of the soils. The modifications used in this study are outlined below.

The modified code consists of four entries.

The first entry consists of two letters, a capital one indicating the first level of FAO classification and a small letter giving the second level FAO classification. The FAO letter codes and their meanings are given in appendix 1.

The second entry is a capital letter indicating the geological formation (or lithology) from which the soil has developed. The relevant codes and their meanings relevant in this study area are:

CODE	GEOLOGICAL FORMATION
F	Fine grained sandstone (Mariakani Sandstone)
C	Coarse grained sandstone (Mazeras Sandstone)
L	Oolitic limestone (Kambe Limestone)
T	Layered and fragmented shales (Jurassic Shales)
M	Medium grained sands (Magarini Sands)
A	Alluvial deposits silts and clays (Bay Sediments)
X	Various parent rocks

The third entry is a small letter indicating the internal drainage class. Four classes are recognised, their codes, meaning and identification criteria are given below:

LETTER CODE	DRAINAGE CLASS	IDENTIFICATION CRITERION
p	poorly drained	mottles apparent at the surface, gleying from 30 to 40cm depth.
i	imperfectly drained	mottles starting from 30-60cm depth below the surface.
w	well drained	no mottles, or only present below 120cm depth.
e	excessively drained	no mottles present and rapid to very rapid percolation.

Colour mottling may reflect either the genetic processes in soil formation, e.g. weathering of parent material, or drainage conditions of the soil. The mottles used in the identification criteria above refers only to those reflecting (reduced) drainage conditions. The drainage class criteria is the shallowest depth at which mottles are found. The abundance, size, contrast of the mottles were described according to the Guidelines for Soil profile description (FAO, 1977), and are given in the profile descriptions in appendix 2.

The fourth entry is a small numeral indicating the textural 'group'. Four textural groups, obtained by combining two, three or four classes in the textural triangle, are recognised and are as given below (clay content is used as a rough guide as to which group a textural class belongs. The higher the clay content the lower the numeral value of the group).

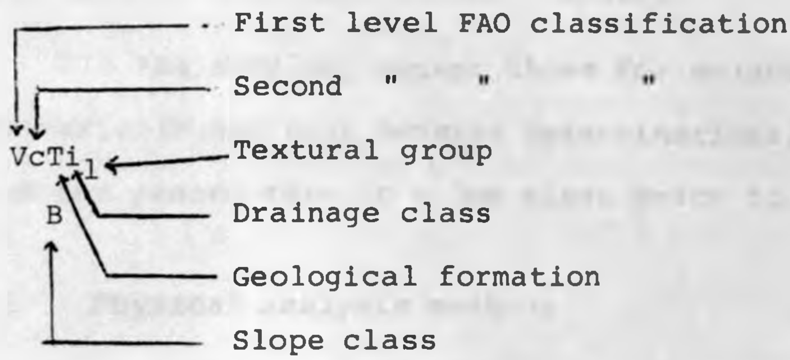
TEXTURAL GROUP	CONSTITUENT TEXTURAL CLASSES
1	clay, silty clay, and sandy clay
2	clay loam, silty clay loam and sandy clay loam
3	loam, silt loam, silt and sandy loam
4	loamy sand and sand.

The slope class code(s) underlying the unit codes are the same as those used by the KSS, (van de Weg, 1978), viz.

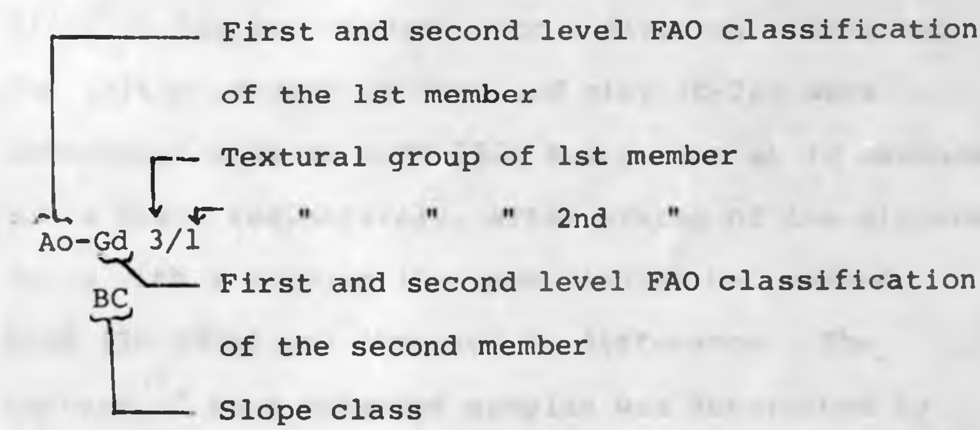
CODE	SLOPE(%)	NAME OF MACRO-RELIEF
A	0-2	Flat to very gently undulating
B	2-5	Gently undulating
C	5-8	Undulating
D	8-16	Rolling
E	>16	Hilly to mountaneous

Soil association codes consist of letters indicating the first and second FAO classifications of the members joined by a hyphen and followed by textural classes of the two members. The code of the most extensive member appearing on the left of the hyphen. Soil complexes are indicated by both levels of FAO classification with a slanting line to separate the members.

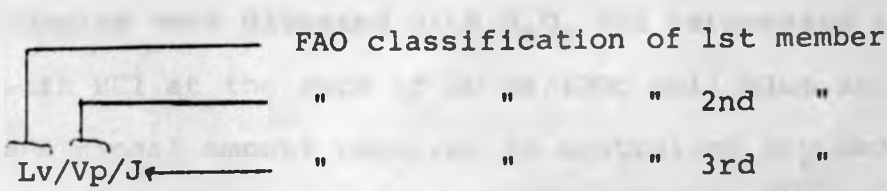
To illustrate the code system some examples are given below. The code for an imperfectly drained, clayey Chromic VERTISOL, developed from Jurrasic Shales is:-



The code for a soil association consisting of loamy Orthic ACRISOL and a clayey Dystric GLEYSOL is



The code for a soil complex consisting of vertic LUVISOLS, pellic VERTISOLS and FLUVISOLS is:-



3.3 LABORATORY METHODS

The physical and chemical methods used in this study are those now in use at the National Agricultural Laboratories, Nairobi. These are only briefly described here but the detailed procedures and calculations are given by Hinga et.al. (1980).

All the samples, except those for moisture characteristic and bulk density determinations, were ground and passed through a 2mm sieve prior to analysis.

3.3.1 Physical analysis methods

Texture was determined by the hydrometer method (Day, 1956). Samples were dispersed with Calgon (sodium hexametaphosphate/sodium carbonate mixture) by stirring for ten minutes with a dispersion stirrer. The silt plus clay (0-50μ) and clay (0-2μ) were determined with an ASTM 152H hydrometer at 40 seconds and 2 hours respectively, after mixing of the dispersed soils with a plunger (for one minute) had ceased. Sand (50-200μ) was obtained by difference. The texture of some selected samples was determined by the pipette method for soil classification purposes.

In the pipette method, (Day, P.R., 1956 and 1965) samples were digested with H_2O_2 and carbonates removed with HCl at the rate of 10 me/100g soil plus an additional amount required to neutralize any excess $CaCO_3$ present. The samples were washed with distilled water, filtered by suction and then dispersed with Calgon by shaking overnight on an overhead shaker. Sand particles were fractionated using 47, 105, 250, 500 and 2000μ sieves. Clay (0-2μ) was determined by pipetting (at 10cm depth) immediately and again three hours fourty minutes after a thorough mixing with a plunger. The fractions were then dried and weighed. Silt (2-50μ) was obtained by subtracting the clay fraction from the sum of sand, organic matter and carbonate fractions.

Bulk density was obtained by weighing an oven-dry (105^{o}) sample of a known volume, (Richards, 1954).

The moisture characteristics were determined from core samples of known volume at 0.0, 0.1, 0.3, 1.0 and 15 bars (viz. pF 0.0, 2.0, 2.5, 3.0 and 4.2). A pressure plate apparatus was used for 15 bar equilibrations and a kaolin sand box for 0.0 to 1.0 bar equilibrations. Disturbed samples were used for the 15 bar equilibrations. The Field Capacity (FC) and Permanent Wilting Point (PWP) were taken as the moisture contents at 0.3 and 15 bars respectively. The available moisture storage capacity (AMSC) was taken as the difference in moisture contents between these two values.

3.3.2 Chemical Analysis Methods

Both pH_{H_2O} and pH_{KCl} were determined using a glass electrode pH-meter (Dole, 1941; Bates, 1954) in a soil to water or KCl solution ratio of 1:2.5 as adopted by the Soil Reaction Committee of the International Soil Science Society (1930).

Electrical conductivity (EC) was determined with a conductivity meter (US Salinity Laboratory, 1954) in a soil to water ratio of 1:2.5. Where the EC was 1.0 mmho/cm or more a saturation extract was made and both pHe and ECe were determined on the extract.

Organic carbon was determined by oxidising the carbon with a known volume of a mixture of potassium dichromate and concentrated sulphuric acid. The excess dichromate was determined by titration with ferrous sulphate and diphenylamine indicator. Phosphoric acid was added to sharpen the end point (Walkley and Black, 1965).

Nitrogen was determined by Kjedahl method (Bremner, 1965). Organic nitrogen compounds were digested with a mixture of sulphuric acid and selenium compounds. The mixture was made alkaline with sodium hydroxide thereby releasing ammonia which was absorbed in boric acid. The ammonia released was determined by titration against dilute sulphuric acid.

Exchangeable cations were leached from the soil with neutral ammonium acetate (Bray and Willhite, 1929).

Sodium and potassium were determined with an EEL flame photometer. For calcium and magnesium determinations lanthanum chloride was added to the samples. Calcium was then determined on an EEL flame photometer and magnesium by Atomic absorption spectrophotometry.

Cation exchange capacity (CEC) was determined using ammonium acetate at pH 7.0 as the saturating solution, (Chapman, 1965). Samples were leached with ammonium acetate, then washed with 95% ethyl alcohol, and subsequently saturated with acidified sodium chloride to leach out the adsorbed NH_4 cations. Ammonia released by steam distillation from the leachate was absorbed in boric acid and determined by titration against dilute hydrochloric acid. However, when the soil pH exceeded 7.5 samples were saturated with sodium acetate at pH 8.2 (Bower et.al., 1952), then washed with 95% ethyl alcohol and saturated with ammonium acetate. Sodium in the final leachate was determined with an EEL flame photometer.

Available nutrients were extracted using a mixture of 0.1N HCl/0.025N H_2SO_4as the extractant by standing the sample and the mixture for one hour, then shaking in a mechanical shaker for ten minutes. Activated charcoal was previously added to absorb organic matter (Mehlich et.al., 1962). Extracted nutrients were analysed as follows:

Calcium, potassium and sodium using an EEL flame photometer. Anion exchange resin was added to remove interferring phosphate and sulphate anions. Magnesium was determined on the atomic absorption spectrophotometer (Mehlich, 1955). Phosphorus was determined as a molybdo-vanada-phosphoric acid complex on a colorimeter (Kitson and Mellon, 1944). Manganese was determined colorimetrically using phosphoric acid-potassium periodate for colour development (Mehlich, 1958).

Exchange acidity was determined in the few samples whose pH_{H_2O} was less than 5.0. The samples were leached with normal KCl, subsequently titrated with sodium hydroxide then hydrochloric acid in that order. From the first titration both exchangeable aluminium and hydrogen were obtained. The second titration gave the exchangeable aluminium content. Hydrogen was then obtained as the difference between the two titrations.

3.4 LAND EVALUATION METHODS

In the absence of basic yield data, which forms the basis of an economic analysis, this study was limited to a purely physical analysis. Therefore this study is a specific purpose physical land evaluation, in which purely physical criteria, viz. land qualities were used to define the suitability classes. Social-economic considerations in this study were used only to the extent of defining the relevant land utilization types (LUTs). In the evaluation, the principles and concepts of the 'Framework for Land Evaluation' (FAO, 1976) were followed as closely as possible. Agroclimatic zones formed broad land mapping units to which the defined LUTs are relevant. However, an LUT's suitability was assessed for each soil mapping unit in each agro-climatic zone. The various methods used in this land evaluation are described below:

3.4.1 Agroclimatic Zone Methodology

Monthly rainfall data, for stations in and around the study area of upto 1980 were collected from Meteorological Department Headquarters, Nairobi as mentioned in Section 3.1. For those stations wih less than fifteen years records, the annual rainfall figures were adjusted* using the data of the nearest stations with at least twenty years of records by the weighting method of Braun (1978).

Penman's open water evaporation data as estimated by Woodhead (1968) were adapted and used. Due to the lack of meteorological data for stations in the study area, the altitude dependent regression of Woodhead (1968) as modified by Braun (1978), to

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$$* \text{ Adjusted Average of A} = \frac{\text{sum of periods 1,2,3,4..for A}}{\text{sum of the same periods 1,2,3,4..for B}} \times \text{long term average for B.}$$

include distance from the coast was used to estimate annual evaporation, viz.

$$Eo = 2175 + 2.47Y - 0.358h$$

where Y and h are distance from the coast (in kilometres) and altitude (in metres) respectively, for the station in question. The ratio of average annual rainfall to annual evaporation was computed and expressed as a percentage. The ratio of annual rainfall to annual evaporation for each station was also computed on an yearly basis to show the temporal variation for that station.

The average annual rainfall to annual evaporation ratios (r/Eo) were plotted on a map and agro-climatic zone boundaries drawn. The boundary criteria which were adopted from the draft 'agro-climatic zone map of Kenya' (Braun et.al., 1980) are shown on the resultant agroclimatic zone map (Fig. 1).

Monthly evaporation data were estimated for a few stations in or near the study area. Basic in their estimation was the assumption that the monthly evaporation expressed as a percentage of the annual evaporation is constant in the coastal area. Thus the percentage values for those stations with meteorological data, viz. Mombasa Town (39002), Malindi (93.4000) and Lamu (92.40001) were computed. These values were then used to estimate the monthly evaporation values for the selected stations, viz. Chonyi (93.39013), Kaloleni (93.39038), Giriama St. Georges (93.39041) and Gotani (93.39055). The estimated monthly evaporation values were subsequently used in the calculation of water balances for coconuts and cashewnuts.

3.4.2 Water Balance Method

The assumptions made in this water balance study are:

1) Source of water other than soil storage and rainfall are absent.
2) The same ground cover is assumed for the two agroclimatic zones.
3) Rainfall in any given month was assumed to come at the beginning of each month.
4) Rainfall saturates the soil storage before run-off and deep percolation starts.
5) The initial storage is recharged and used to meet the evaporative demand before the balance is stored.
6) The ratio of actual to potential evapotranspiration is constant in the two agroclimatic zones for each crop.

Directly measured crop factors (ET/Eo) or crop coefficients (ETc/ETo) for cashewnuts and coconuts are not available in literature. The evaporative demands (Eo) in the study area and in Nachingwea are of a similar magnitude therefore a crop factor of 0.8 used in Nachingwea for cashewnuts was also used in the study area. Coconuts have a higher water requirement than cashewnuts therefore a crop factor of 0.9 was assumed for coconuts. The potential crop evapotranspiration was then estimated using the equation:

$$ETc = f\ Eo$$

where ETc = potential crop evapotranspiration

Eo = potential open water evaporation

f = crop factor

Climatic data for Chonyi, Giriama and Gotani were used in the water balance calculations for agro-climatic zones III, IV and V respectively. Monthly moisture deficits for each zone was calculated on a yearly basis for selected available moisture storage capacity ranges. The resultant moisture deficits, annual or that of a given period was subsequently regressed against copra and cashewnut yields. The water balance calculation sheet is presented in appendix Al.

3.4.3 Definition of Land Utilization Types

Observations on the kind of crops grown and the percentage area covered by each crop, together with a visual assessment of their performance were made in many parts of each soil mapping unit. Subsequently farmers, agricultural officers, land adjudicators and other officers in the study area were interviewed. The information obtained was used to define the present compound LUTs and the alternative simple and compound LUTs in terms of the key attributes produce, capital intentisy (herein substituted with production costs), labour intensity, level of technology and farm power.

The 'produce' was described in terms of percentage occupied by the major crops in a LUT. 'Production costs', was given in monetary terms and described as low (less than KSh. 500), moderate (KSh. 500-1000) or high (more than KSh. 1,000). The production costs include the cost of seeds, fertilizers, agrochemicals, ploughing costs and costed family or hired labour. The production costs are valid for 1980.

'Labour intensity' was given in mandays per hectare annually and was described as low (less than 50 mandays), moderately high (50-100 mandays) or high (more than 100 mandays). The labour includes that provided by the family but excludes land ploughing by tractors.

Farm power was described as either manual or partially mechanised. Ox-ploughing is not used here consequently it was omitted as a source of farm power.

Low level of technology is generally applied in the present LUTs but an intermediate level of technology is assumed for all alternative simple and compound LUTs. For a given level of technology the management or agronomic practise is uniquely defined for each crop, therefore, the various levels are defined for each simple LUT below:

For maize, low level of technology implies use of local unimproved seeds, broadcasting of seeds, untimely planting, inadequate weed control, no fertilizer application and no application of agro-chemicals to control pests and disease. Intermediate level of technology implies use of improved cultivars available, planting in rows, modest fertilizer application, use of agrochemicals to control pests and diseases, timely planting and timely and effective weed control.

For cashewnuts, low level of technology implies use of unselected planting material, improper spacing, inadequate weed, pest or disease control, untimely harvesting and improper pruning (canopy control). Intermediate level of technology implies the use of selected high yielding seedlings (Clone A81), planting in hedgerows with proper hedge row canopy control, some chemical pest and disease control, adequate weeding, timely harvesting and some fertilizer application.

For coconuts, low level of technology implies the use of unselected planting materials, very close planting, no proper weed, pest or disease control. Intermediate level of technology implies use of selected high yielding seedlings, at the recommended spacing, modest fertilizer application, adequate weed, pest and/or disease control, timely harvesting and improved and efficient method of processing nuts into copra.

For animals, improved pastures and levels of animal husbandry are assumed. Fertilizers will be applied to the pastures while husbandry levels assumed will reduce the high calf mortality rates.

The infrastructure requirements described here include all those facilities required by, but not restricted to, an individual farmer, e.g. roads, loans, extension advisory services, cattle dips and produce buying centres.

The overall level of technology (synonymous with level of inputs cf. Shah et.al. (1980) is obtained by combining the level of each key attributes as shown in Table A2.

Socially farmers are reluctant to remove the unproductive or pest infested tree crops which are the major components of the present land use, therefore the recommendations aimed at improving the present level of technology and/or introduction of uses which do not involve unacceptable changes in the present land use. Where improvement involves removal of old and unproductive trees, they should be replaced in phases.

Table A2. <u>Overall technology level</u>

Key attribute	Level of key attribute defining the OVERALL LOW level of technology	Level of key attribute defining an Intermediate overall level of technology
production cost	low	medium to high
labour intensity	high	low to moderate
power source	manual	partially mechanised
infrastructure	poorly provided	well provided

3.4.4 Diagnostic criteria and evaluation procedures

The diagnostic criteria, i.e. land qualities most likely to determine the suitability of land for the defined simple LUTs were identified and studied. For each mapping unit the diagnostic criteria were rated according to a proposed scheme. Specifications of the diagnostic criteria used to define the suitability class limits, i.e. conversion tables were set up taking into account the performance of the 'simple' LUTs in the field and any available information from the literature.

No major land improvements were considered, therefore only the 'current suitability' was considered. The suitability of each mapping unit for each relevant alternative was assessed and assigned. The suitability orders and their classes used in this study are:-

Order	Classes	Suitability
Suitable	S1	highly suitable
	S2	moderately suitable
	S3	marginally suitable
Not suitable	NS	not suitable

The physical suitability, prevailing social-economic conditions, nutritional requirements of the local population and the anticipated changes in the present land use were considered in the selection of the land use alternative to be recommended for a given unit.

4. THE CONTEXT OF THE STUDY AREA

4.1 LOCATION, COMMUNICATION AND POPULATION

The Chonyi-Kaloleni study area is located in the Southern Division of Kilifi District. It comprises an east-west strip of land between the longitudes $3^{O}45'S$ and $3^{O}47'S$ and is bounded in the west by Gatani-Bamba road and in the east by Wimbi river. It lies north of Mwamba-ya-Nyundo, Kaloleni and Mwarakaya trading centres and is approximately 12,700 hectares in extent.

Kaloleni, the major administrative and trading centre, is centrally located south of the study area. The strip traverses three administrative locations, namely from east to west - Chonyi South, Kaloleni and Kayafungo.

The Mariakani-Takaungu road is the principal one through the study area. It is a murram road with major branches via Gotani, Chonyi, Mwarakaya and Lutsangani. Minor raods linking small trading centres north of the study area pass through to Kaloleni. The Sabaki-Mombasa pipeline road cuts through the eastern part of the area. In general the area is very accessible but some parts, e.g. Pingilikani, Kinane, Mwamleka are only accessible with difficulty through small motorable tracks. A tarmac road joins Kaloleni to Mazeras and Mombasa.

The area is inhabited by two ethnic members of the Mijikenda, i.e. the Wachonyi and Wagiriama who occupy the area to the east and west of Kaloleni centre, respectively. The population data for the study area was not available but the population status can be inferred from locational data presented in Table 1 , which are based on, or derived from, Kenya population census 1969 and 1979 (the latter was not published at the time of writing this Thesis).

In general Southern division has a higher population density than the overall density for Kilifi district (cf. 136 and 34 persons per sq. km for the division and district, respectively in 1979). For the three locations the population density is highest in Kaloleni, due to the presence of the trading centre, and lowest in Kayafungo location in the west. Excluding the contribution from the trading centre, a decreasing trend from Chonyi in the east with 141 persons per sq. km to Kayafungo, in the west, with 83 persons per sq. km is evident. This trend closely follows the decrease in annual rainfall in the same direction. The pressure on the land is expected to decrease in the same direction, viz. westward. The annual population growth rate is high for all the locations ranging from 3.2% per annum in Chonyi to 4.3% per annum in Kaloleni through an intermediate 3.37% per annum value for Kayafungo. These population growth rates are comparable to the national

Table 1. The population, density and growth rates for Chonyi, Kaloleni and Kayafungo locations and the Southern division total (Kilifi district)

Administrative Area	POPULATION		Population Density (persons per sq. km)		Growth rate
	1969	1979	1969	1979 (*)	(*) % per annum
Chonyi Location	23,358	30,783	107	141	3.2
Kaloleni "	13,927	19,921	143	205	4.3
Kayafungo "	16,877	22,562	63	84	3.37
Southern Division	112,493	151,544	101	136	3.47
Kilifi District	307,568	430,986	25	34	4.0

(*) Density and growth rates calculated on the assumption that the administrative boundaries have not changed since 1979 values of 3.5 to over 4% per annum.

4.2 CLIMATE

The prevailing climatic conditions, particularly temperature and the balance between rainfall and evaporation, determines the potential for crop production in an area. At the Kenya coast, the energy income (i.e. light and temperature) is sufficient for year-round crop growth, but water availability is a major environmental constraint and limits year-round production.

The temperature variations and hence evapotranspiration variations are small, therefore rainfall, (both amount and distribution) is the major determinant of the water budget at the coast. The observation by Kowal (1979) that the main feature of tropical rainfall is its seasonality and year to year variation holds true for coastal Kenya. Consequently a year to year water balance approach was adopted for cashewnuts and coconuts. Long term averages of the climatic variants were only used here to show the general trends.

4.2.1 Adjusted Rainfall Averages

The rainfall averages for stations with short recorded periods are not reliable (Braun, 1977), therefore, for stations with less than twenty years of records, adjusted rainfall averages were calculated.

For Gotani, with only four years of records the rainfall was adjusted with respect to the rainfall for Giriama:

year	1979	1978	1977	1976	sum
Gotani	891	1118	879	607	3495(mm)
Giriama	1060	851	1033	783	3727(mm)

Twenty seven year rainfall average for Giriama = 978mm

Adjusted rainfall average for Gotani

$$= \frac{891 + 1118 + 897 + 607}{1060 + 851 + 1033 + 783} \times 978mm$$

$$= 917mm$$

Similar calculations were made for the other stations. Where two stations were available, adjustments were calculated using both stations and their mean obtained. Table 2 gives the calculated adjusted rainfall averages.

The adjusted rainfall averages for the stations are in good agreement with values expected from the rainfall gradients of surrounding stations. Sokoke plantations demonstrates this point. The rainfall average at Kibarani experimental farm is 1018mm and that of Ganze dispensary is 804mm. The expected average for Sokoke is between these two values. The unadjusted average for Sokoke plantation is only 729mm but on adjustment an agreeable average of 892mm is obtained.

Table 2. Adjusted rainfall averages, and adjusting stations for some stations with less than twenty years' record

STATION	RAINFALL(mm)	ADJUSTING STATION	ADJUSTED RAINFALL(mm)	MEAN ADJUSTED RAINFALL (mm)
SOKOKE PLANTATIONS 93.39005	829	KIBARANI EXPTAL* FARM 93.39009	859.4	891.5
93.39012		GANZE DISPENSARY 93.39009	930.8	
JARIBUNI DISPENSARY 93.39026	814	KIBARANI EXPTAL* FARM 93.39009	685.1	753.4
		GANZE DISPENSARY 93.39012	821	
TAKAUNGU 93.39035	1053	KILIFI DC. CAMP 93.39004	1084.5	1060.8
		MTWAPA 93.39036	1053	
BAMBA 93.39016	618	GANZE DISPENSARY 93.39012	623.7	623.7
RABAI 93.39043	1075	RURUMA 93.39039	1090.3	1090.3
GOTANI 93.39055	825	GIRIAMA St. GEORGES 93.39041	917	917

(* EXPTAL means EXPERIMENTAL)

4.2.2 Annual Potential Evaporation (Eo)

The potential evaporation of meteorological stations used in this study have not been determined. The annual potential evaporation (Eo) was therefore calculated using Braun's (1977) modification of Woodhead's (1968) altitude dependent equation. The Eo for Gotani (93.39055), 228.6 metres above sea level and 35.5 kilometres from the coast, is calculated as an example:

$$\text{Eo (Gotani)} = 2175 + (2.47 \times 35.5) - (0.358 \times 228.6)$$
$$= 2180.85 \quad 2181\text{mm}$$

The calculated Eo values for the stations used in this study, together with their altitude and distance from the coast are given in Table 3. The Eo values increase inland as the rainfall decreases.

4.2.3 Agro-Climatic Zones

The agroclimatic zone concept used here is based on the ratio of average annual rainfall (or the adjusted average annual rainfall) to average annual potential evaporation, r/Eo. This approach is an improvement (Braun, 1977) of the original ecological zones concept of Pratt, Greenway and Gwynne (1966) based on vegetation.

The r/Eo ratio was calculated for each station using the average annual rainfall and potential evaporation data in Tables 2 and 3. The calculated ratios

Table 3. Stations, altitude, distance from coast and their potential evaporation

STATION		ALTITUDE (h)	DISTANCE (Y)	Calculated POTENTIAL EVAPORATION
NAME	NUMBER	(in metres)	from Coast (in kilometres)	(in mm)
MAZERAS R. STATION	93.39000	163.76	22	2171
MOMBASA OLD OBS.	94.39002	4.58	0	2174
KILIFI DC.	93.39004	3.0	0	2182
SOKOKE PLANTATION	.39005	129.24	10.5	2155
KIBARANI	.39009	15.24	4	2179
GANZE	.39012	182.68	24	2169
CHONYI	.39013	256.03	18	2128
BAMBA	.39016	243.84	44	2196
MARIAKANI VET.	.39017	206.34	36	2190
MAJI YA CHUMVI	.39023	166.42	49	2236
JARIBUNI	.39026	60.96	14	2188
JIBANA DISPENSARY	.39030	116.0	15	2171
TAKAUNGU	.39035	18.29	1.5	2172
MTWAPA	.39036	21.34	4	2177
MAZERAS NURSERY	.39037	164.59	22	2170
KALOLENI	.39038	255.55	25	2152
RURUMA	.39039	171.3	22	2168
GIRIAMA	.39041	243.84	26	2152
RABAI	.39043	161.54	24	2176
GOTANI	.39055	228.6	35.5	2180.85

and the respective average annual rainfall and potential evaporation are given in Table 4. The r/Eo ratios were plotted on a map (scale 1:250,000) and agroclimatic zone boundaries were drawn assuming a linear change in r/Eo ratio with distance between any two stations. The assumption is expected to be reasonably valid where the relief changes gradually with distance as is the case in the study area. The resultant agroclimatic zones map and the boundary criteria are given in figure 1. From this map it is deduced that about 61% of the study area lies in agro-climatic zone III, 25% of the area in zone IV while the remaining 14% is in zone V.

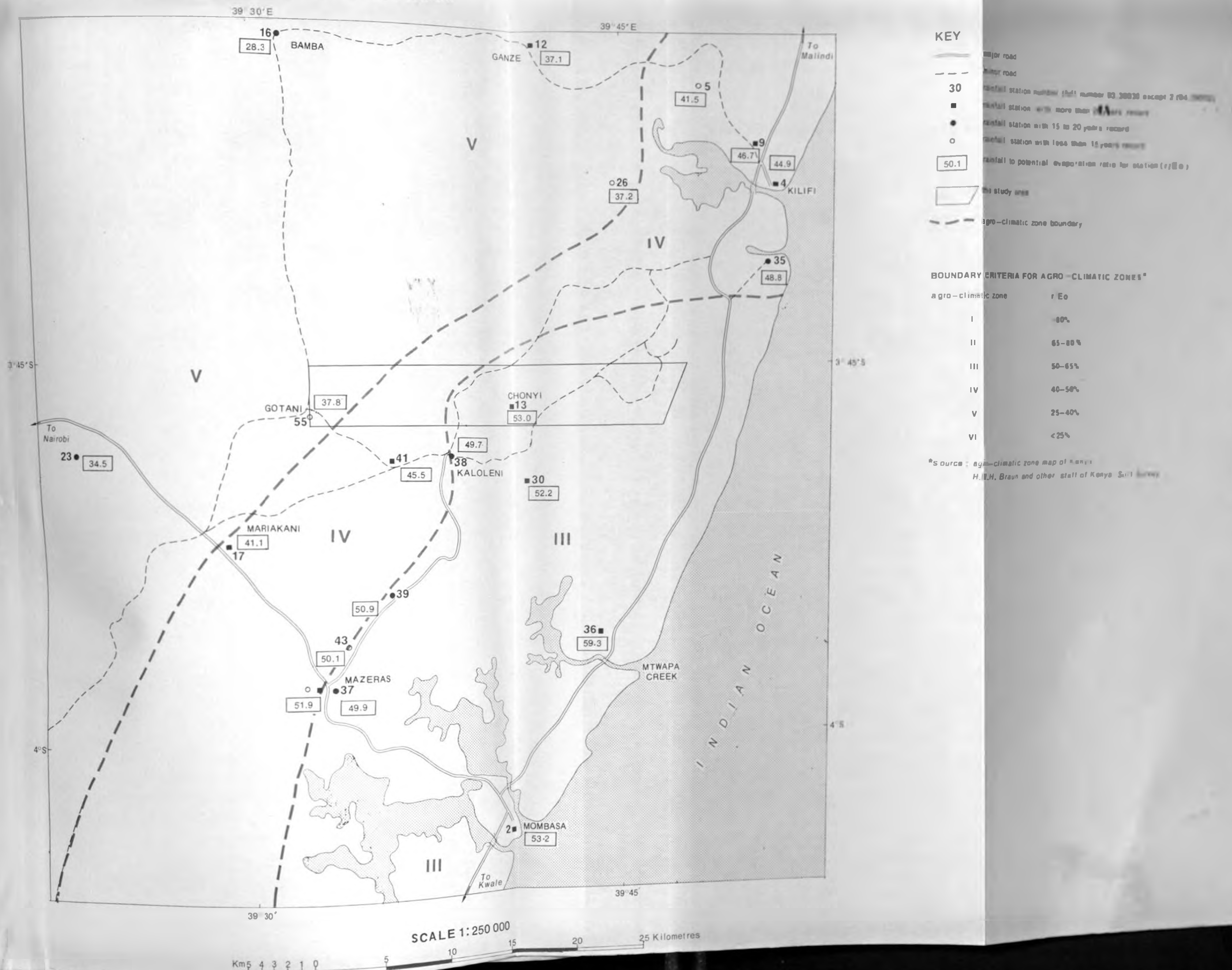
The agroclimatic zones calculated from long term averages of rainfall and potential evaporation are not by themselves sufficient to evaluate the potential for crop production due to the annual variations in the r/Eo ratio. To demonstrate this fact, the year to year r/Eo ratio and hence the agroclimatic zones were calculated for each station assuming constant Eo values from year to year. Furthermore, the constant Eo is likely to reduce the r/Eo variations and therefore the variations are probably underestimated. Although Eo does vary from year to year, annual variations are likely to be small compared to the annual rainfall variations, therefore the estimated annual r/Eo ratios may be reasonably valid.

Table 4. Average annual rainfall(r), annual potential evaporation(Eo), r/Eo ratios and agroclimatic zones of stations

STATIONS		RECORDED YEARS	AVERAGE ANNUAL RAINFALL(r) (mm)	ADJUSTED AVERAGE RAINFALL(r') (mm)	ANNUAL POTENTIAL EVAPORATION(Eo) (mm)	r/Eo ratio	AGROCLIMATIC ZONE
NAME	NUMBER						
MAZERAS	93.39000	23	1127	-	2171	51.9	III
MOMBASA	94.39002	30	1156	-	2174	53.2	III
SOKOKE PLANTATION	93.39005	6	729	895	2155	41.5	IV
KIBARANI	93.39009	29	1018	-	2179	46.7	IV
CHONYI	93.39013	34	1128	-	2129	53.0	III
GANZE	93.39012	27	804	-	2169	37.1	V
BAMBA	93.39016	18	618	623	2198	28.3	V
MARIAKANI	93.39017	25	901	.	2190	41.1	IV
MAJI YA CHUMVI	93.39023	20	771	-	2237	34.5	V
JARIBUNI	93.39026	6	814	753	2188	37.2	V
JIBANA	93.39030	25	1132	-	2171	52.2	III
TAKAUNGU	93.39035	17	1053	1061	2171	48.8	IV
MTWAPA	93.39036	22	1292	-	2177	59.3	III
MAZERAS NURSERY	93.39037	18	1083	-	2170	49.9	IV/III
KALOLENI	93.39038	20	1068	-	2151	49.7	IV/III
RURUMA	93.39039	20	1103	-	2169	50.86	III/IV
GIRIAMA	93.39041	27	978	-	2152	45.5	IV
RABAI	93.39043	14	1075	1090	2177	50.1	III/IV
GOTANI	93.39055	4	.625	917*	2180	37.82	V

* This adjusted rainfall average was not used because it gives a r/Eo ratio of 42.08 thus placing Gotani in agroclimatic zone IV whereas field observations place it in agroclimatic zone V. However, it is a boundary case.

Fig.1 AGRO-CLIMATIC ZONE MAP OF KILIFI AREA



Nevertheless they clearly illustrate the year to year variations. The percentages of the years a station was in a given agroclimatic zone based on yearly r/Eo values were calculated and are given in Table 5 together with the agroclimatic zones calculated from long-term averages of r and Eo values.

It is clear from Table 5 that the agroclimatic zones calculated from long-term averages of r and Eo values are not always the most frequently occurring ones. For example, in Kibarani (93.39009), Mariakani (93.39017), Jibana (93.39030) the long-term derived agroclimatic zones are less frequent. This discrepancy is probably caused by a skew distribution of annual rainfall. This variability emphasises that agroclimatic zones based on long-term averages do not always represent the most commonly occurring situations experienced by crops. Hence there is a need to calculate a year to year water balance study when evaluating land for crop production.

In view of the above observations, coupled with their proximity to the study area, Chonyi (93.39013), Kaloleni (93.39038), Giriama (93.39041) and Gotani (93.39055) representing agroclimatic zones III, IV and V were selected for studying the monthly and seasonal variations of the climatic components (rainfall and potential evaporation) for use in the water balance calculations.

Table 5. Annual variations in Agroclimatic zones compared to the long term average agroclimatic zone for various stations

STATION		TOTAL RECORDED YEARS	PERCENTAGE OF YEARS WITH CONDITIONS OF AGROCLIMATIC ZONE						LONG TERM AVERAGE AGROCLIMATIC ZONE
NAME	NUMBER		II	III	IV	V	VI	VII	
MAZERAS	93.3900	23	26	22	22	22	9	0	II
KIBARANI	".3909	29	14	31	17	35	3	0	IV
GANZE	".39012	27	4	15	22	37	22	0	V
CHONYI	".39013	34	18	35	12	32	3	0	III
BAMBA	".39016	18	0	0	20	30	50	0	V
MARIAKANI	".39017	25	0	21	21	46	11	0	IV
MAJI YA CHUMVI	".39023	20	0	0	30	50	10	10	V
JIBANA	".39030	25	33	25	[illegible]	29	4	0	III
TAKAUNGU	".39035	17	18	29	12	29	0	12	IV
MTWAPA	".39036	22	29	38	14	19	0	0	III
KALOLENI	".39038	20	20	20	30	30	0	0	IV/III
RURUMA	".39039	20	15	40	15	35	5	0	III/IV
GIRIAMA	".39041	27	15	15	30	37	4	0	IV
GOTANI	".39055	4	0	20	20	60	0	0	V

4.2.4 Monthly Potential Evaporation

Monthly potential evaporation data for Chonyi, Kaloleni, Giriama and Gotani were not available. Furthermore, the altitude dependent equation of Woodhead (1968) is only valid for annual potential evaporation. However the monthly potential evaporation for the four stations was estimated assuming that the ratio of monthly to annual potential evaporation for any given month is constant and equal for all stations in the coastal area. To test this assumption the ratio of monthly to annual potential evaporation was calculated for all months for Msabaha (93.40007), Lamu (92.40001), Mombasa Town (94.390o9), Mombasa Airport (94.39002) and Malindi (93.40009) for which monthly, Eo data were available. The calculated ratio of monthly to annual potential evaporation, together with the respective monthly potential evaporation and annual potential evaporation for the five coastal stations are given in Table 6. A test for any significant difference between the ratios was rejected using the two tailed t-test at the 0.5 level of significance, hence justifying the above assumption. Due to its proximity to the study area the ratios for Mombasa Airport were used to calculate the monthly evaporation values for the four stations in the study area. The calculated monthly potential evaporation values for the study area stations are given in Table 7.

Table 6. Monthly potential evaporation, ratio of monthly to annual potential evaporation of some coastal stations

STATION / MONTH	MSABAHA (93.40007)		LAMU (92.40001)		MALINDI (94.40009)		MOMBASA AIRPORT (94.39021)		MOMBASA TOWN (94.39019)	
	Monthly Potential Evaporation	RATIO (%)	M.P.E *	RATIO (%)	M.P.E**	RATIO (%)	M.P.E**	RATIO (%)	M.P.E**	RATIO (%)
JANUARY	167	8.14	219	9.4	210	9.3	211	9.57	206	9.96
FEBRUARY	151	7.36	199	8.55	197	8.7	204	9.25	200	9.67
MARCH	176	8.58	220	9.45	215	9.52	221	10.02	216	10.44
APRIL	162	7.89	182	7.82	185	8.23	180	8.16	176	8.51
MAY	140	6.82	173	7.43	171	7.57	152	6.89	119	5.75
JUNE	126	6.14	162	6.90	156	6.91	148	6.7	137	6.62
JULY	130	6.34	166	7.23	156	6.91	144	6.53	129	6.24
AUGUST	141	6.87	185	8.07	175	7.45	162	7.34	137	6.62
SEPTEMBER	157	7.65	193	8.29	191	8.46	181	8.21	169	8.17
OCTOBER	173	8.43	214	9.2	202	8.94	198	8.98	191	9.24
NOVEMBER	158	7.70	206	8.85	195	8.63	200	9.07	196	9.48
DECEMBER	160	7.80	205	8.81	205	9.07	204	9.25	196	9.48
ANNUAL	2052		2327		2259		2205		2068	

(Evaporation in mm and ratios in percentage)

** M.P.E is used as an abbreviation for Monthly Potential Evaporation
Source of Monthly potential evaporation: Woodhead, T., 1968 "Studies of potential evaporation in Kenya".

7. Estimated monthly potential evaporation for Chonyi, Kaloleni, Giriama and Gotani

MONTH / STATION	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Chonyi	212	206	222	181	122	141	133	141	174	197	202	198	2128
Kaloleni	214	208	225	183	124	142	134	142	176	199	204	200	2151
Giriama	214	208	225	183	124	143	134	176	199	204	204	200	2152
Gotani	218	212	228	186	126	145	137	145	179	202	207	203	2188

Table 8. Mean monthly rainfall (mm) data for Chonyi, Kaloleni, Giriama and Gotani

STATION Name	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Chonyi	36.2	21.2	47.9	130.1	245.9	85.5	88.9	80.2	97.2	120.4	110.7	76.5	1128
Kaloleni	34.0	29.7	36.8	123.0	194.6	98.6	42.7	72.1	80.4	118.5	104	107.1	1068
Giriama	31	19.9	48.5	125.1	211.2	89.4	66.1	82.2	64.8	106.7	93.5	55.8	978
Gotani	26.8	24.7	37.9	130.2	141.5	51.0	45.1	65.6	42.7	67.3	100.8	80.2	825

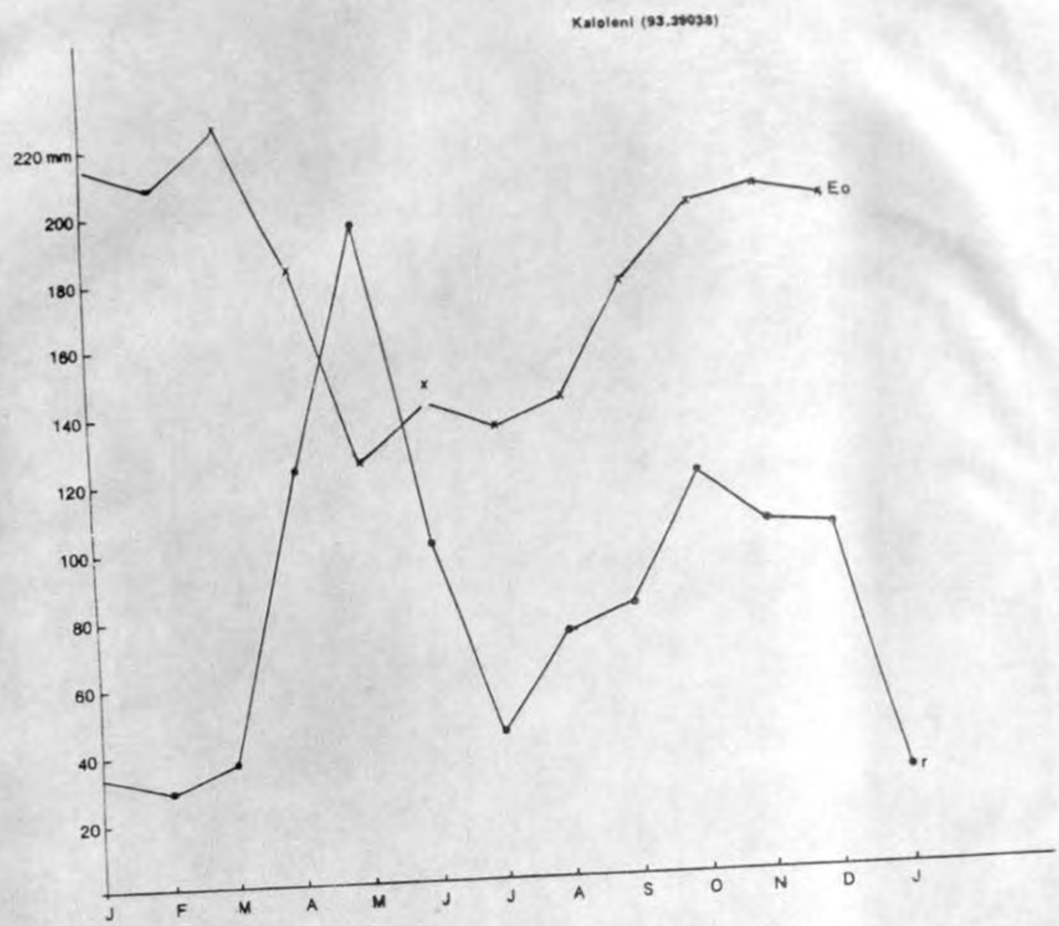
Table 7 shows that the potential evaporation increases from Chonyi (in the east) to Gotani (in the west). Rainfall decreases following the same trend, see table 8. Potential evaporation is highest when the rainfall is lowest, viz. in the months of October to March and decreases to a minimum as the rainfall increases in the April-August period. Therefore it can be concluded that potential evaporation increases with decrease in rainfall both in time and space for the study area.

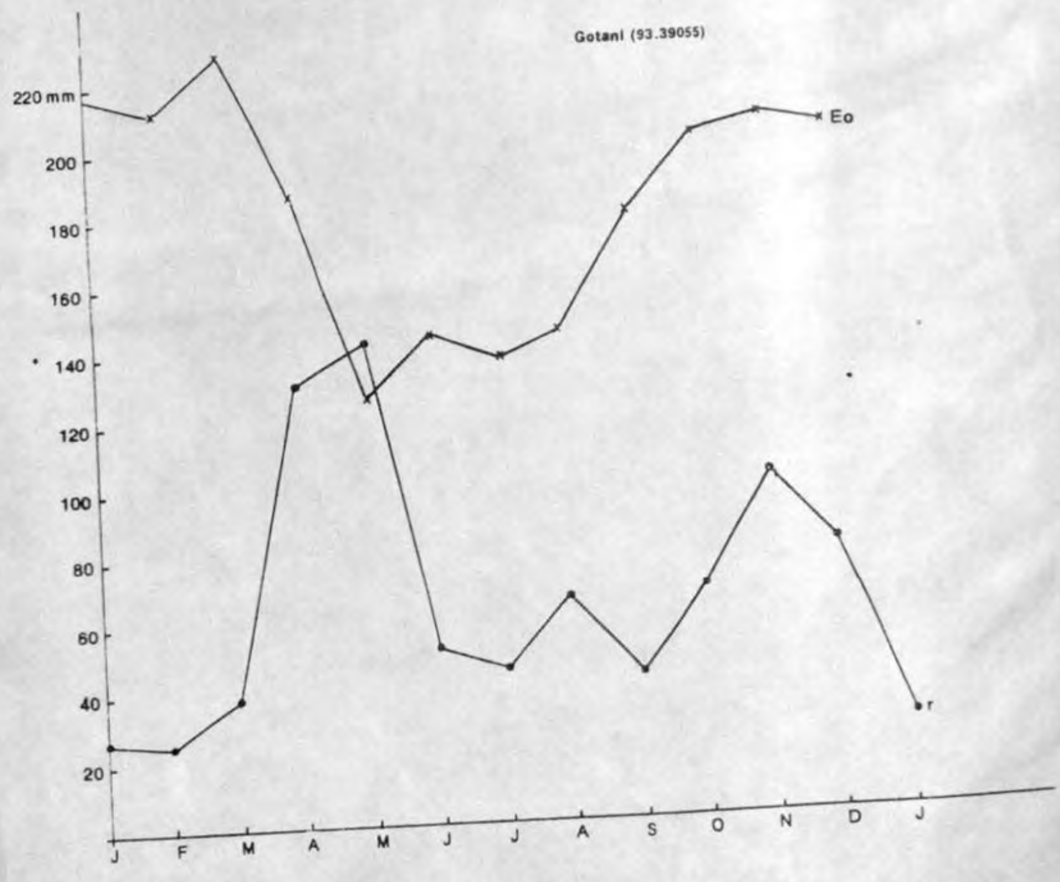
4.2.5 Monthly Rainfall and Potential Evaporation

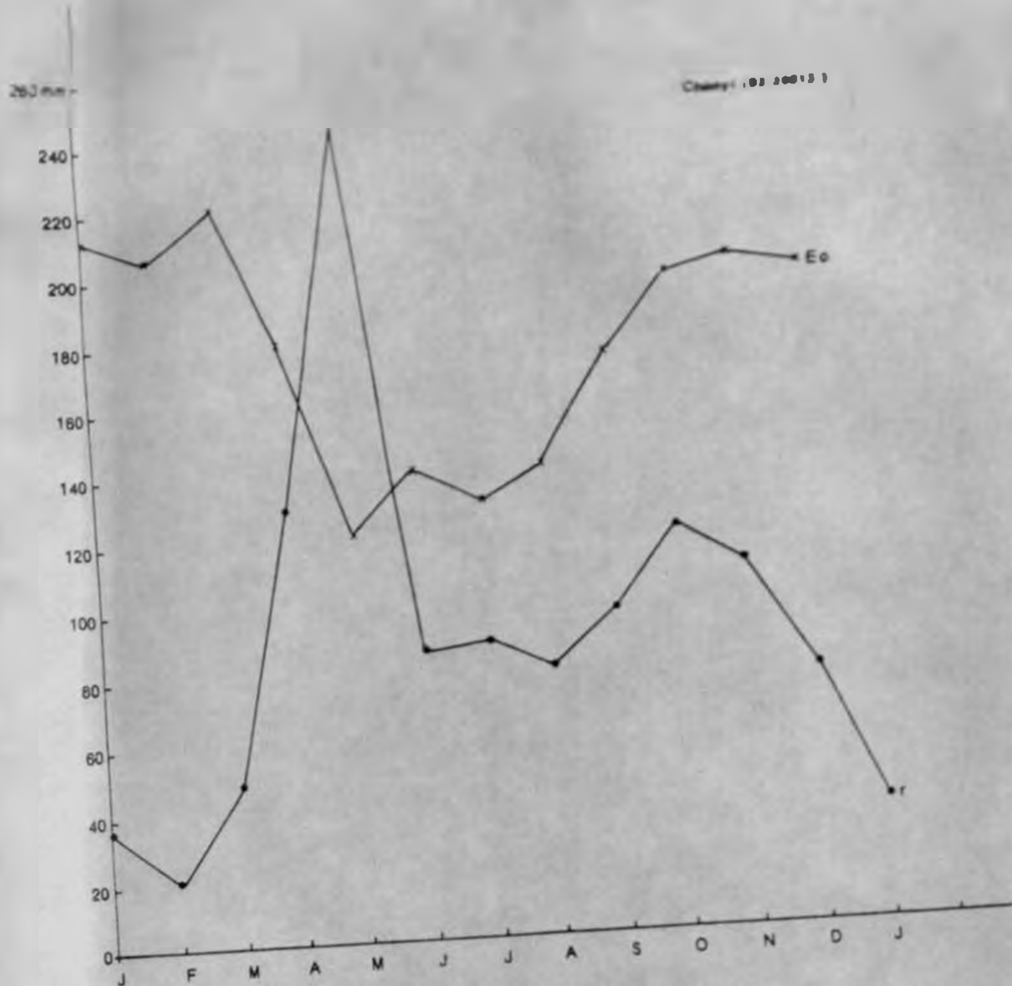
The rainfall in the study area is characterized by a bimodal pattern with the 'long' rainy season lasting from April to June with a peak in May. The intensity of the peak however, decreases from over 204mm in Chonyi (in agroclimatic zone III) to about 140mm, in Gotani (in agroclimatic zone V). The 'short' rainy season lasts from September to December with a peak in October except for Gotani where the peak is in November. The average monthly rainfall of the four stations is given in Table 8 and plotted in figure 2. The monthly potential evaporation is also plotted for comparison.

The monthly potential evaporation exceeds monthly rainfall during most of the months of the year except during the April-June rainy season for all the stations. Thus the area suffers moisture deficits even during the 'short' rainy September-

FIG 2. MONTHLY RAINFALL (r) AND POTENTIAL EVAPORATION (Eo) OF CHONYI, GIRIAMA, KALOLENI AND GOTANI







260 mm
240
220
200
180
160
140
120
100
80
60
40
20
0
Eo
r
J
F
M
A
M
J
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O
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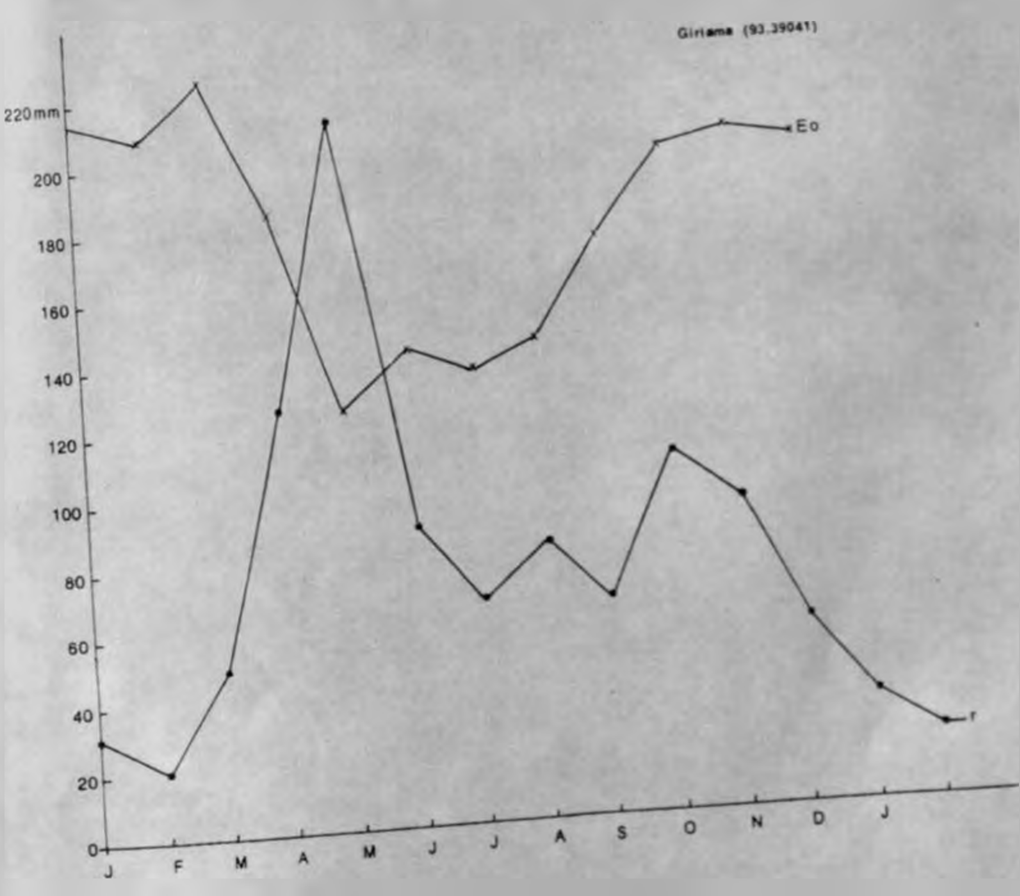


Giriama (93.39041)
220 mm
200
180
160
140
120
100
80
60
40
20
0
Eo
r
J
F
M
A
M
J
J
A
S
O
N
D
J

December season. Taking months with less than 50mm rainfall as dry months, Chonyi, Kaloleni and Giriama experience dry months from January to March while in addition, June, September and December are also dry months for Gotani.

5. RESULTS AND DISCUSSIONS

5.1 GEOLOGY, PHYSIOGRAPHY AND THEIR RELATION TO SOIL TYPES

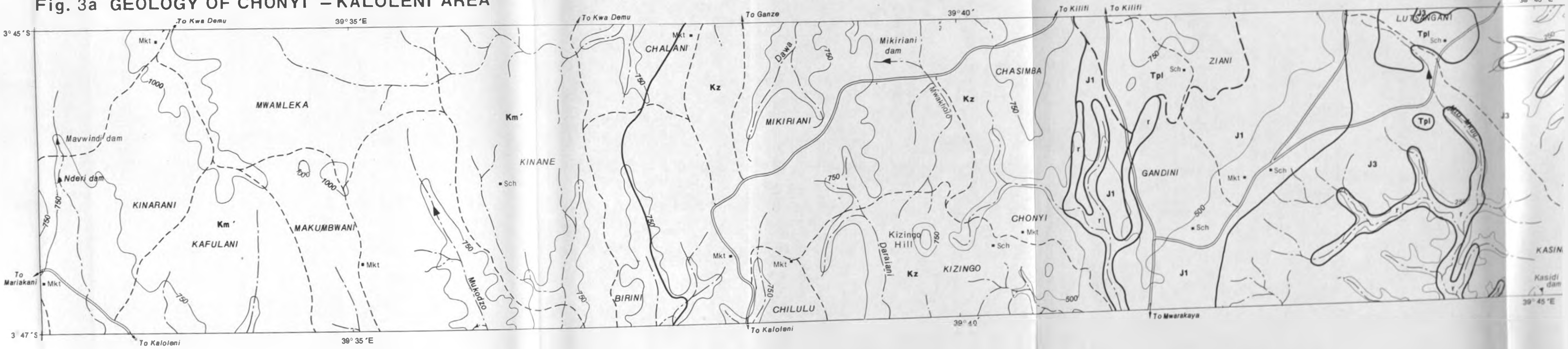
The study area is part of the 'Kilifi-Mazeras area' originally mapped by Caswell (1956). During the time of this study the geology was under revision by the Mines & Geology Department. The study area is covered by five formations of sedimentary origin dating from Triassic to Pleistocene Ages. The rocks dip gently eastwards, consequently they become younger towards the east. The formations mapped by Caswell (1956) in the study area are shown in figure 3a. These formations include:

1. Mariakani Sandstones
2. Mazeras Sandstones
3. Kambe Limestones
4. Upper Jurrasic Shales
5. Magarini Sands

The physiographic units are closely related to the geological formations and are shown in figure 3b. Each of these formations, its associated physiography and soil types developed from each, are briefly described below.

The Mariakani Sandstone covers the area north and north-west of Kaloleni. It consists of fine grained arkoses and flaggy siltstones with occasional shale bands, the latter being exposed at Gotani and

Fig. 3a GEOLOGY OF CHONYI – KALOLENI AREA



SCALE 1:50.000

Metres 1000 500 0 1 2 3 4 5 6 7 8 Kilometres

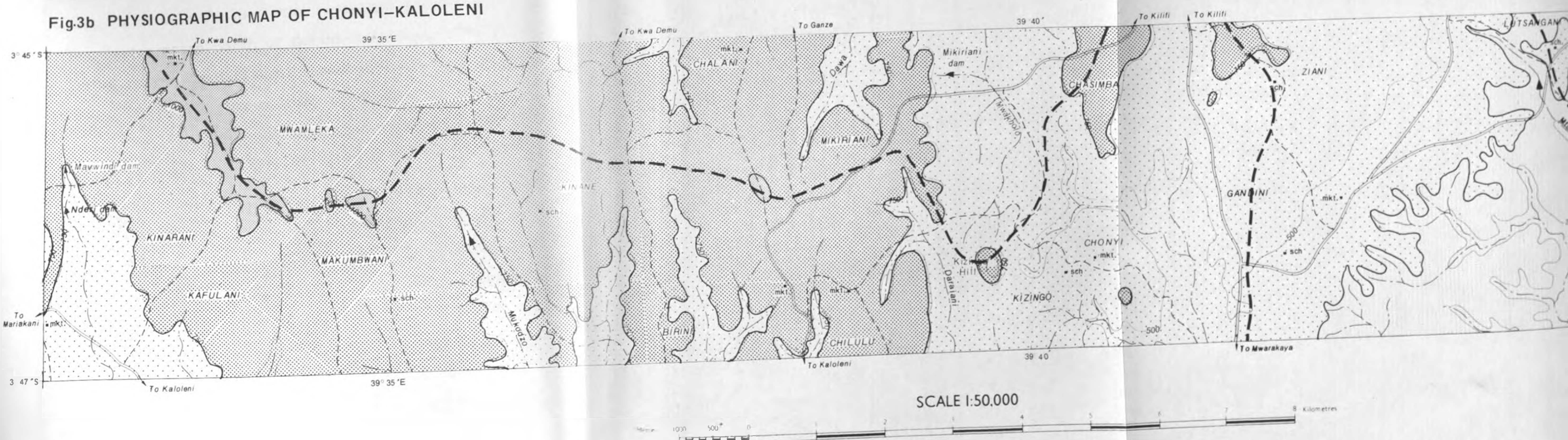
LEGEND

r	Alluvium (RECENT)
Tpl	Magarini Sands (PLIOCENE)
J3	Upper Jurassic Shales (JURASSIC)
J1	Kambe Limestone (JURASSIC)
Kz	Mazeras Sandstones (TRIASSIC)
Km´	Mariakani Sandstones (TRIASSIC)

KEY

- geological boundary
- uncertain geological boundary
- road
- motorable track and footpath
- Mkt. market
- Sch. school
- river / dam
- cattle dip
- 1000 / 750 contour V.I. 250 ft

Fig.3b PHYSIOGRAPHIC MAP OF CHONYI-KALOLENI



LEGEND

OVER 1,000 FEET	350–750 FEET
750–1,000 FEET	LESS THAN 350 FEET

KEY

- water shed
- road
- motorable track and foot path
- mkt. market
- sch. school
- river / dam
- cattle dip
- 1000, 750 Contour V.I 250 ft

Kizurini. The sandstone is composed mainly of quartz and feldspar in a ratio of 3:2 cemented by muscovite and some chloritic minerals. The sandstones show a regional dip of 2^{o}E. Weathered specimens are yellowish brown with dark brown 'mottles'. A more resistant, massively bedded sandstone, limestone are exposed north of Kaloleni-Gotani road.

The Mariakani Sandstones forms a gently undulating landscape with only a few V-shaped valleys for example Mukodzo river valley. Slopes of upto 7% are common in this landscape. The resistant sandstones form a minor scarp north of Gotani-Kaloleni. The soils developed from the Mariakani Sandstones are excessively drained, very deep, brown loamy fine sands of unit $QcFe_4$. Developed from the shale bands are well drained, deep, dark red sandy clays of unit $LcFw_1$.

The Mazeras Sandstones, now thought of as being an upper member of the Mariakani Sandstones, outcrops east of Kaloleni. The Mazeras Sandstones are coarse grained, gritty quartzo-feldspatic sandstones cemented by muscovite or silica. There are bands of shales in this formation which may be yellow, grey, brownish, green or purple in colour. The shales outcrop in the Mwakholo valley in the study area. The sandstones are faulted e.g. north of Chief's Camp Chonyi. Manganese and ferruginous concretions found in some profiles are associated with this faulting. Overlying the sandstones are red sands which probably belong to the Magarini Sands.

The Mazeras Sandstones forms a strongly dissected landscape marked on the eastern side by a ridge of hills. Kizingo and Chasimba hills which rise to 229 and 290 metres respectively are the prominent features in this landscape. The lowest part of the landscape is the Mwakholo valley consisting of marls

On the hill crests are the well drained, very deep sandy clay loamy soils of unit $AoCw_2$, while developed on the flanks are well drained, very deep, yellowish red sandy clay soils of unit $LcCw_1$. On the flanks of Kizingo hill are imperfectly drianed deep red sandy clay soils while developed from the marls in Mwakholo valley are poorly drained, deep olive clays of unit $LgAp_1$.

The Kambe Limestone outcrops east of the Mazeras Sandstone which they overlie uncomfortably. In this study area they are pale brown to grey, oolitic limestone of low sand content. The limestone appears strongly jointed due to solution effects (Caswell, 1956). Large boulders are commonly found forming pinnacles. An outlier of Magarini Sands covers the Kambe Limestone in Ziani area as shown in fig. 3a. In the study area, the Kambe Limestone forms a low ridge rising to about 240 metres in some parts. Slopes here are generally less than 10%.

Developed from the Kambe Limestone are well drained very deep, dark red sandy clays of unit $NdLw_1$. From the Magarini Sand outliers are developed sandy clay loams with gravel or ironstones in the subsoil. In the valley west of Gandini school are developed soils of varying colour, depth and drainage conditions of unit LV/Vp/I.

The Upper Jurassic Shales outcrop east of the Kambe Limestone. They are indurated, well laminated, easily fragmented, dark grey to green in colour. The majority of the shales are calcareous and in places contain septarian nodules in the succession. The Upper Jurassic Shales form a strongly dissected landscape characterised by many V-shaped valleys. On the elevated parts of this landscape are Magarini Sands outliers. The base of the 'Magarini caps' is marked by well sorted gravels which become coarser towards the base.

Developed on the ridge crests of the Shale landscape are imperfectly drained, deep, olive brown to brown cracking clays of unit $VcTi_1$. In the minor valleys and valley sides are developed soils with varying drainage condition, depth, and colour conditions in unit BV/Vp.

Magarini Sands outcrop east of the upper Jurassic Shales and as outliers in the Jurassic Shales, Kambe Limestone and possibly Mazeras Sandstones.

These unconsolidated sands are of a disputed aeolian origin and consist mainly of quartz and feldspars coated with oxides which give them their bright red colour. The upper layers are medium grained becoming coarser at the base. Underlying the sands in Wimbi river valley are yellowish marls probably parts of Marafa beds (Thompson, 1956).

The Magarini Sands form the coastal ridge east of the Shales with deeply incised valleys, e.g. Wimbi valley east of Pingilikani. Developed from the Magarini Sands are well drained, very deep, medium grained, red sandy clay loam soils of unit $FrMw_2$. In the Wimbi valley soils of varying drainage conditions, depth, colour and texture has developed from the various parent materials present.

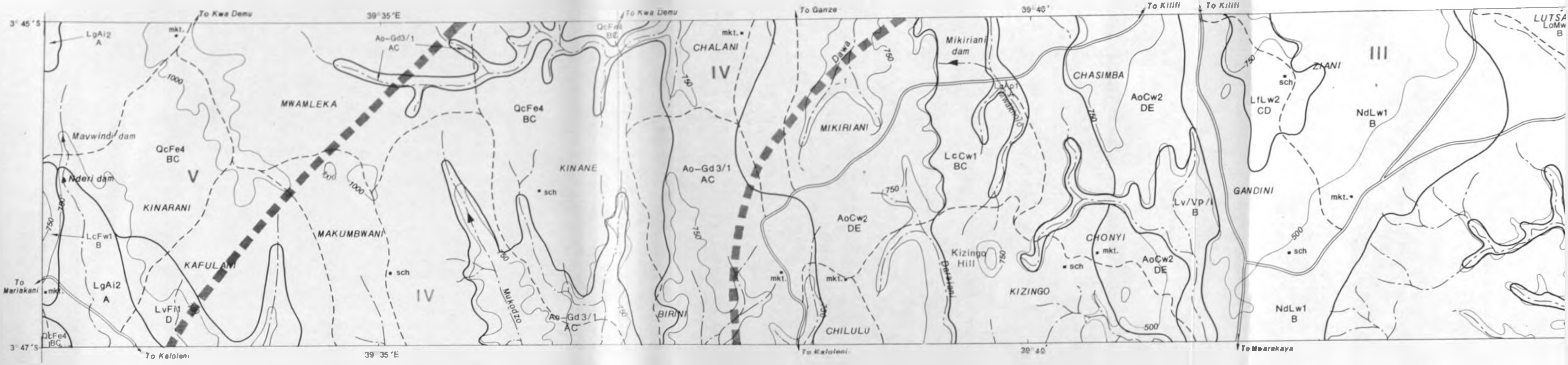
5.2 SOILS

The study area comprises soils with widely varying characteristics, notably texture, consistence, cation exchange capacity, colour and drainage conditions due largely to differences in their parent materials.

In all, about 200 augerings, 44 profile pits, a road cut and a sand pit were described. The location of these observations is shown in fig. 4b. Representative profiles were sampled and analysed in the laboratory. Six major soils, viz. VERTISOLS, ARENOSOLS, NITOSOLS, FERRALSOLS, ACRISOLS and LUVISOLS and four minor ones, viz. GLEYSOLS, CAMBISOLS, LITHOSOLS and FLUVISOLS were identified. These soil units, their associations or complexes were described in sixteen mapping units which are delineated on a soil map, fig. 4a, at a scale of 1:50,000.

Brief descriptions of these mapping units are given in the soil map legend. In the following description of each mapping unit, the general environmental conditions, profile characteristics, range of characteristics and soil classification are given. In the range of characteristics only those properties with marked variations are described. The representative profile(s) for each unit are given in Appendix 2.

Fig.4a. SOIL MAP OF CHONYI-KALOLENI AREA



SCALE 1:50,000

Metres 1000 500 0 2 8 Kilometres

LEGEND

V – VERTISOLS

VcTi1 — imperfectly drained, deep to very deep yellowish brown to light olive brown, very firm, cracking clay, overlying shale fragments (chromic VERTISOLS)

Q – ARENOSOLS

QcFe4 — excessively drained, very deep, yellowish brown to pale brown, loose, very fine sand to loamy very fine sand (cambic and albic ARENOSOLS)

F – FERRALSOLS

FrMw2 — well drained, very deep, dark red to dusky red, friable sandy clay loam, underlying 10–30cm sandy loam (rhodic FERRASOLS)

A – ACRISOLS

AoCw2 — well drained, very deep, red, friable sandy clay loam, overlying 20–40cm coarse sandy loam (orthic ACRISOLS)

L – LUVISOLS

LgAp1 — poorly drained, moderately deep, brown to yellow, mottled, very firm clay, underlying 10–20cm very dark greyish brown, friable clay loam (gleyic LUVISOLS)

LgAi2 — imperfectly drained, very deep, yellowish brown to light olive brown, mottled, very firm clay loam, with calcium carbonate concretions (gleyic LUVISOLS)

LvFi1 — imperfectly drained, deep to very deep, yellowish brown to light olive brown, mottled, very firm, cracking sandy clay, underlying 10–20 cm fine sand to loamy fine sand (vertic LUVISOLS)

LfLw2 — well drained, moderately deep to deep, dark reddish brown, friable sandy clay loam, overlying concretionary nodules, in places over ironstone (ferric LUVISOLS)

LcFw1 — well drained, deep, dark reddish brown, firm to very firm, sandy clay, underlying 0–10cm sandy loam (chromic LUVISOLS)

LcCw1 — well drained, very deep, yellowish red to strong brown, friable to firm, sandy clay, in places sand (chromic LUVISOLS)

LcMw1 — well drained, very deep, yellowish red, friable to firm, sandy clay, with 10–25cm sandy clay loam topsoil, in places overlying concretionary nodules (chromic LUVISOLS)

NdLw1 — well drained, very deep, dark red to dusky red, friable, fairly rocky, sandy clay to clay (dystric NITOSOLS)

ASSOCIATION

Ao-Gd 3/1 — association of
– well drained, very deep, yellowish red to yellowish brown, friable to firm, fine sandy loam, overlying 20–60cm fine sand (orthic ACRISOLS)
– poorly drained, very deep, grey, mottled, firm to very firm, sandy clay to clay (dystric GLEYSOLS)

COMPLEXES

Lv/Vp/I — complex of –
– imperfectly drained, very deep, yellowish brown, firm clay loam (vertic LUVISOLS)
– poorly drained, deep, dark yellowish brown to dark greyish brown, very firm, cracking clay (pellic VERTISOLS)
– well drained, shallow, brownish yellow to dark brown, sandy clay loam, overlying bedded limestone (LITHOSOLS)

Bv/Vp — complex of –
– imperfectly drained, very deep, light olive brown to light brownish grey, mottled, firm, cracking clay (vertic CAMBISOLS)
– poorly drained, very deep, very dark greyish brown, very firm, cracking clays (pellic VERTISOLS)

Lv/Lc/J — complex of soils of varying drainage conditions, depth, colour, consistence and texture (vertic LUVISOLS, chromic LUVISOLS and FLUVISOLS)

KEY

NdLw1
B

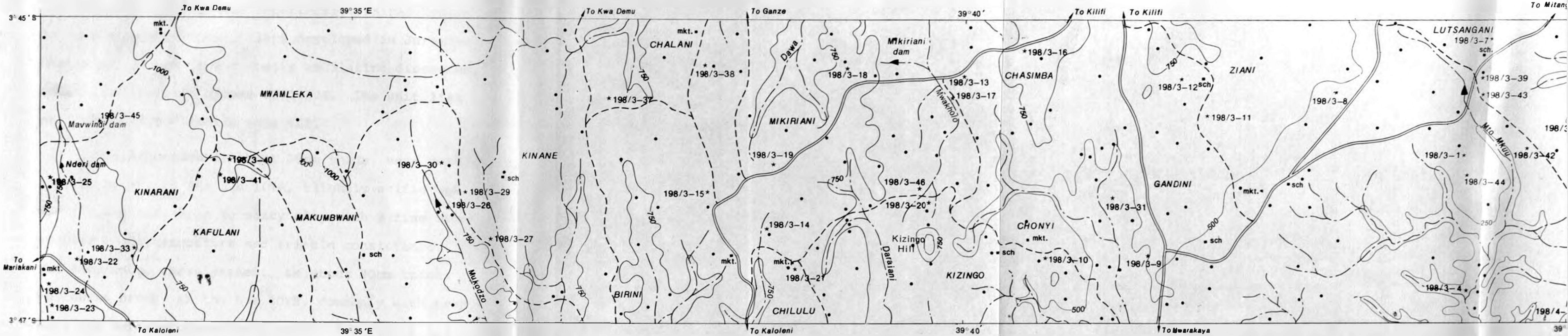
3 Sq cm

mkt.

sch.

—1000—
—750—

Fig. 4b LOCATION OF PROFILE PITS AND AUGERINGS



SCALE 1:50,000

Metres 1000 500 0 1 2 3 4 5 6 7 8 Kilometres

KEY

*198/3-21	profile pit, with reference number	
•	augerhole	
road		
motorable track and footpath		
• mkt	market	
• sch	school	
river / dam		
cattle dip.		
1,000 / 750	contour V.I 250 ft	

5.2.1 Mapping unit $VcTi_1$ - Extent: 2380 hectares.

This unit comprises imperfectly drained, deep to very deep (80-160cm), clays developed in Jurassic Shales and occurs in a strongly undulating dissected, coastal upland with slopes of 0-10%. The unit lies entirely in agroclimatic zone III.

The A-horizon is about 15cm thick, very dark greyish brown, in the hue 10YR, slightly acidic (pH 6.0), silty clay loam to silty clay with a fine sub-angular blocky structure and friable consistence. The B-horizon, where present, is about 30cm thick, yellowish brown, in the hue 10YR, commonly with prominent red mottles; moderately acidic (pH 5.5) clays. It has a medium to coarse angular blocky structure with a very firm consistence. The C-horizon is over 70cm thick. It is yellowish brown to light olive brown or grey, in the hues 10YR and 2.5Y, with yellowish red or dark brown mottles, moderately alkaline (pH 8.0), calcareous and cracking clay with a coarse angular blocky structure and a very firm consistence (see Plate 1). Manganese and/or iron concretions are common in the subsoil. The available moisture storage capacity to a depth of 150cm is 110mm and the subsoil has a low vertical permeability.

The clays have a high CEC, % carbon and base saturation. However, there are marked variations in pH, CEC, % carbon and the thickness of the A-horizon.

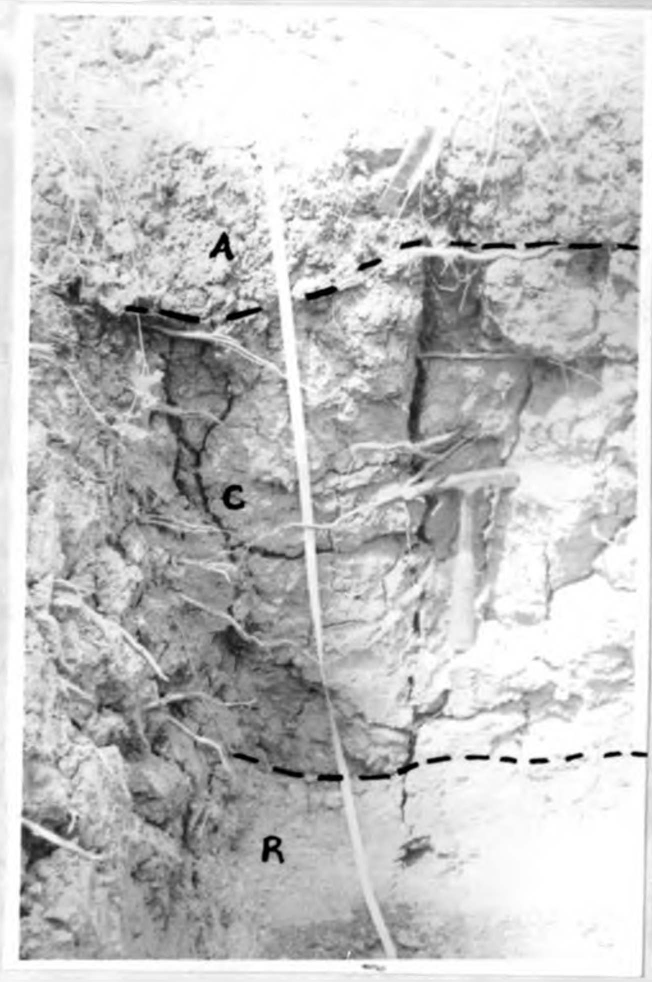


Plate 1. A Chromic VERTISOL in unit $VcTi_1$.

A - fine subangular blocky A-horizon

C - coarse angular blocky C-horizon

R - weathering shale fragments

note: The wide vertical cracks in the C-horizon

- coconut roots which are concentrated along ped faces and cracks

The A-horizon is 12 to 28cm thick with % carbon ranging from 0.95 to 2.4%. The base saturation and pH increase with depth from 67% to 100% and 5.4 to 8.0 respectively. Cation exchange capacity ranges from 13 to 50 me/100g soil.

The soils were classified as Chromic VERTISOLS in the FAO legend and as Palleustollic CHROMUSTERTS in the Soil Taxonomy.

5.2.2 Mapping Unit $QcFe_4$ - Extent: 3140 hectares

This mapping unit comprises excessively drained, extremely deep (more than 160cm), loamy sand and/or sandy loams, developed in fine grained Mariakani Sandstones. It occurs in a gently undulating coastal upland with 2-8% slopes and lies in agroclimatic zones IV and V.

The A-horizons are up to 90cm thick. They are dark to yellowish brown, in the hue 10YR, slightly acidic (pH 6.3), loamy fine sands with a single grain to porous massive structure and loose to very friable consistence. The B-horizons (where present) are yellowish brown, in the hue 10YR, moderately acidic (pH 5.6), loamy fine sands to fine sands with a porous massive structure and a friable consistence. The B-horizon is about 30cm. The C-horizons are generally more than 100cm thick. They are yellow to pale brown, in the hue 10YR, moderately acidic (pH

5.7), loamy fine sand to fine sand with a porous massive structure and a friable consistence. The loamy fine sands have a low available moisture storage capacity of about 40mm in the rootable 200cm depth. Their vertical permeability is high but the surface is susceptible to sealing.

The top and sub-soil of the loamy fine sands have a very low CEC of about 4 and 3 me/100g soil and base saturation of about 70% and 45% respectively. The pH, CEC, base saturation and the thickness and % carbon content of the A-horizon show marked variations. The CEC ranges from 1.2 to 6.6 me/100g soil, the base saturation from 43% to 85% and pH from 5.4 to 7.8, the latter value being that of a calcareous B-horizon. The thickness of the A-horizon ranges from 30 to 90cm while % carbon ranges from 0.06 to 0.74%.

These sands were classified as Cambic and albic ARENOSOLS in the FAO legend and as typic QUARTZIPSAMMENTS in the Soil Taxonomy.

Inclusions of poorly drained, moderately deep, sandy loams with compacted subsoils occur in minor valleys and depressions of this unit (see Plate 2).

5.2.3 Mapping unit $FrMw_2$ - Extent: 732 hectares

This unit comprises well drained, excessively deep (more than 160cm), sandy clay loams developed in Magarini Sands. It occurs on the coastal ridge

Plate 2. A gleyic LUVISOL in a local depression in unit $QcFe_4$.

note: the single horizontal root along the abrupt boundary between A and B horizons.

with slopes of up to 22% and lies in agroclimatic zone III. The unit has a thick oxic B-horizon.

The A-horizon is about 28cm thick, dark reddish brown, in the hue 2.5YR, slightly alkaline (pH 7.1), loamy sand with a weak fine subangular blocky structure and a friable consistence. The oxic B-horizon is very thick, i.e.more than 120cm, dark to dusky red, in the hue 2.5YR, slightly acidic (pH 6.0), sandy clay loam with a porous massive structure, which becomes coarse prismatic when dry and with a friable consistence. The available moisture storage capacity is about 100mm in a 160cm deep profile. Vertical permeability is high but on the steep slopes run-off is also high.

The sandy clay loams have a low CEC of about 6.2 and 2.4 me/100g soil in the topsoil and subsoil respectively. The base saturation is over 75% in the entire profile but the % carbon is low, about 0.61 in the topsoil.

The pH and slopes show marked variations. The pH decreases from 7.1 in the topsoil to 5.5 in the subsoil. On the crest the slope is 7% but increases to about 22% on the flanks.

The sandy clay loams were classified as Rhodic FERRALSOLS in FAO legend and as typic EUSTRUSTOX in the Soil Taxonomy.

5.2.4 Mapping Unit $NdLw_1$ - Extent: 1090 hectares

Unit $NdLw_1$ comprises well drained, very deep to extremely deep (more than 160cm), sandy clays developed from oolitic Kambe Limestone in a fairly rocky, gently undulating coastal upland with slopes of up to 5%. The unit lies in agroclimatic zone III.

Profiles in this unit are characterised by a moderately thick A-horizon and a thick argillic B-horizon but generally with no C-horizon. The A-horizon is about 20cm thick, dark reddish brown to dusky red, in the hues 5YR and 2.5YR, slightly acidic (pH 6.2), sandy clay loam with a moderate fine crumb structure and a friable consistence. The B-horizon is over 200cm thick, dusky red in the hues 10R and 2.5YR, slightly acidic (pH 6.3), friable sandy clay with a moderate, medium subangular blocky structure and common thin clay cutans. Although developed from limestone the profiles are not calcareous and are very deep even when an auger is located next to a rock outcrop. The profile is not stony. Vertical permeability is high and the soil has an available moisture storage capacity of about 180mm over a depth of 160cm.

The topsoil and subsoil of this unit have a CEC of about 9 and 6 me/100g soil and base saturation of about 80 and 40% respectively. The % carbon in topsoil and subsoil is 0.7 and 0.25 respectively. The characteristics of the profiles in this unit do not vary widely except CEC which ranges from 4.8 to 9.4 me/100g soil and base saturation which ranges from about 80% in topsoil to about 40% in the lower parts of the B-horizon.

The soils of this unit were classified as Dystric NITOSOLS in the FAO legend and as typic RHODUSTULTS in the Soil Taxonomy.

On the elevated parts of this unit, sandy clay loams of unit Lfw_2 occur as inclusions.

5.2.5 Mapping Unit $AoCw_2$ - Extent: 1415 hectares

The soils of this unit are well drained, extremely deep (more than 160cm), sandy clay loams developed from coarse grained Mazeras Sandstones. They occur on the crests of hilly coastal uplands with slopes of up to 22% and lie in agroclimatic zone III. The dark red colour in this unit is probably due to the influence of Magarini sand caps on the crests.

The A-horizon is about 17cm thick, dark reddish brown in the hue 5YR, slightly acidic (pH 6.2), friable to loose sandy loam with a porous massive structure. The B-horizon is more than 150cm thick, dark red, in the hues 10R and 2.5YR, moderately acidic (pH 5.8), friable to firm sandy clay loam with a weak, fine to medium subangular blocky structure and few thin clay cutans. The vertical permeability is high but the available moisture storage capacity is low, about

52mm in the rootable 160cm depth.

The % carbon is low, less than 1% in the entire profile. The CEC is about 5.6 and 4 me/100g soil in the topsoil and subsoil respectively while the base saturation is above 50% except in the lower subsoil where it falls below 50%. The pH decreases from 7.2 in the topsoil to 4.6 in the subsoil. The CEC ranges from 6.6 me/100g soil in the topsoil to 3.0 me/100g in some parts of the B-horizons. Base saturation also shows a decreasing trend with depth from 83% to 33% in some parts of the B-horizon.

Since the base saturation was less than 50% in the lower part of the B-horizon in most profiles, these sandy clay loams were classified as orthic ACRISOLS in the FAO legend and as oxic HAPLUSTULTS in the Soil Taxonomy.

Sand pockets occur as inclusions in this unit but these are of insignificant extent.

5.2.6 Mapping Unit $LgAi_2$ - Extent: 213 hectares

Unit $LgAi_2$ comprises imperfectly drained, very deep, (up to 190cm depth), calcareous clay loams developed in Pleistocene 'bay sediments'. It occurs in an undulating plain with slopes of up to 2% and lies in agroclimatic zone V.

The A-horizons are about 20cm thick, dark brown, in the hue 10YR, moderately acidic (pH 5.8), firm sandy clay loams with porous massive structures. The A-horizon is very susceptible to surface sealing. The B-horizons are over 160cm thick, yellowish to olive brown, in the hues 10YR and 2.5Y; slightly to moderately alkaline (pH 7.2 and 8.0), mottled, very firm clay loams with coarse angular blocky structures with common, moderately thick clay cutans. The C-horizons, where present, are light olive brown, in the hue 2.5Y, moderately to strongly alkaline (pH 8.4) clay loams abruptly overlying rock. The subsoil has few, fine, manganese and coarse calcium carbonate concretions.

The vertical permeability in this unit is low and it has an available moisture storage capacity of 130cm over a depth of 135cm.

The topsoil has a CEC and base saturation of about 14 me/100g soil and 65% respectively. The % carbon is low. The subsoil CEC and base saturation are high, over 16 me/100g and 70% respectively. The pH, CEC and base saturation show some marked variations. The pH increases from 5.6 in the topsoil to 8.1 in the subsoil, CEC from 6.4 to 22 me/100g soil and base saturation from 64 to 100% down the profile.

These clay loams were classified as gleyic LUVISOLS in the FAO legend and as vertic ALBAQUALFS in the Soil Taxonomy.

5.2.7 Mapping unit $LgAp_1$ - Extent: 55 hectares

This unit comprises poorly drained, very deep (more than 120cm) clays developed from calcareous marls in the Mazeras Sandstones. It occurs in the deeply incised Mwakholo river valley and lies in agroclimatic zone III. Annual floods are common in this valley.

The A-horizon is dark brown, in the hue 10YR, moderately acidic (pH 5.8), friable, mottled loam with a weak medium crumb structure and is about 25cm thick. The B-horizon is about 40cm thick, brown, in the hue 7.5YR, near neutral (pH 6.6), very firm, mottled clay with a fine to medium angular blocky structure. This horizon has continuous clay cutans. The lower part of the B-horizon is reddish brown, in the hue 5YR, moderately alkaline and strongly calcareous. The C-horizon is a light grey, in the hue 7.5YR, moderately alkaline (pH 8.2), very firm mottled clay with a coarse subangular blocky structure. There are vertical cracks and manganese concretions in the subsoil. Underlying the C-horizons are pale green marls. The clays are very susceptible to erosion where the slopes are high.

The clays have a moderate CEC of about 11 and 15 me/100g soil in the topsoil and subsoil respectively. The base saturation is over 80% in the entire profile while organic carbon in the A-horizon is about 0.9%. The electrical conductivity (EC) of

1:2.5 soil suspension in water is high in the subsoil, about 2.0 mmhos/cm. The electrical conductivity of the saturation extract (ECe) is 5.5 to 10.0 mmhos/cm in the lower part of B-horizon and C-horizon respectively. The subsoil has a high content of magnesium which probably arises from a high magnesium content in the parent marls.

The clays were classified as gleyic LUVISOLS in the FAO legend and as vertic ALBAQUALFS in the Soil Taxonomy.

5.2.8 Mapping unit $LvFi_1$ - Extent 193 hectares

This unit comprises imperfectly drained, deep to very deep (about 125cm deep), sandy clays developed from fine grained Mariakani Sandstones, and occurs on a gentle scarp separating a Coastal upland and a Plain. The scarp has slopes of up to 16% and lies in agroclimatic zones IV and V.

The topsoil is dark greyish brown, in the hue 10YR, slightly acidic (pH 6.2), very friable, sandy loam with a porous massive structure. The A-horizon thickness is variable since this unit is transitional from $QcFe_4$ to $LgAi_2$.

The B-horizon is about 80cm thick, dark greyish brown to olive brown, in the hues 10YR and 2.5Y, near neutral (pH 6.6), mottled, very firm sandy clay with a coarse angular blocky structure and common, moderate clay cutans. There are vertical cracks in the B-horizon and the lower parts of the B-horizon are calcareous. The vertical permeability is low in the subsoil. The profile has a low available moisture storage capacity of about 95mm over the entire 125cm deep profile.

The CEC and base saturation in the A-horizon is about 8.8 me/100g soil and 80% respectively. The organic carbon is about 0.7% in the same horizons. The subsoil has a CEC of about 16 me/100g soil and a base saturation of about 90%. The thickness of the A-horizon, CEC and base saturation show marked variations. A-horizon thickness ranges from 8.8 to 18.2 me/100g soil and 73 to 100% respectively, generally increasing with depth.

The soil was classified as a vertic LUVISOL in the FAO legend and as an aquic arenic PALEUSTALF in the Soil Taxonomy.

5.2.9 Mapping unit $LfLw_2$ - Extent: 100 hectares

This unit consists of well drained, moderately deep (105cm), sandy clay loams developed from medium grained sands and occurs on the elevated parts of the Coastal uplands with slopes up to 11% near Gandini, and lies in agroclimatic zone III.

The A-horizon is about 12cm thick, reddish brown, in the hues 5YR and 2.5YR, moderately acidic (pH 5.9), friable sandy loam with a weak crumb structure. The B-horizon is at least 65cm thick, reddish brown, in the hue 2.5YR, slightly acidic (pH 6.1), friable, sandy clay loam with a porous massive structure and patchy thin clay cutans. The B-horizon is underlain by either a gravelly sandy clay loam layer and/or a broken ironstone layer at 80cm depth. The ironstone consists of concretionary nodules about 2mm in diameter, whose exteriors are redder than interiors. The profile has a high permeability but decreases considerably in the ironstone layer. The available moisture storage capacity is expected to be moderate but was not determined due to the difficulty of sampling the gravelly layer.

The A-horizon has a CEC and base saturation of about 10 me/100g soil and 70% respectively. The % carbon is high, 1.3%. In the subsoil the CEC and base saturation are lower, about 4.0 me/100g soil and 50% respectively. The thickness of B-horizon, CEC and base saturation are variable. The B-horizon thickness ranges from 65 to 95cm, the CEC from 9.4 to 2.4 me/100g soil generally decreasing with depth while base saturation ranges from 70 to 90%.

The sandy clay loams were classified as <u>ferric LUVISOLS</u> in the FAO legend and as <u>petroferric HAPLUSTULTS</u> in the Soil Taxonomy.

5.2.10 Mapping Unit $LcCw_1$ - Extent: 1928 hectares

This unit comprises well drained, extremely deep (more than 160cm), sandy clays developed from coarse grained Mazeras Sandstones. It occurs on the flanks of ridges and hills with slopes of up to 11% and lies in agroclimatic zone III.

The A-horizon is about 14cm thick, dark brown, in the hue 7.5YR, slightly acidic (pH 6.2), friable sandy clay loam with a porous massive structure. The B-horizon is over 120cm thick, red to yellowish red in the hues 2.5YR and 5YR, moderately acidic (pH 5.3), friable, sandy clay with a weak medium subangular blocky structure and patchy, thin clay cutans. The profile has an apparently high vertical permeability but infiltration may be low due to both surface sealing and moderate slopes. The available moisture storage capacity is about 10 mm/10cm over the entire rootable depth of more than 250cm.

The topsoil CEC is about 7 me/100g soil and a base saturation of about 70%. The % carbon is about 0.74%. In the subsoil the CEC and base saturation are 5.7 me/100g soil and more than 50% respectively.

The thickness of the A-horizon ranges from 25 to 40cm and % carbon from 0.9 to 0.5%. The CEC in the topsoil does not show marked variation but base saturation ranges from 60 to 85%. In the subsoil, the CEC ranges from 3.4 to 8.4 me/100g soil and base saturation from 54 to 85%.

The soils were classified as chromic LUVISOLS in the FAO legend and as oxic PALEUSTULTS in the Soil Taxonomy.

5.2.11 Mapping Unit $LcMw_1$ - Extent: 25 hectares

The unit comprises well drained, very deep (110cm), sandy clays developed from medium grained Magarini Sands. The unit occurs as an inclusion on the elevated grounds of unit $VcTi_1$. At the boundaries of this unit are profiles with gravelly layers and/or two genetic sequences. This unit is in agroclimatic zone III and has slopes of up to 5%.

The A-horizons are reddish brown, in the hues 5YR and 2.5YR, moderately acidic to near neutral (pH 5.4 to 6.9), friable sandy clay loams with weak subangular blocky structure. On average the horizons are about 20cm thick. The weakly developed argillic B-horizons are yellowish red, in the hue 5YR, slightly alkaline (pH 7.5), friable to firm sandy clays with moderate to weak subangular blocky structures and common, thin clay cutans. In places the B-horizon is underlain by concretionary gravels while at the edge of the unit are profiles with two genetic sequences (see Plate 3). The upper sequence resembles profiles of this unit, while the lower sequence resembles the profiles in unit $VcTi_1$. The profiles in this unit have a high

Plate 3. A transitional profile between unit $LcMw_1$ and $VcTi_1$ showing two genetic sequences.

I - sequence with characteristics of unit $LcMw_1$

II - sequence with characteristics of unit $VcTi_1$

note: the gravelly layer at the base of sequence I and the change in structure from subangular blocky to angular blocky in II.

vertical permeability and a high available moisture storage capacity of about 300mm in the rootable 3 metre profile.

The CEC and base saturation in the topsoil are about 8 me/100g soil and about 60% respectively. The % carbon is about 0.5%. The pH, CEC and base saturation are very variable especially in the subsoil. In the topsoil the pH ranges from 5.4 to 6.9, the CEC from 6 to 10 me/100g soil and the base saturation from 64 to 90%. In the subsoil, the colour varies from yellowish red to dark red. In the yellowish red subsoil, pH is about 7.5, CEC about 6 to 14 me/100g soil and base saturation is above 80%. For the red subsoils, pH ranges from 4.7 to 5.1, CEC from 5.6 to 7.6 me/100g soil and base saturation from about 40 to 50%. The red subsoils are limited in extent.

These sandy clays were classified as chromic LUVISOLS in FAO legend and as oxic HAPLUSTULTS in the Soil Taxonomy.

5.2.12 Mapping Unit $LcFw_1$ - Extent: 45 hectares

This unit comprises well drained, deep (110cm), sandy clays developed from shales and siltstones in the Mariakani Sandstones. The unit occurs in an undulating upland in agroclimatic zone V.

The A-horizon is about 10cm thick, yellowish brown, in the hue 10YR, slightly acidic (pH 6.1), friable sandy loam, with a porous massive to single grain structure. The subsoil is reddish brown, in the hue 5YR, near neutral (pH 6.9), very firm sandy clay with a moderate to medium subangular blocky structure and common moderately thick clay cutans. The Bt-horizon is abruptly underlain by rock at 110cm depth. The sandy clays have a moderate vertical permeability and an available moisture storage capacity of about 120mm in the entire profile. In many parts of this unit the A-horizon has been eroded away.

The A-horizon has a CEC of about 10 me/100g soil and a base saturation of about 70%. The organic carbon content is about 0.78%. The subsoil CEC is about 12 me/100g soil with a base saturation of about 80%. The thickness of the A-horizon varies between 0 and 10cm. The pH increases with depth from 5.8 to 8.4, and CEC from 10 me/100g in the topsoil to 17.3 me/100g soil in the subsoil. The base saturation ranges from 58 to over 90% in the subsoil.

The soils in this unit were classified as chromic LUVISOLS in the FAO legend and as PALEUSTALFS in the Soil Taxonomy.

5.2.13 Mapping Unit Ao-Gd 3/1 - Extent: 1155 hectares

This unit is a soil association consisting of two members of a catenary sequence. The dominant member is a well drained, very deep (more than 150cm), sandy loam, occurring on the valley sides and crests of ridges and merging into excessively drained sandy loams of unit $QcFe_4$. The second member of more limited extent is a poorly drained, very deep (more than 160cm) sandy clay to clay occurring in the valley bottoms. Both members are developed from fine grained Mariakani Sandstones. The well drained member occurs on slopes of 5 to 11% and the poorly drained member on 0-2% slopes. The association lies in both agro-climatic zones III and IV.

On the valley sides, the A-horizons are dark yellowish brown to dark brown, in the hues 7.5YR and 10YR, moderately acidic (pH 5.5), friable, loamy fine sands to fine sandy loams with a porous massive structure. The subsoil is yellowish brown to yellowish red, in the hues 7.5YR and 5YR, moderately acidic (pH 5.9), friable to firm sandy loam to sandy clay with a porous massive or weak subangular blocky structure and patchy thin clay cutans. The sandy clays and sandy loams have a high vertical permeability and an available moisture storage capacity of about 300mm over a 3 metre profile.

The topsoil CEC of this member is 6.4 me/100g soil and the base saturation is about 45%. The % carbon is 0.23% in the topsoil. In the subsoil, CEC is about 5.4 me/100g soil, with a base saturation of more than 50%. There are some marked variations in the characteristics of this member. The CEC ranges from 1.8 to 11 me/100g soil, % carbon from 1.1 to

0.2% and base saturation from about 30 to 80%. The pH ranges from 4.7 to 6.5.

The sandy clays and sandy loams were classified as Orthic ACRISOLS in the FAO legend and as arenic HAPLUSTALFS in the Soil Taxonomy.

In the valleys, the A-horizons are about 15cm thick, light yellowish brown to dark grey, in the hue 10YR, moderately acidic (pH 5.9), mottled, friable sandy clay loams with a porous massive structure. The B-horizons are grey, in the hue 10YR, slightly acidic (pH 6.2), mottled, firm to very firm sandy clays to clays with a low permeability.

The topsoil CEC is about 4.8 me/100g soil with a base saturation of about 60%. The organic carbon content is about 0.62%. In the subsoil, the CEC is about 8 me/100g soil and the base saturation about 50%.

The CEC ranges from 4.3 to 11 me/100g soil and organic carbon from 0.2 to 0.72%. In the subsoil the CEC ranges from 5.6 to 15.6 me/100g soil. The base saturation and pH range from 43 to 100% and 5.7 to 7.0 respectively.

These poorly drained soils were classified as dystric GLEYSOLS in the FAO legend and as aeric PALEAQUULTS in the Soil Taxonomy.

5.2.14 Mapping Unit Lv/Vp/I - Extent: 200 hectares

This unit is a soil complex consisting of three members. The first member is an imperfectly drained, very deep (more than 150cm) clay loam. The second member is a poorly drained very deep (more than 120cm), sandy clay to clay. The third member is a well drained, very shallow (less than 30cm) clay loam. The first and third members constitute three quarters of this unit. These soils are developed from Kambe Limestones and Alluvial deposits derived from Mazeras Sandstones and Magarini Sands. This soil complex occurs in a minor valley and lies in agroclimatic zone III.

The first member's A-horizon is 20-50cm thick, dark brown, in the hue 7.5YR, moderately acidic (pH 5.9), friable clay loam with a medium subangular blocky structure. The upper B-horizon is yellowish brown, in the hue 10YR, slightly acidic (pH 6.2), friable to firm clay loam with a fine angular blocky structure and common moderate clay cutans. The lower part of the B-horizon is brownish yellow, in the hue 10YR, moderately alkaline (pH 8.1), calcareous, firm gravelly clay loam with a fine angular blocky structure. This member has a high permeability and an available moisture storage capacity of about 170mm in a 150cm depth of profile.

This member was classified as a <u>vertic LUVISOL</u>

in the FAO legend and as vertic HAPLUSTALFS in the Soil Taxonomy.

The second member has a 20cm thick A-horizon. The A-horizon is dark greyish brown, in the hue 10YR, slightly acidic (pH 6.3) firm sandy clay to clay. The subsoil is a dark greyish brown, in the hue 10YR, slightly alkaline (pH 7.4), very firm cracking clay with moderate slickensides. There are vertical cracks which open on the surface.

These clays were classified as pellic VERTISOLS in the FAO legend and as PELLUSTERTS in the Soil Taxonomy.

The third member is a dark brown, in the hue 10YR, moderately acidic (pH 5.9), friable clay loam with a porous massive structure which abruptly overlies rock at 30cm depth. This member was classified as a LITHOSOL.

5.2.15 Mapping Unit Bv/Vp - Extent: 390 hectares

This complex consists of two members occurring in a minor valley in the 'shales'. The first member is an imperfectly drained, very deep mottled clay comprising 60% of the unit and the second is a poorly drained, very deep cracking clay.

The first member has a dark to very dark greyish brown (hue 10YR) slightly acidic (pH 6.2), clay loam A-horizon with a medium crumb structure and a friable consistence. The subsoil is a light olive brown to light brownish grey, in the hues 2.5Y and 10YR, moderately acidic (pH 5.5) clay with prominent coarse red mottles and a coarse angular blocky structure. Some weathering rock fragments are present in the subsoil. The subsoil has cracks which do not open to the surface.

The CEC in the topsoil is about 26 me/100g soil but increases to about 33 me/100g soil in the subsoil. The organic carbon content is about 2.7% in the topsoil. Base saturation is invariably above 67%.

This member was classified as a vertic CAMBISOL in the FAO legend and as a vertic INCEPTISOL in the Soil Taxonomy.

The second member's A-horizon is very dark greyish brown, in the hue 10YR, slightly acidic (pH 6.4), mottled clay with a medium subangular blocky structure and a firm consistence. The subsoil is dark grey to olive yellow, in the hues 10YR and 2.5Y, slightly alkaline (pH 7.2), mottled clay with a coarse angular blocky structure and a very firm consistence. The profile has cracks which open to the surface during some periods of the year.

The topsoil and subsoil CEC is 30.5 and 23.5 me/100g soil respectively. The organic carbon is about 2% in the topsoil and the base saturation is invariably 75% in the entire profile.

These poorly drained clays were classified as Pellic VERTISOLS in the FAO legend and as PELLUSTERTS in the Soil Taxonomy.

5.2.16 Mapping unit Lc/Lv/J - Extent: 200 hectares

This unit is a complex comprising poorly drained, very deep clay loams; well drained, very deep sandy clay loams and pockets of excessively drained sands. This soil complex occurs in the Wimbi Valley in agroclimatic zone III. Chromic and vertic LUVISOLS constitute 90% of the unit.

The A-horizon of the well drained member is dark brown, in the hue 5YR, slightly acidic (pH 6.3), loamy sand to sandy loam with a porous massive structure and a friable moist consistence. The subsoil is brown to yellowish red, in the hues 5YR and 10YR, slightly acidic (pH 6.2), gravelly sandy clay loam with a massive to weak subangular blocky structure and a firm moist consistence. The CEC varies from 8.6 me/100g soil in the topsoil to 13.4 me/100g in the subsoil. The organic carbon content is about 0.8% in the topsoil.

This member was classified as a Chromic LUVISOL in the FAO legend and as a typic PALEUSTALF in the Soil Taxonomy.

The A-horizon of the poorly drained member is a very dark greyish brown, in the hue 10YR, neutral (pH 6.8), mottled cracking sandy clay loam with a weak fine subangular blocky structure and a firm consistence. The subsoil is a dark grey to light olive brown, in the hues 10YR and 2.5Y, acidic to neutral (pH 5.5 to 7.0), mottled, cracking clay to clay loam with a coarse angular blocky structure and a very firm moist consistence. The chemical properties of this member are variable. The CEC ranges from 23 me/100g soil in the topsoil to 15 me/100g in the subsoil. The pH is 8.5 in the upper topsoil decreasing to 6.5 in lower topsoil. In the subsoil pH increases from 5.1 to 8.1 with depth. Organic carbon is about 1.1% in the topsoil.

This member was classified as a vertic LUVISOL in the FAO legend and as a vertic HAPLUSTALF in the Soil Taxonomy.

The third member consists of excessively drained, very deep pockets of sand. These sands are probably Fluvisols but since they are only of a small extent no profile was described.

5.3 LAND QUALITIES AND THEIR RATING CLASSES

The land qualities considered relevant to the present and alternative LUTs in the Chonyi-Kaloleni study area are:

1. availability of moisture
2. August-December rainfall (for cashewnuts only)

3. availability of nutrients
4. presence or hazard of waterlogging
5. rootability
6. susceptibility to soil erosion
7. workability of the soil
8. possibilities of mechanisation, and
9. carrying capacity of the land

The rainfall requirements of some crops given in section 2.3 are higher than the annual rainfall in the study area. This observation was emphasised by van Eijnatten et.al. (1977) and Child (1964) who stated that coconuts north of Mombasa and ten kilometres from the Coast were growing under marginal conditions. Availability of moisture may therefore be considered the most limiting land quality and consequently it was investigated in greater detail than the other land qualities.

Carrying capacity of land is a very important land quality with respect to animal production but because of the short duration of the present study it was not possible to assess this land quality in the study area. However, grazing (both beef and dairy cattle) is an important component of the present land use, therefore its consideration in the land use recommendations was based on carrying capacity estimates for areas of similar agroclimatic conditions in Kwale and at Mtwapa. The land qualities 1 to 8 listed above are discussed and the classes used to rate them given in the following sections.

5.3.1 Availability of moisture

Moisture deficits were used to quantify this land quality. The available moisture storage capacity, evapotranspiration, and monthly rainfall were used in the calculation of moisture deficits as described in section 3.4.2.

5.3.1.1 Available moisture storage capacity (AMSC)

Moisture contents at suctions of 0, 0.1, 0.3, 1.0 and 15 bars together with the AMSC for selected profiles are presented in table 9. The AMSC are expressed in mm per 10cm soil depth which is equivalent to volumetric moisture content on a percent basis.

The AMSC's were regressed against the respective clay contents but the regression coefficients were not significant. The analysis suggested however that the soils could be placed in two groups, i.e. a clayey group (>50% clay) in which the AMSC decreased as the percentage clay increased, and a sandy group (<50% clay), in which the AMSC increased as the percentage clay increased. The data for the two groups were subjected to a multiple regression analysis using the forward selection procedure (Drapper et.al., 1966) to obtain the best regression equation between the AMSC and soil characteristics selected on the basis

Table 9. Moisture contents at various suctions and available moisture storage capacities (AMSC) of some representative profiles

AGRO CLIMATIC ZONE	MAPPING UNIT AND PROFILE No.	DEPTH (cm)	MOISTURE CONTENTS gm/100cm³ AT ....(Bars)					AMSC mm/10cm
			0.0	0.1	0.3	1.0	15.0	
III	VcTi$_1$	0-17	67.9	37.5	33.0	28.2	24.8	8.2
		17-30	50.5	43.6	41.9	39.3	32.4	9.5
	198/3-1	30-78	45.0	42.4	41.2	39.4	32.4	6.8
		78-100	52.6	49.1	46.6	44.0	38.6	8.0
		100-160	49.6	47.5	45.2	43.5	37.6	7.6
		0-15	48.0	30.0	26.1	21.2	21.1	5.0
	198/4-32	15-26	47.4	31.2	27.0	21.2	13.2	13.9
		26-64	49.6	39.0	34.4	31.1	20.5	14.0
		64-110	37.2	35.2	34.2	32.0	28.0	7.0
		110-133	40.1	38.0	36.7	33.5	31.2	5.5
	FrMw$_2$	0-10	39.4	17.4	15.4	11.6	7.4	8.0
		10-28	50.5	17.2	15.3	10.9	9.5	5.8
		28-60	38.4	17.5	15.4	9.7	8.7	6.7
		60-160	37.2	18.5	16.0	11.4	9.2	7.4
	LcMw$_1$	0-8	40.4	21.4	17.8	14.6	10.0	7.7
		8-25	42.1	18.3	16.3	13.3	9.3	7.1
	198/3-39	25-60	40.5	23.7	20.1	17.1	8.5	11.6
		60-150	40.4	23.7	21.0	17.7	12.3	8.7
	NdLw$_1$	0-10	42.9	22.9	20.6	18.0	12.9	7.8
		10-25	39.8	24.3	23.2	18.4	13.9	9.2
	198/3-8	25-55	38.0	25.7	23.4	18.5	14.8	8.7
		55-200	36.9	25.9	23.8	18.1	13.6	10.2
	198/3-9	0-20	41.8	20.0	17.6	15.5	12.9	4.8
		20-68	34.2	21.4	20.3	18.7	14.9	5.4
		68-230	37.5	26.2	22.4	19.6	15.2	7.2
	Lv/Vp/I	0-18	41.8	28.1	24.1	20.8	11.0	13.0
		18-39	40.1	33.2	30.0	25.4	17.5	12.4
		39-80	40.1	33.8	31.1	28.0	19.4	11.8
		80-170	40.4	36.9	34.1	30.0	24.2	10.2

Table 9. (continued)

AGRO CLIMATIC ZONE	MAPPING UNIT AND PROFILE No.	DEPTH (cm)	MOISTURE CONTENTS gm/100cm³ AT ....(Bars)					AMSC mm/10cm
			0.0	0.1	0.3	1.0	15.0	
III	$AoCw_2$	0-17	36.3	12.9	11.2	7.7	6.4	4.8
	198/3-16	17-33	35.5	16.2	15.0	10.7	7.0	7.9
		33-160	34.2	16.8	15.6	10.8	10.6	4.5
	$LcCw_1$	0-15	36.6	17.8	14.8	11.5	10.7	4.1
	198/3-20	15-36	35.5	22.8	21.2	16.9	9.4	8.7
		36-75	43.2	23.6	22.1	20.1	13.2	8.9
		75-160	36.8	20.6	17.8	15.7	5.2	9.6
	Ao-Gd 3/1	0-20	38.3	10.6	3.8	3.9	3.2	2.6
IV	198/3-38	20-35	38.0	12.7	8.0	6.1	3.7	4.2
		35-70	40.8	17.6	13.5	11.4	5.1	8.3
		70-160	32.5	19.6	17.1	15.1	6.1	8.3
	$QcFe_4$	0-30	41.7	17.0	5.9	5.3	3.6	3.3
		30-54	42.4	21.3	9.7	6.5	3.9	6.9
	198/4-40	54-135	37.4	15.5	6.4	4.9	4.6	1.8
		135-160	32.9	7.9	5.0	3.8	3.6	1.4
	$LcFw_1$	0-8	32.0	20.2	17.9	16.1	9.1	8.8
	198/3-25	8-25	36.3	25.8	22.5	20.4	15.3	7.2
		25-75	38.1	30.8	29.4	27.0	19.6	9.8
		75-110	39.4	36.5	34.6	32.[illegible]	20.2	14.5
	$LgAi_1$	0-15	40.5	26.8	22.4	17.8	12.8	9.5
	198/3-24	15-35	39.7	34.1	32.4	29.4	20.2	12.0
		35-72	36.9	33.7	32.1	30.6	22.9	9.2
		72-135	39.4	33.1	30.6	27.7	21.6	9.0
	$LvFi_1$	0-20	35.3	17.7	13.6	10.8	6.2	7.4
	198/3-33	20-40	34.1	24.2	21.4	18.7	9.6	11.8
		40-70	36.0	32.0	30.0	28.7	19.2	10.8
		70-125	31.3	27.5	26.2	23.6	21.7	4.5

of their importance in predicting the AMSC. The characteristics used were % clay (X_1), % silt (X_2), % sand (X_3), % carbon (X_4) and bulk density (X_5).

For the clayey group, % clay, bulk density and % carbon were the most important factors and were entered into the equation in that order. The resultant regression equation

$$Y = 2.38 - 0.16X_1 + 11.05X_5 + 3.03X_4$$

where Y = AMSC and the other factors are defined as above.

However, the equation only accounted for 56% of the variations in the AMSC ($r^2 = 0.5558$).

For the sandy group, % sand, % carbon, bulk density and % silt were the most important characteristics and resulted in the equation

$$Y = 10.197 - 0.155X_3 + 2.84X_4 + 4.688X_5 - 0.058X_2$$

where all the factors are as defined above. This regression equation also accounted for 56% of the variations in the AMSC, ($r^2 = 0.561$).

The AMSC of each profile was obtained by summing up the AMSC values of its constituent horizons over the entire rootable depth for a specific crop. Augerings at the bottom of profile pits with tree crops in the vicinity justified a rootable depth of 3 metres for the tree crops. Coconut roots were found to penetrate to a depth of 4 metres in profile 198/3-14, (Plate 4), however, this 4 metre rootable depth could not be substantiated for other profiles, hence the use of 3 metres in the AMSC calculation for tree crops. A rootable depth of 1.5 metres was assumed for maize where no rooting restrictions were present. The AMSC's of representative profiles of various mapping units for maize and tree crops in the three agroclimatic zones are presented in table 10.

5.3.1.2 Potential crop evapotranspiration

The estimated potential crop evapotranspiration values for coconuts and cashewnuts for agroclimatic zones III, IV and V are presented in table 11.

Constant monthly potential evapotranspiration values were used in the calculations of moisture deficits on a yearly basis. This assumption follows from the earlier assumption that Eo is fairly constant from year to year. The year by year monthly and annual moisture deficits for coconuts and cashewnuts in agroclimatic zones III and IV for selected ranges of available moisture storage capacities are presented in appendix 3.

5.3.1.3 Yields and moisture deficits

Yields of coconuts and cashewnuts for the study area were not available. Furthermore, the estimates of yields per hectare of the crops in

Plate 4. Coconut root distribution in a sand pit (unit $AoCw_2$).

A - very few lateral roots (0-30cm)

B - many lateral roots (30-150cm)

note: vertical roots were found in the white sand at the bottom of the profile (about 4 metres).

Table 10. The available moisture storage capacities (AMSC's) of selected mapping units for maize and tree crops

Agroclimatic zone	Mapping unit	Rootable depth (cm)		(AMSC (mm)	
		Maize	Tree crops	Maize	Tree crops
III	$VcTi_1$	64	-	91	-
	$FrMw_2$	150	300	107	218
	$LcMw_1$	150	300	138	269
	$NdLw_1$	150	300	127	297
	Lv/Vp/J	150	200	168	209
	$AoCw_2$	150	300	74	142
	$LcCw_1$	150	300	126	270
IV	Ao-Gd 3/1	150	300	131	295
	Ao-Gd 3/1	150	300	61	138
V	$QcFe_4$	150	300	47	61
	$LcFw_1$	110	110	120	120
	$LvFi_1$	125	125	95	95
	$LgAi_2$	72	135	72	129

Table 11. Estimated monthly potential evapotranspiration (ETc) of coconuts and cashewnuts in agroclimatic zones III, IV and V

CROP	ACROCLIMATIC ZONE	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC.
COCONUTS	III	191	194	200	163	110	127	120	127	157	177	182	178
	IV	193	187	203	165	112	129	121	129	158	179	184	180
	V	196	191	205	167	113	131	123	131	161	182	186	183
CASHEWNUTS	III	169	165	178	145	98	113	106	113	139	158	162	158
	IV	171	166	180	146	99	114	107	114	141	159	163	160
	V	174	170	182	149	101	116	110	116	143	162	166	162

Kilifi district are not always reliable. For example, in 1978 the yields of the two crops in Kilifi district from various sources differ:

	Hectares planted(1978)	Yields	Source of information
Coconuts	649	477 tonnes	MoA Annual Report, Coast Province
	687	767 tons	Kilifi District Agricultural Office
cashew	-	8719.4 tons	MoA Annual Report Coast Province
	-	8300 tons	Agnoloni et.al. (1980)

Data on yields and estimates of area in production under the two crops were obtained from various sources, and yields per hectare for the entire district estimated. The sources of the data included MoA Annual Reports for Coast Province and Kilifi District, Copra delivered to Kilifi District Co-operative Union (Mukabi et.al., 1980) and C.A.R.S. communications numbers 5 and 7 (1979).

These yield estimates, annual rainfall, annual deficits, rainfall and deficits for selected periods preceeding or during the year of production are presented in appendices 5a, 5b, 5c and 5d. Most of the coconuts in Kilifi district are produced in the Southern Division. Mukabi et.al. (1980) showed that from 1973 to 1980, the copra delivered to Kilifi District Co-operative Union from Southern Division constituted 98.6 to 77.9%. The locations Chonyi, Jibana and Kaloleni, which are mostly in agroclimatic zone III, produced 84 to 64% of the copra in the division. Earlier the Kilifi gazetter (1956) ranked the 'soil types' according to their decreasing importance for coconuts as:

1. Kambe Limestone
2. Mazeras Sandstone
3. Windblown sands
4. Lagoonal sands and coral breccia
5. Magarini Sands
6. Mariakani Sandstones, and
7. Upper Jurassic Shales.

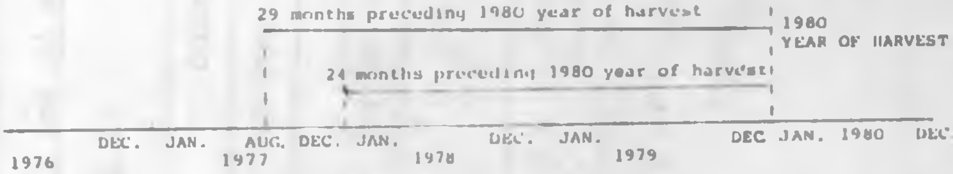
In the study area, Kambe Limestone and Mazeras Sandstones are in agroclimatic zone III. It may therefore be concluded that the bulk of the copra produced in the study area is from agroclimatic zone III. However, in the absence of yield data for agroclimatic zone IV the same yield estimates were used for both agroclimatic zones, viz. zones III and IV.

Similarly for cashewnuts it can be shown that the bulk of the yields are from agroclimatic zone III. Agnoloni et.al (1980) showed that 78% of the cashew yields in Southern Division are produced from Chonyi and Kaloleni which are in agroclimatic zone III.

However the Southern Division produces only 7.7% of the cashews produced in Kilifi district, nevertheless the yield estimates may be assumed reasonable for agroclimatic zone III.

A regression analysis similar to that of Smith (1968) between estimated copra yields and rainfall, moisture deficits during the 24 and 29 months preceeding the year of harvest was carried out for agroclimatic zones III and IV. The periods preceeding the year of harvest and the year of harvest, as considered in this study, are illustrated in figure 5 below:

Fig. 5. Periods preceeding the 1980 year of harvest for coconuts



The correlation coefficients obtained from this analysis are presented in Table 12. From Table 12, four points are clear. Firstly, rainfall is positively while moisture deficit is negatively correlated with copra yields in both zones for the two periods considered. Secondly, the correlation coefficients for the two periods are significant in zone III, but in zone IV the correlation coefficients are not

Table 12. Correlation coefficients between estimated copra yields and rainfall, moisture deficits during the 29 and 24 months preceding the year of harvest in agro-climatic zones III and IV

Agroclimatic zone	CORRELATION COEFFICIENTS (r) FOR			
	RAINFALL		MOISTURE DEFICITS	
	29 months BEFORE HARVEST	24 months BEFORE HARVEST	29 months BEFORE HARVEST	24 months BEFORE HARVEST
III	0.552*	0.488*	-0.562**	-0.581**
IV	0.465(NS)	0.598*	-0.516(NS)	-0.511(NS)

* - significant at p=0.05 level; ** - significant at p=0.01 level; NS = not significant

significant except for that between copra yield and total rainfall during the 24 months preceeding the year of harvest. Thirdly, the correlation coefficients for the two periods are similar, therefore neither of the periods appears to be a better predictor of yields than the other. Finally, although moisture deficits are significantly correlated at $p = 0.01$ level and rainfall at $p = 0.05$ level, (in zone III), the correlation coefficients are low. The regression equations (i) and (ii) relating copra yields (Y) to moisture deficits during the 29 and 24 months preceeding the year of harvest respectively are

(i) $Y = 218.9 - 0.049X_1$, (where X_1=moisture deficits 29 months before year of harvest)

(ii) $Y = 221 - 0.058X_2$ where X_2=moisture deficits during 24 months preceding the year of harvest

The regression equations account for only 35% of the variations in copra yields, which is very low compared to the relationship between copra yields and the integrated moisture deficits of Smith (1968) which accounted for about 66% of the variations in copra yield.

The low correlation coefficients in the present study may be attributed to three factors. First, the copra yield data for the whole district was used instead of the actual yield data for agroclimatic zone III and IV in the study area. This was prompted by the lack of yield data for the two zones. Moreover some of the yield data was probably unreliable. Secondly, the copra yields used were underestimated because yield losses due to tapping, sale of whole nuts, and domestic consumption of nuts, which were difficult to estimate, were not included in the yield figures. Thirdly, the basic assumption in the water balance calculation that all rainfall infiltrates into the soil' storage may underestimate the moisture deficits. Low correlation coefficients may also indicate that other factors not considered, e.g. soil fertility, are significant.

Significant, albeit rather low, correlation coefficients have been established between copra and moisture deficits during the 24 months preceding the year of harvest for zone III. This parameter was therefore taken as a suitable index for the availability of moisture for coconuts in the study area.

For cashewnuts, estimated yields were regressed against rainfall and moisture deficits during periods similar to those considered by van Eijnatten (1979), viz. annual, January to June and July to December period in the year of production. In addition, the August-December period was considered because flowering, fruiting, nut maturation and the bulk of the harvesting takes place during this period as stated in section 2.3.2. Furthermore, to investigate the observation that yields are low during years with high annual rainfall, the yields were grouped into those from years with more than 1000mm and those from years with less than 1000mm. The correlation coefficients obtained for these analyses are presented in Table 13.

In agroclimatic zone III, 'all years' yields were generally negatively correlated with annual rainfall which may be attributed to rain causing the abortion of flowers and nutfall as observed by van Eijnatten (1979). This negative effect is taken into account by introducing the harmful effect of rainfall as a separate land quality in section 5.4.2. van Eijnatten found a very strong negative influence of annual rainfall on productivity when rainfall exceeded 1000mm, (r = -0.91*) which he attributed to influence of rainfall on flowering, nutfall and harvesting but a positive insignificant influence of rainfall on yields (r = 0.3) when rainfall was less than 1000mm, when presumably rainfall had less effect on flower abortion and nutfall. A similar analysis in this study did not show such a strong negative influence but there was a generally significant positive influence of annual rainfall on yields in zone III when annual rainfall was below 1000mm (r = 0.763*). Moisture deficits generally showed a (positive) but largely non-significant relationship with estimated yields. The

Table 13. Correlation coefficients between estimated cashew yields and rainfall, moisture deficits during various periods in the year of production in zones III and IV

Agroclimatic zone	Variable	Correlation Coefficients (r) for			
		Annual	Jan-June	July-Dec	Aug-Dec
III	Rainfall				
	All years	-0.552**	0.071(NS)	-0.504*	-0.525*
	Years > 1000mm	-0.397(NS)	-0.255(NS)	-0.350(NS)	-0.134(NS)
	Years < 1000mm	0.763*	0.663(NS)	0.69*	0.68*
	Deficits				
	All years	0.309(NS)	0.183(NS)	0.44(NS)	0.448(NS)
	Years > 1000mm	0.294(NS)	0.277(NS)	0.159(NS)	0.218(NS)
	Years < 1000mm	-0.734*	-0.662(NS)	-0.652(NS)	-0.631(NS)
IV	Rainfall				
	All Years	-0.458(NS)	0.187(NS)	-0.554**	-0.593*
	Years > 1000mm	-0.424(NS)	0.628(NS)	-0.616(NS)	-0.645(NS)
	Years < 1000mm	-0.598(NS)	0.476(NS)	-0.390(NS)	-0.505(NS)
	Deficits				
	All years	0.435(NS)	0.119(NS)	0.518*	0.546**
	Years > 1000mm	0.530(NS)	-0.358(NS)	0.687(NS)	0.600(NS)
	Years < 1000mm	0.593(NS)	0.372(NS)	0.652*	0.724*

* — significant at p=0.05; ** — significant at p=0.01; (NS) — not significant

highest and only significant correlation coefficients being obtained between annual moisture deficits and yields when rainfall was less than 1000mm (r = -0.734*).

In zone IV, the 'all years' yields were best correlated with July-December and August-December rainfall in an inverse relationship which may again be attributed to the harmful effect of rainfall during flowering, nut maturation and harvesting period. Slightly lower but still significant positive correlations between moisture deficits for July-December and August-December and 'all years' yields were also obtained. Higher positive and significant correlation coefficients were obtained between July-December and August-December moisture deficits and yields from years with less than 1000mm. These positive correlation coefficients probably reflect the strong negative influence of the July-December rainfall on yields referred to above. Since other water balance studies e.g. Dagg and Tapley (1967) have shown that moisture stress in cashewnuts reduces yields, it appears that there is probably a strong confounding effect between the harmful effects of August-December rainfall and the availability of moisture in the soil. The August-December rainfall effect appears to be more important than the availability of moisture particularly in zone IV. Long term field studies to determine yields and moisture deficits together with measurements of rainfall at various sites in different agroclimatic zones are required to confirm the existence of this confounding effect and to distinguish between these two effects.

The correlation coefficients between rainfall and yields are negative (though not significant) during years with more than 1000mm, and positive (generally significant) during years with less than 1000mm in zone III. These signs suggest that van Eijnatten's threshold value of 1000mm at Mtwapa may be generally valid in this area for zone III. Although rainfall in the July-December period did not give significant correlation coefficients for years with less than and more than 1000mm rainfall in zone IV, the coefficients were negative for both groups of data suggesting that the 1000mm threshold found by van Eijnatten at Mtwapa may not be valid in this area for zone IV.

In this study no suitable index was obtained to quantify the availability of moisture for cashewnuts. Although the effect of August-December moisture deficit is confounded with the harmful effect of rainfall during the same period, the August-December moisture deficit was used in this study in the absence of a better index to quantify the availability of moisture for cashewnuts. Generally, the sensitive growth period for water deficits in tree crops, e.g. citrus, is that period from flowering and fruit set to fruit maturation (Doorenbos et.al., 1979). Assuming this same moisture sensitive growth period also applies to cashewnuts, the use of August-December moisture deficits would be justified, since, as stated by Acland (1971), peak flowering period, nut maturation and peak harvesting lasts from August to December.

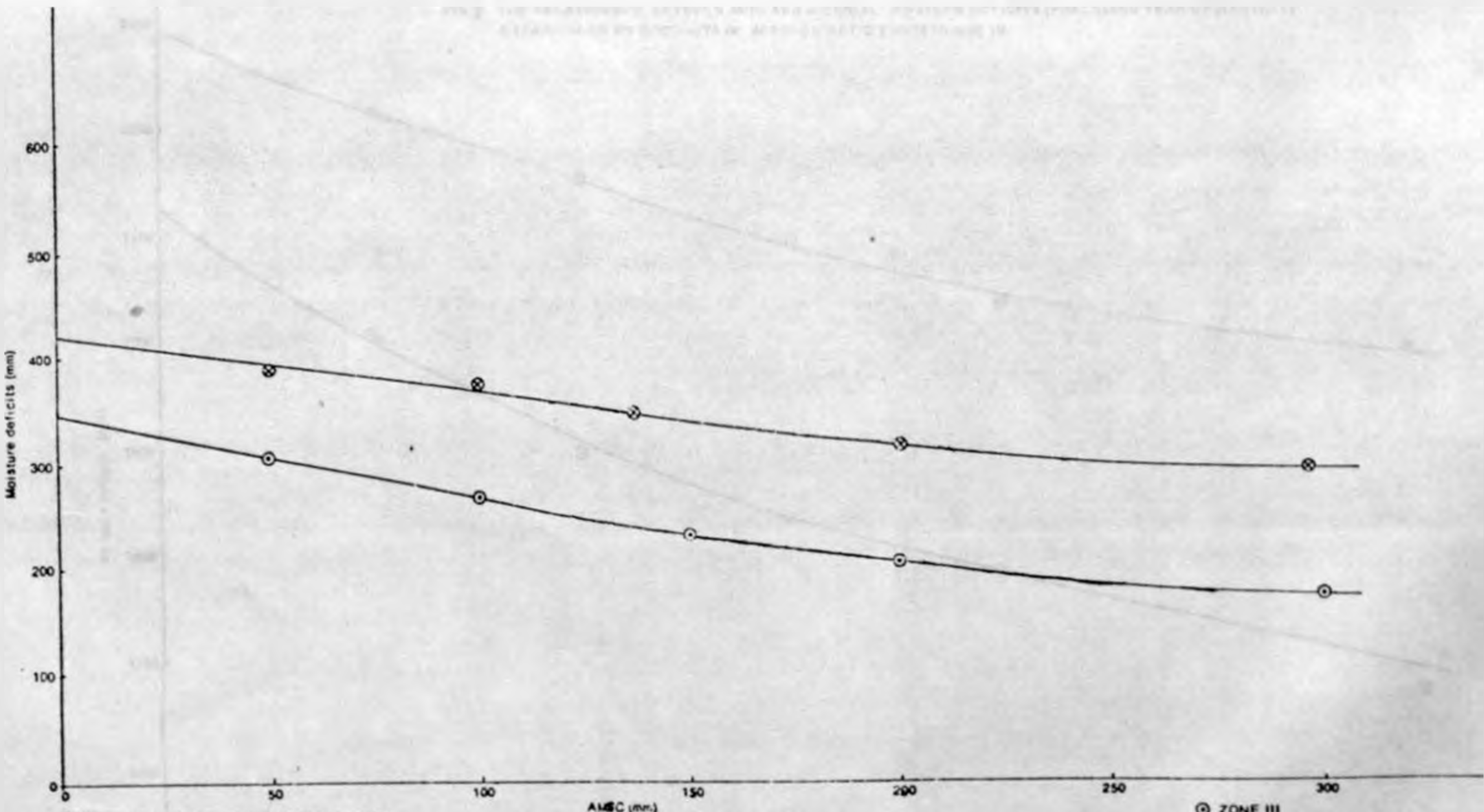
The regression equation between cashew 'all years' yields (Y) and August-December moisture deficits:-

(iii) $Y = 261 + 0.645X$ where x = moisture deficit in Aug-Dec period

Overlooking the confounding effects referred to earlier, this equation only accounted for 30% of the variation in cashewnut yields ($r^2=0.298$).

Since moisture deficits will be influenced by the AMSC values, which differ from soil to soil, the relationships between the moisture deficit parameters, viz. moisture deficits 24 months preceding the year of harvest for coconuts and moisture deficits during the August-December period in the year of harvest for cashewnuts, and the AMSC values were investigated. The relationships between AMSC values and August-December moisture deficits are given in Figure 6, while the calculated year to year moisture deficits for selected AMSC values are presented in appendices

FIG 6 THE RELATIONSHIP BETWEEN AMSC* AND AUGUST-DECEMBER MOISTURE DEFICITS EXPERIENCED BY CASHEWNUTS IN AGRO-CLIMATIC ZONES III AND IV



*AMSC is the available moisture storage capacity

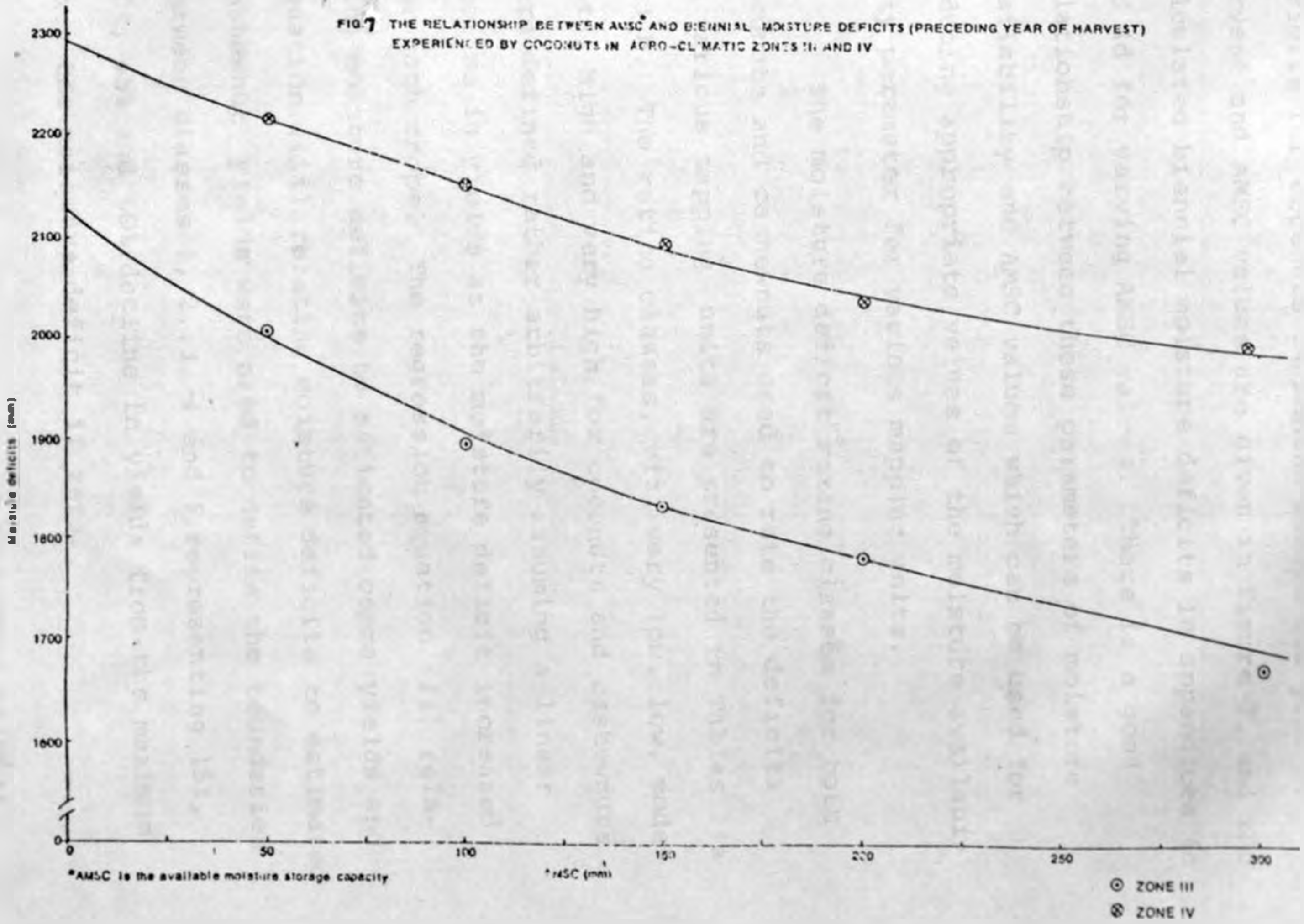


FIG 7 THE RELATIONSHIP BETWEEN AMSC* AND BIENNIAL MOISTURE DEFICITS (PRECEDING YEAR OF HARVEST) EXPERIENCED BY COCONUTS IN AGRO-CLIMATIC ZONES III AND IV

*AMSC is the available moisture storage capacity

4a and 4b. The relationship between moisture deficits for coconuts 24 months before the year of harvest and AMSC values are given in Figure 7, and the calculated biennial moisture deficits in appendices 4c and 4d for varying AMSC values. There is a good relationship between these parameters of moisture availability and AMSC values which can be used for deducing appropriate values of the moisture availability parameter for various mapping units.

The moisture deficit rating classes for both coconuts and cashewnuts used to rate the deficits in various mapping units are presented in Tables 14a and b. The rating classes, viz. very low, low, moderate, high and very high for coconuts and cashewnuts were defined rather arbitrarily assuming a linear decline in yields as the moisture deficit increased for both crops. The regression equation (ii) relating moisture deficits to estimated copra yields and equation (iii) relating moisture deficits to estimated cashewnut yields were used to define the boundaries between classes 1, 2, 3, 4 and 5 representing 15%, 30%, 45% and 60% decline in yields from the maximum when the moisture deficit if zero.

5.3.2 Harmful effect of August-December rainfall

The harmful effect of August-December rainfall on cashew productivity has been established, but since this effect is not due to the availability of soil

Table 14a. Rating classes for 24 months moisture deficits experienced by coconuts

Class	Range of average moisture deficits (mm)
1	0 - 570
2	571 - 1140
3	1141 - 1700
4	1701 - 2200
5	>2200

Table 14b. Rating classes for August-December moisture deficits experienced by cashewnuts

Class	Range of average moisture deficits (mm)
1	<160
2	161 - 320
3	321 - 470
4	471 - 625
5	>625

moisture per se, therefore, it was treated as a separate land quality.

The regression equation between cashewnut yields and August-December rainfall, viz.

$$Y = 667 - 0.495X$$

where Y = cashew yields and X = August-December rainfall only accounted for 35% of the cashew yield variations (r^2=0.352). Nevertheless, assuming a linear decline in cashew yield from a maximum with increase in rainfall, this equation was used to arbitrarily define boundaries for classes 1, 2, 3, 4 and 5 representing 15%, 30%, 45%, and 60% decline in yields. The rating classes and their average rainfall ranges are presented in Table 15.

Table 15. Rating classes for the harmful effect of August-December rainfall on cashewnuts

Class	Average rainfall range (mm)
1	0 - 235
2	236 - 470
3	471 - 700
4	701 - 940
5	>940

5.3.3 Availability of nutrients

Cation exchange capacity, base saturation, exchangeable cations, % organic carbon, and available phosphorus were used to rate the land quality 'availability of nutrients'. Cation exchange capacity and base saturation were rated separately as subratings R_1 and R_2 respectively. Each exchangeable cation % organic carbon and available phosphorus (by Mehlich I method) were rated separately and combined into a subrating R_3. The subrating R_1, R_2 and R_3 were then summed up to give the final rating R of the availability of nutrients.

The CEC class ranges used by various institutions vary widely as illustrated in table A16.

Table A16. Some classes used to rate CEC

CLASS	CEC Ranges used by (me/100g soil)			
	van de Weg (1977)	Unger, L.J. (1972)	N.Z. Soil Bureau (1980)	L.C.D. Thailand (1973)
1	>16	>30	>40	>20
2	12-16	15-30	25-40	15-20
3	6-12	7-15	12-25	10-15
4	2-6	3-7	6-12	5-10
5	<2	<3	<6	<5

These class boundaries appear to be selected arbitrarily. However, a CEC of 10 me/100g soil is generally adequate for agricultural purposes. The rating classes used in this study are given in Table 16a and were selected to accommodate the CEC ranges in the study area into the maximum number of classes.

Four classes were identified for subrating base saturation as shown in Table 16b. The 35% and 50% class boundaries were selected on the basis of soil classification, e.g. separation of ACRISOLS from LUVISOLS and Alfic UDIPSAMMENTS from other UDIPSAMMENTS. Five classes were not considered practical.

Table 16a. Rating R_1 of the Cation Exchange Capacity (CEC)

Class	CEC Ranges (me/100g soil)
1	>16
2	10-16
3	5-10
4	2-5
5	<2

Table 16b. Rating R_2 for base saturation

Class	% Base Saturation
1	>75%
2	50-70%
3	35-50%
4	<35%

The exchangeable cations, % organic carbon and available phosphorus were rated according to Table 16c. In the selection of class ranges, an attempt was made to make the upper limit of class 5 coincide with the minimum requirement of each cation (if this minimum was known e.g. for K, 0.1 me/100g is considered an absolute minimum requirement for most crops). Secondly the class limits were selected to accommodate the soils of the study area into a maximum number of classes. The final rating R_3 was obtained from Table 16d.

Table 16c. Rating R_3 of exchangeable cations, % organic carbon and available Phosphorus (Mehlich method)

CLASS	Ca^{++} me/100g S	Mg^{++} me/100g S	K^{+} me/100g S	% Carbon	P (ppm) (Mehlich)
1	>15	>3.0	>1.2	>5	>80
2	10-15	1-3	0.6-1.2	2.0-5.0	40-80
3	5-10	0.5-1	0.2-0.6	1.0-2.0	20-40
4	2-5	0.2-0.5	0.1-1.0	0.5-1.0	10-20
5	<2	<0.2	<0.1	<0.5	<10

Table 16d. Rating R_3 of the sum of exchangeable cations, % carbon and available phosphorus

Class	Sum of exch. cations, % carbon and available P
1	<7
2	8 - 12
3	13 - 17
4	18 - 22
5	>23

The subratings R_1, R_2 and R_3 are summed up and rated according to Table 16.

Table 16. Rating R of available nutrients

Class	Subrating $R_1 + R_2 + R_3$
1	<4
2	5 - 7
3	8 - 9
4	10 - 12
5	>13

5.3.4 Availability of oxygen

Oxygen acts as an electron acceptor in the respiration of roots of intact plants and in the individual cells or tissues. Veldkamp (1979), citing Harris and van Bavel (1957), stated that root respiration is the most sensitive aspect of plant activity in regard to soil aeration and that it may be assumed that a reduction in respiratory activity is the first step in the growth-limiting effects of insufficient aeration. In addition, low oxygen content in the soil may cause a build up of products toxic to the plants. Plants differ in their tolerance to low oxygen contents of soil air, and therefore the availability of oxygen is an important land quality to consider in land evaluation.

A quantitative determination of oxygen contents and diffusion rates in soil air is very involved and laborious. Due to a lack of data on soil aeration status, a qualitative method using internal drainage classes was used to rate the availability of oxygen as shown in Table 17 below. The internal drainage classes were defined in chapter 3.

Table 17. Rating of the availability of oxygen for root growth

Class	Internal drainage class
1	well to excessively drained
2	moderately well drained
3	imperfectly drained
4	poorly drained

Source: van de Weg et.al. (1977)

5.3.5 Rootability

Rootable depth is important to plants not only for providing anchorage to plants but also because it determines the AMSC and the soil volume tapped for nutrients by the plant. Since the influence of soil depth on AMSC has already been taken into account in the land quality availability of moisture, the rootability is considered mainly in relation to anchorage. The land quality rootability was rated using the depths to the limiting layers according to Table 18 below.

Table 18. Rating of the rootable depth

Classes	Depth to limiting layer (cm)
1	>300
2	150-300
3	80-150
4	30-80
5	<30

These rating classes have special reference to tree crops.

5.3.6 Susceptibility to soil erosion

The land characteristics considered in the rating of susceptibility to soil erosion are slope class (R_1), rainfall erosivity (R_2), slope length (R_3) and soil erodibility. Only susceptibility to sheet erosion is considered. Maximum slope angles were used to determine the rating of slope class according to Table 19a.

Table 19a. Rating of slope gradient

Class	% slope gradient range
1	0 - 5
2	6 - 8
3	9 - 16
4	17 - 30
5	>30

The subratings on rainfall erosivity are adopted from Gachene and Barber (1982), who calculated the erosivity factor from Moore's regression equations (Moore, 1979). The rating classes are given in Table 19b.

Table 19b. <u>Rating of rainfall erosivity</u>

Class	Erosivity units*
1	<100
2	101-200
3	201-300
4	301-400
5	>400

Source: Gachene and Barber (1982)

* Erosivity in English units

This approach of rating rainfall erosivity appears to be a better approach than that of Braun and van de Weg (1977) currently being used by the KSS, because as pointed out in section 2.2.3, the latter approach appears to assume the presence of vegetation cover which is not always present.

The parameter slope length was rated according to Table 19c.

The subrating of soil erodibility is based on 1) organic carbon content, 2) flocculation index, and 3) silt to clay ratio in the topsoil. These are rated according to the schemes below (Source: van de Weg et.

al. (1972).

Table 19c. Rating of slope length

Class	Slope length (metres)
1	<50
2	51-100
3	101-200
4	201-300
5	>300

Source: Gachene and Barber (1982)

1) Organic carbon

Class	% Carbon
1	>2%
2	1-2%
3	<1%

2) Flocculation index

Class	% Flocculation index
1	>70%
2	50-70%
3	<50

3) Silt to clay ratio

Class	Ratio of $\frac{\text{silt}}{\text{clay}}$
1	<0.20
2	0.2-0.40
3	>0.40

The final subrating erodibility is found by summing the subratings, 1, 2 and 3 above according to Table 19d.

Table 19d. Rating of erodibility

Class	Sum of 1, 2 and 3
1	3-4
2	5
3	6
4	7
5	8-9

The final rating of susceptibility to erosion was obtained by multiplying together the subratings on erosivity, slope length, slope gradient and erodibility. The products were rated according to Table 19.

Table 19. Rating of susceptibility to erosion

Class	Product of Sub-ratings
1	<8
2	9-40
3	41-170
4	171-320
5	>320

5.3.7 Workability of the soil

This land quality is concerned with the ease of cultivation and preparation of the seed bed. Since most of the cultivation takes place when the soil is either dry or moist, dry and moist consistence were used to assess this land quality. The rating of this land quality was qualitatively made according to Table 20. The lowest class determined the final rating of workability taking class 1 and 5 as highest and lowest respectively.

Table 20. Rating of workability of the soil

Class	Dry consistence	Moist consistence
1	loose	loose
2	soft	very friable
3	slightly hard	firm
4	hard	very firm
5	very hard	extremely firm

5.3.8 Possibilities of mechanisation

The rating of the possibilities of mechanisation was based on 1) steepness of slope, and 2) stoniness, rockiness, shallowness.

1) The subrating of steepness of slope was made according to the scheme below:

Class	% Slope range
1	0-9
2	10-18
3	19-27
4	28-36
5	>36

2a) The subrating of shallowness, stoniness and rockiness was made according to the schemes 2a, 2b and 2c.

Class	depth to bedrock (cm)
1	>50
2	25-50
3	15-25
4	<15

2b) Rockiness

Class	distance between rocks (m)
1	>100
2	100-35
3	35-10
4	10-3.5
5	<3.5

The final rating of the possibility of mechanisation is obtained by the lowest rating in 1 and 2.

The ratings of these land qualities for each mapping unit are given in Table 21.

Table 21. Rated land qualities for each mapping unit

LAND QUALITY / MAPPING UNIT		$VcTi_1$	$QcFe_4$	$FrMw_2$	$AoCw_2$	$LgAp_1$	$LgAi_2$	$LvFi_1$	$LfLw_2$	$LcFw_1$	$LcCw_1$	$LcMw_1$	$NdLw_1$	Ao-Gd 3/1	Lv/Vp/I	Bv/Vp	Lv/Lc/J
AVAILABILITY OF MOISTURE	a)	4	5	4	4	4	4	4	4	4	4	4	3	4	4	4	3
	b)	3	3	2	2	2	2	3	3	3	3	2	2	3	2	3	2
AUGUST-DECEMBER RAINFALL (for cashew only)		3	2	3	3	2	3	2	3	2	3	3	3	2	3	3	3
AVAILABILITY OF NUTRIENTS		2	4	3	3	2-3	2	2-3	3	2	3	2	2	4	2	2	2
AVAILABILITY OF OXYGEN		3	1	1	1	4	3	3	1	1	1	1	1	2+4	3	4	3+4
ROOTABILITY		4(5*)	1	1	1	3(5*)	3(5*)	3(4*)	4	3	1	1	1	1	3+5	3(5*)	3
SUSCEPTIBILITY TO SOIL EROSION		4	3	4	4	1	2	3	1	3	4	3	3	4	3	3	3
WORKABILITY OF THE SOIL		4	1	1	2	4	4	2	3	3	3	2	2	3	4	5	4
POSSIBILITY OF MECHANISATION		2	1	5	3	1	1	2	4	2	2	1	4	2	5	3	5

* This rating applies to tree crops whose roots are destroyed by shrinking and expansion in these units

a) for coconuts
b) for cashewnuts

2c) Stoniness

Class	Distance between the stones (m)	Qualitative frequency of stones in the plow layer
1	more than 30	none
2	10-30	very few
3	3-10	few
4	1-3	moderate
5	<1	frequent

5.4 LAND UTILIZATION TYPES

Land use was described in two parts, first the present compound utilization types and secondly the alternative simple and compound land utilization types. Seven present compound LUTs and eight alternative LUTs were identified and described. The quantifiable key attributes of the seven present LUTs and three alternative simple LUTs are presented in Table 22 while the distribution of the present compound LUTs is given in Figure 8.

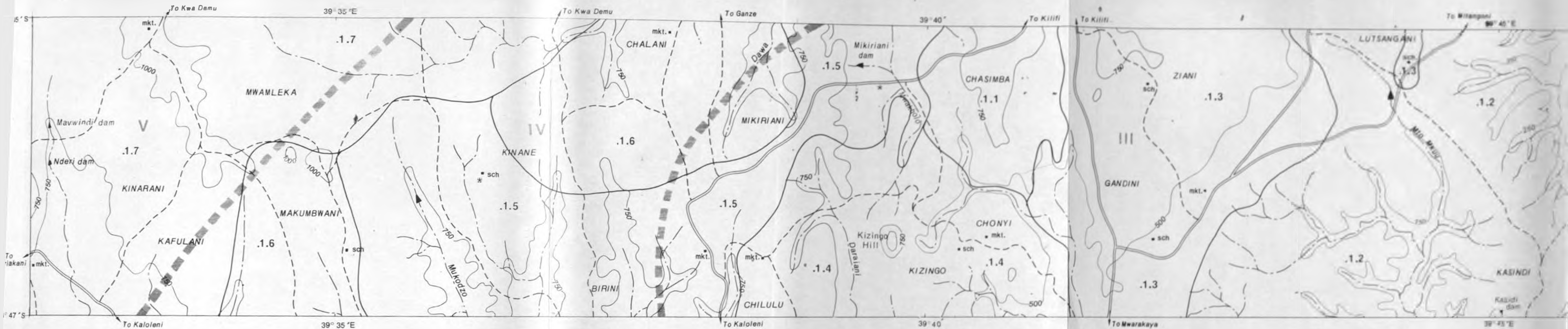
Difficulties were encountered in the definition of the LUTs due to a general lack of basic data, e.g. on yields, capital and labour intensity; the absence of some annual crops in the field during the survey period; unreliable information supplied by the farmers, and finally the information given by agricultural officers referred to administrative areas which did not coincide with the study area. To overcome some of these difficulties some key attributes were deduced

Table 22. Quantifiable key attributes for the present land utilization types

Number of LUT	Land utilization type	Produce (% area of LUT devoted to crops)	Production costs KSh. per hectare	Labour intensity man-days per hectare	Farm Power	Level of Technology
.1.1	Cultivation of perennial crops, cashews dominant; low level of technology	Tree crops - 50-70% Annual crops - 10-20% Bush - 20-40%	Low (approx. KSh. 450 annually)	Low - approx. 40-50 mandays annually	Manual	Low
.1.2	Cultivation of annual crops; maize dominant; intermediate technology	Maize - 70-80% Cotton - 10% Bush - 10-20%	High (approx. KSh. 1000 annually)	Moderate, approx. 50 mandays annually	Partly mechanised	Intermediate
.1.3	Cultivation of perennial crops, coconut dominant; low level of technology	Coconuts - 40-50% Cashew - 15-20% 'Others'* - 10% Annuals - 20-35%	Low (approx. KSh. 500 annually)	Low - approx. 45 mandays annually	Manual	Low
.1.4	Cultivation of perennial crops, coconut and citrus dominant; low level of technology	Coconut - 30-40% Citrus - 10-20% Cashew - 10-15% Annuals - 40-50%	Low (approx. KSh. 500)	Low (about 50 mandays annually)	Manual	Low
.1.5	Mixed farming, coconut dominant, unimproved cattle: low level of technology	Coconut - 40-80% Cashew - 10-80% Annuals + pasture - 30-40%	Low (approx. KSh. 380 annually)	Low (approx. 37 mandays annually)	Manual	Low
.1.6	Cultivation of perennial crops; coconut and cashew dominant; low level of technology	Coconut - 40-50% Cashew - 30-40% Maize - Inter-cropped	Low (approx. KSh. 300 annually)	Low (only about 25 mandays annually)	Manual	Low
.1.7	Extensive grazing, zebu cattle; low level of technology	Pasture - 70-90% Crops - 10-30%	Low (approx. KSh. 200 annually	Low (only about 20 man-days annually)	Manual	Low
.2.1	Cultivation of cashew, intermediate level of technology	Cashewnut yield estimates of 2700-4300 kg/ha	High establishment costs approx. KSh. 2400 High maintenance costs about KSh. 2000	Moderate; establishment approx 60 man-days. Maintenance approx. 55 mandays. Harvesting 120-140 mandays	Manual	Intermediate
.2.2	Cultivation of coconuts; intermediate level of technology	coconuts, copra. Copra yields estimated at 791-1000 kg/ha	High approx. KSh. 1900 annually	High; Estimated at 90 to 110 mandays annually	Manual	Intermediate
.2.3	Cultivation of maize; intermediate level of technology	Maize. Yields estimated at 2500kg/ha	High (approx. KSh. 1450 annually)	High (about 90 man-days annually	Partly mechanised. Tractors or ox-ploughing	Intermediate

* for these 'other crops' see section 5.4.1.2

Fig. 8 PRESENT LAND UTILIZATION TYPES



SCALE 1:50,000

Metres 1000 500 0 1 2 3 4 5 6 7 8 Kilometres

LEGEND

- .1.1 cultivation of perennial crops, cashew nut dominant. low level of technology
- .1.2 cultivation of annual crops, maize dominant. intermediate level of technology
- .1.3 cultivation of perennial crops, coconut dominant. low level of technology
- .1.4 cultivation of perennial crops, coconut and citrus dominant; low level of technology
- .1.5 mixed farming, coconut dominant, unimproved cattle; low level of technology
- .1.6 cultivation of perennial crops, coconut and cashew nut dominant; low level of technology
- .1.7 extensive grazing of zebu cattle; low level of technology

KEY

- land utilization type boundary
- agro-climatic zone boundary
- road
- motorable track and foot path
- • Mkt. market
- • Sch. school
- river/dam
- ∗ cattle dip
- 1000 / 750 contour V.I 250 ft

from related data elsewhere notably from Mtwapa and Kwale. The definitions of the LUTs should thus be viewed cautiously, bearing these points in mind.

5.4.1 Present land utilization types

The present land utilization types consists of small-holder, rainfed farming at low and intermediate levels of technology. Low level of technology is predominant and implies cultivation of local unimproved seeds, unselected tree planting materials without fertilizers or agro-chemical inputs for pest and disease control. Farm power is manual and livestock where present are zebu cattle grazing on unimproved pastures with or without dipping. Intermediate level of technology is applied by farmers receiving loans from Integrated Agricultural Development Project (IADP) and Agricultural Finance Corporation (AFC). This level of technology implies use of improved seeds, selected tree planting materials with modest fertilizer applications and agro-chemical inputs as a means controlling pests and diseases. Farm power is partially mechanised, with tractors being used for ploughing. Livestock where present consist of improved cattle receiving fodder supplements. The level of technical knowledge in the study area generally decreases westwards.
The seven present compound LUTs identified and described are:

- cultivation of perennial crops, cashews dominant;

low level of technology
- cultivation of annual crops, maize dominant; intermediate level of technology
- cultivation of perennial crops, coconut dominant; low level of technology
- cultivation of perennial crops, coconut and citrus dominant; low level of technology
- mixed farming, coconut dominant, unimproved cattle; low level of technology
- cultivation of perennial crops, coconut and cashew dominant; low level of technology and
- extensive grazing of zebu cattle; low level of technology.

These present LUTs are described below

5.4.1.1 Cultivation of perennial crops, cashews dominant; low level of technology

This LUT is found in agroclimatic zone III around Pingilikani on the coastal ridge and Chasimba in the west. It covers approximately 1400ha. Cashews are concentrated on the crests and flanks of the ridge in pure stands. Coconuts are interplanted with annual crops in the valleys,(Plate 5).

Tree crops occupy 50-70% of the area in this LUT of which about 80% is under cashews, about 10% under coconut with citrus and mangoes occupying the remaining 10%. Annual crops, viz. maize, cassava,

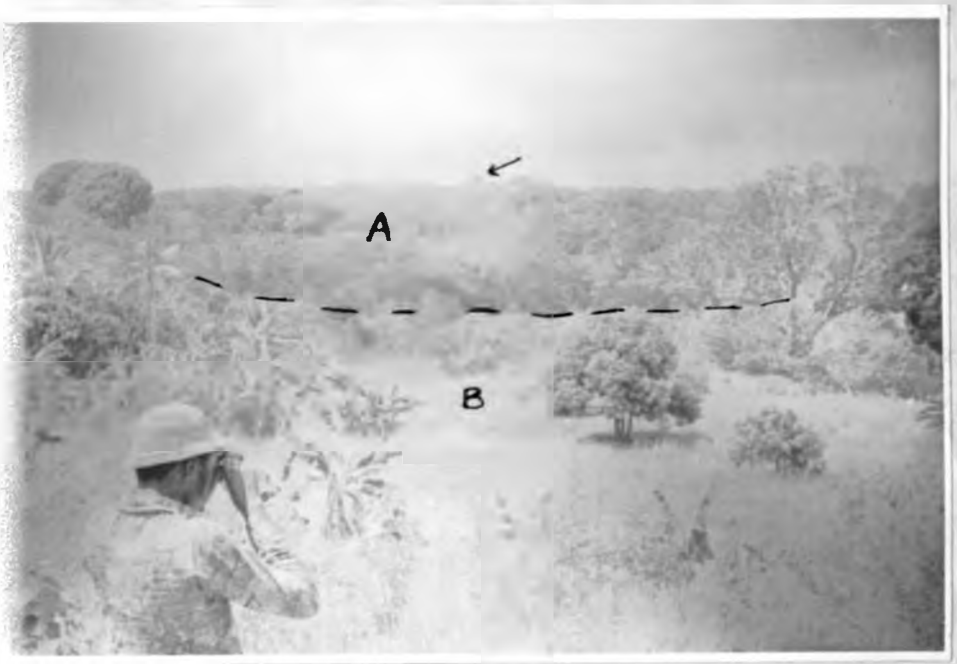


Plate 5. Present land use in units $FrMw_2$ and Lc/Lv/J - LUT.1.1: cultivation of perennial crops; cashew dominant.

A - cashew in unit $FrMw_2$

B - coconut and 'open spaces' for annual crops in unit Lc/Lv/J.

note: a lone coconut among the cashew (arrowed) simsim and pulses are planted on approximately 10% of the area in this LUT. The remaining area, approximately 30%, is left under bush in which zebu cattle graze. This grazing area is generally not sufficient, furthermore there are no watering points, consequently the cattle also graze and drink in the adjacent low lying area "Shales area" in the west.

The production costs (based on 1980 figures) in this LUT are low, amounting to about KSh. 450 per hectare annually. This figure excludes any investment in trees, establishment costs, farm structures and implements. Family labour has been costed and included in this figure. Labour constitutes about 90% of this cost. Land preparation for annual crops, weeding, harvesting and maintenance of the trees are the labour demanding farm operations. Costs of seeds account for the remaining 10% since fertilizers and agrochemicals are not applied.

Labour intensity is low, amounting to 40-45 man-days per hectare annually. There are no pronounced peak labour demands hence family labour is generally adequate.

Farm power is exclusively manual. Ox-ploughing and tractor ploughing are not used.

The cashews are closely spaced (6-9 metres) and nearly all the canopies are touching. This and poor agronomic practices currently applied here reflect a low level of technology.

5.4.1.2 Cultivation of annual crops, maize dominant; intermediate level of technology

This LUT is in agroclimatic zone III, south of Lutsangani hill in the "Shales". It covers approximately 2800ha. All the land west of river Mtomkuu is cultivated but to the east some land is not cultivated. In all, 90% of this LUT is cultivated, see Plate 6.

Food crops are grown on 80% of the cultivated area with maize being interplanted everywhere with other crops. Interplanting with cassava, pulses and 'other crops' occurs to the extent of approximately 40%, 30% and 10%, respectively. Except for the area interplanted with cassava, simsim is planted after the maize crop. Cowpeas and green grams are the most important pulses while 'other crops' include rice, vegetables and some bananas and coconuts in the valleys. Cotton is grown in pure stands in the remaining 10% of the cultivated area. Livestock from adjacent areas graze in the 10% not under cultivation.

The 1980 production costs are high, amounting to about KSh. 1000 per hectare annually. This cost can be broken down as about 90%, 5% and 5% for annual food crops, cotton and simsim, respectively. Tractor ploughing and labour costs, seeds, fertilizers and agrochemicals are the capital consuming operations and

Plate 6. Present land use in unit $VcTi_1$ - LUT.1.2: cultivation of annual crops; maize dominant.

note: the unhealthy coconuts due to root damage by cracking of the soil. Their roots are shown in Plate 1. The profile is only a metre away from the coconuts.

inputs.

Labour intensity is moderate, about 50 mandays per hectare annually. Land ploughing which is done by tractors is excluded. There are pronounced labour demand peaks and family labour is generally insufficient, hence hired labour is employed.

Farm power is partially mechanised. Tractors are used by most of the farmers to plough the land, but ox-ploughing is not practised. Other farm operations are exclusively manual.

Improved seeds are planted, fertilizers and agrochemicals are applied, furthermore, maize is planted in rows and tractors are used for ploughing. These agronomic practices reflect an intermediate level of technology. The amount of fertilizers and agrochemicals used, however, are inadequate.

5.4.1.3 Cultivation of perennial crops, coconuts dominant; low level of technology

This LUT is found in agroclimatic zone III, north of Mwarakaya and around Lutsangani 'hill'. It covers approximately 1600ha.

Tree crops are grown in 65 to 80% of the area in this LUT of which coconuts and cashews take approximately 50 and 15%, respectively. The remaining area under tree crops is planted with mangoes and citrus trees. Interplanting of coconuts, cashewnuts, mangoes and citrus trees is common but pure stands of cashews are also present. Annual food crops are planted in 35 to 20% of this LUT. Maize is the most common annual crop and is interplanted with cassava and pulses in some 'open spaces' without trees, see Plate 7. Parts of the area under trees are used for grazing goats but cattle (where present) graze in the Shales to the east.

The production costs (1980) are low to medium, amounting to about KSh. 500. Labour costs constitute about 90% of the total costs, while seeds take up the other 10%. Broken down to individual crops, coconuts, cashew and annual crops account for 40%, 20% and 40% of the total costs, respectively.

The labour intensity is about 50 mandays per hectare annually, of which about 46%, 35% and 19% are devoted to coconuts, annual crops and cashews, plus other tree crops, respectively. Due to lack of pronounced labour peaks, family labour is generally adequate.

Farm power is manual. Low level of technology is employed here. The coconuts are infested with rhinocerous beetles, maize seeds are unimproved and planted randomly. This level of technology is expected to improve following a series of seminars given to the farmers in this LUT.

Plate 7. Present land use in units $NdLw_1$ and $LfLw_2$ - LUT .1.3: cultivation of perennial crops; coconut dominant.

note: the two extremely tall unproductive coconut trees (arrowed), probably due to ironstone layer at 80cm depth in unit $LfLw_2$.

5.4.1.4 Cultivation of perennial crops, coconuts and citrus dominant; low level of technology

This LUT is in agroclimatic zone III and is concentrated around Kizingo area. It covers an area of about 1150ha. Cashews are grown on the elevated parts while coconut and citrus interplanted with annual crops are grown in depressions. In the western part of this LUT (Chilulu area) 'open areas' are planted to annual crops.

Tree crops are planted on 50-60% of the LUT of which about 30%, 20% and 10% is under coconut, citrus and cashew, respectively. Annual crops are grown in the remaining 40-50% of this LUT. Maize and cassava are again the major food crops and simsim is planted after the maize is harvested.

The 1980 production costs are low, on average, KSh. 500 per hectare annually. About 40% and 60% of the costs are on tree and annual crops, respectively. Labour is again the major cash requiring operation. Thelabour intensity is low, amounting to 45 mandays per hectare, annually.

Farm power is mostly manual but a few farmers use tractors to plough their land especially in Mwakholo river valley for rice and in the 'open areas' for annual crops.

The level of technology applied is low as indicated by very close spacing of both coconuts and cashews. Pest control is generally not taken seriously while unimproved maize seeds are planted randomly.

5.4.1.5 Mixed farming, coconut dominant, unimproved cattle; low level of technology

This LUT is found north of Kaloleni market, in an area stretching from Mwakholo river to Kinane in the west, as shown on the present land use map Fig. 7. It covers an area of approximately 2000 ha. The eastern and western parts of this LUT are in agro-climatic zones III and IV respectively. Part of this LUT is shown in Plate 8.

Tree crops are cultivated on 50-60% of this LUT of which coconuts are grown on about 40% and cashew on the other 20%. The tree distribution is such that coconuts decrease westwards and northwards following the rainfall gradient. Annual crops are interplanted with coconuts in places but they are also planted in 'open spaces" which amount to about 10% of the total area in this LUT. Maize and cassava are again dominant while other annual crops include rice in the valley bottoms and local depressions; simsim, cotton, and tobacco; the latter is grown around homesteads.

Livestock, an integral part of this LUT, consists of mainly zebu cattle and goats. A few farmers possess improved cattle. Grazing is partly

Plate 8. Present land use, LUT .1.5 - mixed farming, coconut dominant; in a minor valley of unit Ao-Gd 3/1.

note: the unhealthy coconut in the foreground due to poor drained soil which is often flooded.
- note also the absence of a dense root mat on the exposed soil cluster at the base of this coconut.

done under the trees and partly in semi-improved pastures in open areas, the latter constituting about 30% of this LUT. This grazing area is generally insufficient and the zebu cattle go to graze in the valley to the south west.

The 1980 production costs are low, approximately KSh. 380 per hectare annually. This value excludes livestock production costs which are low except for the few dairy cattle present. About 80% of this production cost goes to coconut and the remaining 20% goes to the production of cashew and annual crops. Labour costs approximate to about 90% of the total production costs. The production costs vary widely in this LUT, therefore the figure given is only an average.

Labour intensity is low, on average 37 mandays per hectare annually. The labour intensity for farmers with improved cattle is however very much higher. Crops take up about 80% of the labour and the remaining 20% is devoted to livestock. Family labour is generally adequate but where improved cattle are kept hired labour is required.

Farm power is largely manual but a few farmers employ contract tractor ploughing in the 'open spaces' for annual crops. Ox-ploughing is not practised.

A low level of technology is applied by the majority of the farmers in this LUT. However a few farmers employ intermediate to high level of technology especially on dairy cattle.

5.4.1.6 Cultivation of perennial crops, coconuts and cashews dominant; low level of technology

This LUT is found in Mikiriani and Makumbwani areas, north and north-west of Kaloleni market. Part of this LUT (around Mikiriani) is in agroclimatic zone III but the rest is in zone IV. In the eastern part coconuts are interplanted with annual crops but cashews become more important in the west. This LUT covers about 1400 hectares.

Tree crops are planted on 60-80% of this LUT of which 40% and 30% are under coconut and cashew, respectively. The distribution of the trees is such that to the east coconuts may cover about 80% but in the west cashew may be found in pure stands. Annual crops are planted to 20-30% of this LUT. Maize is the dominant crop and is interplanted with other annuals and coconuts. In the minor valleys rice is commonly grown. Cotton and tobacco are also grown, the latter around the homesteads. Simsim is grown after the maize is harvested.

The 1980 production costs are low, amounting to about KSh. 300 per hectare annually. Farm operations viz. land preparation, weeding and harvesting account for most of the production cost while the cost of seeds accounts for the remainder.

Labour intensity is low, approximately 25 mandays per hectare annually with 40%, 20%, and 40% of the labour being devoted to coconuts, cashew and annual crops respectively. Peak labour demands are not very high, hence family labour is generally adequate.

Farm power is mostly manual except in a few cases where farmers who are recipients of I.A.D.P. loans use tractors to plough some fraction of their farms. Ox-ploughing is not practised.

A low level of technology is applied. This is reflected by the use of unimproved seeds, unselected planting material, lack of fertilizers and random planting of maize.

5.4.1.7 Extensive grazing of zebu cattle; low level of technology

This LUT lies in agroclimatic zones IV and V. It is found in the Gotani-Mwana Mwinga area and covers approximately 2300 hectares. Cattle graze on unimproved pasture with isolated and non-permanent clusters of cultivated areas, Plate 9. Basic data on the carrying capacity or stocking density in this area was not available. However, de Jong (1977) described a similar LUT in the Kwale area in the same agroclimatic zones. The information given by de Jong was extrapolated to provide a basis for assessing the capital and labour intensity for this LUT.

Plate 9. Unimproved pastures for extensive grazing - LUT .1.7 in units $LgAi_2$, Qcfe4 and $LcFw_1$.

A - grass pasture without shrubs, unit $LgAi_2$

B - grass pasture with shrubs, units $LcFw_1$, Qcfe4

note: an isolated coconut (arrowed) around which a cluster of cultivation was present.

Unimproved pastures covers 70-80% of this LUT and carries an estimated 500 heads of cattle (assuming a stocking density of 1 unit per 8 hectares of land). Annual crops were cultivated on the remaining 10-20% of this LUT. The cultivated area is not permanent, i.e. cultivation is not concentrated on certain locations all the time. Maize, cassava and simsim are the main annual crops. Tree crops, viz. cashews and coconuts are scattered in the pasture and on cultivated areas. Charcoal burning is also practised.

The production costs (1980) are low, and estimated to be less than KSh. 200 per hectare annually. The production costs can be broken down to about 30% for livestock and 70% for crops. This excludes the investment in both animals and tree crops. Labour again is the greatest capital consumer.

Labour intensity is low, estimated at 20 mandays per hectare annually. Grazing requires an estimated 2 mandays per hectare annually assuming that 60 heads of cattle require one person to herd, (Bouwman, 1980). Annual crops require about 15 mandays while tree crops need only about 2 mandays per hectare annually.

A low level of technology is applied as reflected by zebu cattle, rotational cultivation and planting of unimproved seeds randomly.

5.4.2 Alternative land utilization types

The research experiences at the Coast Agricultural Research Station (CARS) and the author's observations in the field were used to identify and describe the relevant alternative simple and compound LUTs in the Chonyi-Kaloleni area. The simple LUTs consist of single enterprises while the compound LUTs are combinations of enterprises of crop(s) with dairy cattle and ranching. All the proposed alternative LUTs are at an intermediate level of technology.

5.4.2.1 The simple land utilization types

The simple LUTs considered relevant in the Chonyi-Kaloleni area are:-

1. cultivation of cashewnuts
2. cultivation of coconuts, and
3. cultivation of maize

Each of these simple LUTs is described below.

5.4.2.1.1 Cultivation of cashewnuts; intermediate level of technology

This LUT will consist of clone A81 planted in 'hedge rows' at a spacing of 2.5 to 3 metres and 9 or 12 metres within and between the rows respectively. The trees will be 'ring weeded' three times annually and bush between the rows slashed a similar number of times a year. When the trees are young, annual food crops with modest fertilizer application, may be planted between the rows. The trees should be rejuvenated, (replacing the old canopy with a new one by severe pruning) at the ages of 8 and 14 years for the 9 and 12 meter row spacings, respectively. Some measure of pest and disease control are assumed.

The expected yields are similar to those obtained at Mtwapa in a similar 'hedge row' experiment by van Eijnatten (1981), viz. 2700 to 4300 kg/ha.

The establishment costs are expected to be high, amounting to KSh. 2,400 per hectare (1980). This includes the cost of land preparation, planting site preparation, planting, seeds and clonal budding but does not include the cost of fertilizers. The maintenance costs (1980) are also high, ranging from KSh. 1655 to KSh. 2080 per hectare annually. Of these costs, harvesting accounts for more than half.

Establishment requires about 60 mandays per hectare annually. Maintenance requires about 55 mandays per hectare annually. The labour required for harvesting depends on the actual yields but may be estimated to range from 120 to 140 mandays per hectare using the yield estimates above and assuming that 30kg are harvested per manday (van Eijnatten, 1981). This labour intensity is very high and family labour will generally not be adequate.

Farm power will be manual. The major infrastructural requirement is an adequate extension service to educate the farmers on establishment, rejuvenation of the trees and means of controlling pests and diseases.

5.4.2.1.2 Cultivation of coconuts; intermediate level of technology

This LUT will consist of planting selected high yielding planting material at a spacing of 9x9 or 12x12 metres. The trees will be 'ringweeded' three times annually. Some measures to control pests and diseases will be applied and nuts will be harvested quarterly. Tapping will not be practised and fertilizers will be applied in two portions, viz. two thirds in the 'long rains' and the remainder during the 'short rains' in amounts indicated in Table 23 below.

The expected yield per hectare depends on the number of coconut plants per hectare. Yields similar to those obtained by van Eijnatten (1981), viz. 791 and 1000kg/ha for plant densities of 123 and 156 palms /ha, respectively, assuming a yield of 45 nuts/palm/ annually and 1.42 grams of copra per nut. To arrive at this estimate van Eijnatten assumed that experiences with fertilizer trials elsewhere can be reproduced in Kenya.

The production costs (1980) are high amounting to KSh. 1923 per hectare annually. These costs include fertilizer and fertilizer application, harvesting and

Table 23. Annual fertilizer recommendations for coconuts at the Coast

NUTRIENT & FERTILIZER	PER PALM	PER HECTARE	
		AT 156 PALMS/HA	AT 123 PALMS/HA
Nitrogen (429g N/Palm)			
(CAN 26%N)	1.66kg	257kg	203kg
Phosphorus (64g P/palm)			
Double super phosphate (20-2%P)	0.32kg	49kg	39kg
Potassium (590g K/palm)			
Muriate of potash (41.5%K)	1.42kg	229kg	173kg

Source: van Eijnatten (1980). 'Improved productivity of coconuts through fertilizers?' CARS Communication 14.

copra production. Costs of fertilizer amount to about half of the total costs.

The labour intensity is moderate to high, ranging from 90 to 103 mandays per hectare annually. Weeding and harvesting are the most labour demanding operations and together they constitute about two thirds of the labour demand. Generally labour is hired to drop the nuts but family labour will be adequate for the other operations. Farm power is expected to be entirely manual.

Adequate extension services, improved methods of copra production and fertilizer outlets are the major infrastructural requirements of this LUT.

5.4.2.1.3 Cultivation of maize, intermediate level of technology

This LUT will consist of the cultivation of coast composite maize, planted on the onset of the 'long rains', in rows at spacing of 30cm and 90cm within and between the rows. Fertilizer applications at the rate of 100kg/ha of double super phosphate at the time of planting and top dressing with 150kg/ha of calcium ammonium nitrate at knee height. The maize should be clean weeded from the time the rows are visible to tasselling or up to 10 weeks whichever is sooner. Thinning to one plant per hole should be done when the maize is 15cm high. The pests and diseases should be controlled using the recommended chemicals.

Adequate conservation measures are assumed to be present.

The yield estimates under the husbandry above is about 2500kg/ha in the Coast Province (Rubui, A.M., 1980). However, the yields will vary depending on the rainfall during the growing season and are expected to decrease with the rainfall gradient across the study area.

The production costs (1980) are estimated at KSh. 1450 per hectare annually. This cost includes that of fertilizer and farm operations. The labour intensity is expected to be high, about 90 mandays per hectare annually. This intensity is too high since land preparation is assumed to be mechanised. It includes labour required for planting, weeding and harvesting operations.

Farm power is expected to be partially mechanised with tractors being used for land preparations. Oxen may be used for land preparation; however, in the author's opinion the shortage of land for grazing the animals may be a constraint to the use of oxen.

The main infrastructural requirements for this LUT are adequate extension services and the provision of loans for purchasing fertilizers and seeds.

5.4.2.2 The compound land utilization types

Various combinations of the simple LUTs with dairy cattle and ranching were used to define the relevant compound land utilization types in the Chonyi-Kaloleni area. These compound LUTs were defined at an intermediate level of technology and includes:-

1. cashewnut-dairy cattle association,
2. coconut-dairy cattle association,
3. maize-dairy cattle association,
4. coconut-cashewnuts, and
5. ranching-cashewnuts association.

Each of these compound LUTs is described below.

5.4.2.2.1 Cashewnut-dairy cattle association; intermediate level of technology

The main component of this LUT is cashewnuts clone A81, planted in 'hedge rows' at a spacing of 3 and 15 metres within and between the rows respectively. Young seedlings should be protected by fencing from cattle and 'ring weeded' three times annually. The canopies should be shaped into hedge rows and rejuvenated by severe pruning after 14 years (in phases) when the canopies of adjacent rows are about to touch. Pasture consisting of shade resistant grasses, e.g. *panicum Maximum* should be planted under the cashew trees and between the rows. Other grasses may be planted in the 'open space' without cashewnut trees. Adequate fertilizers for pasture should be appli-d especially during the establishment period. The cattle to be grazed should be heat-tolerant breeds or crosses e.g. Jersey and Ayrshire x Sahiwal crosses. The number of dairy cattle per farm will depend on the size of the farm and the availability of fodder crops from 'external' sources. The minor and supplementary component of this LUT are the cultivation of food and fodder crops to be grown outside the cashew-pasture complex.

The cashewnut clone A81 at the spacing above is expected to yield over 2,700kg/ha annually. Milk production data was not available therefore it is not possible to estimate the expected yields. However, the results of experiments to evaluate a farming system consisting of cashewnuts and dairy cattle at Mtwapa (1965-1973) using ordinary cashew trees and Jersey cattle showed that there is no drop in milk production due to cashewnuts. Furthermore, the association appeared a better enterprise as the 1972 comparative gross margin figures show (Muturi et.al., 1981).

a) cashewnuts alone	KSh. 190/ha
b) cashew plus dairy cattle	KSh. 464/ha
c) open cashew plus dairy cattle	KSh. 337/ha

The low gross margins are probably due to the genetically low yielding cashewnut trees and is expected to be much higher when cashew clone A81 is used. Inspite of the low gross margins, this experiment has shown the cashew-dairy cattle association to be a viable farming system.

The establishment costs of cashewnuts are expected to be high (more than KSh. 2,000 per ha). The data needed to estimate the establishment cost of pasture and purchase of dairy cattle was not available but is expected to be very high. The maintenance costs of the association could not be estimated due to lack of relevant data, but is expected to be very high, (more than KSh. 1600 per ha annually). Labour intensity is expected to be high (more than 55 mandays/ha and more than 100 mandays/ha annually for establishment and maintenance, respectively. Farm power will be manual.

The main infrastructural requirements include adequate extension service, provision of drinking water for animals, provision of cattle dips, produce buying and input selling centres. Credit facilities to provide the initial capital also need to be established. Co-operative societies should be established to market the dairy produce.

5.4.2.2.2 Coconuts-dairy cattle association; intermediate level of technology

High yielding coconut seedlings will be selected and planted at a spacing of 12x12 metres. The trees will be 'ring weeded' three times annually during the establishment period. Burying coconut husks around the palm should be practised, however, adequate hygienic measures should be taken to avoid breeding rhinoceros beetles. Adequate fertilizers as recommended for the simple LUT - coconut (see Table 23) should be applied. Harvesting of nuts should be on a quarterly basis while tapping should not be practised. Pasture grasses resistant to shade, e.g. *panicum maximum* should be established between the coconut trees, and other pasture grasses and legumes planted in the 'open spaces' without coconuts. Heat tolerant cattle breeds should be kept. Minor components of this LUT include other tree crops, e.g. citrus and cashewnuts which should not be interplanted with coconuts but with pasture beneath them. Maize and other food and fodder crops may be grown in 'open spaces' without coconuts or cashewnuts.

The expected copra yield is about 71.0kg/ha annually for a tree spacing of 12x12metres. Dairy cattle yields under coconuts were not available but the author assumes that the higher gross margins that have been shown with cashewnuts are also possible with coconuts.

The production cost of this association could not be estimated due to lack of relevant data but it is expected to be higher than that of coconuts alone, i.e. KSh. 1920 (in 1980). The labour intensity is expected to be high (more than that of coconuts alone, viz. 103 mandays/ha annually). Harvesting nuts and maintaining the dairy cattle will be the most labour demanding farm operations. Family labour will generally be adequate to maintain the cattle but hired labour will be required for the specialized nut harvesting operations.

Farm power will be exclusively manual except for land preparation for the minor components maize and fodder crops for which land preparation may be partially mechanised in the 'open spaces'.

Infrastructural requirements for dairy cattle are similar to those in the cashew-dairy cattle association but in addition an effective extension service controlling the rhinocerous beetle, which is the most destructive pest for coconuts, is needed. Improved methods for processing nuts into copra should also be initiated by the extension service. Finally, credit facilities need improvement while research findings on high yielding and disease-resistant coconut trees will greatly improve the profitability of this enterprise.

5.4.2.2.3 Maize-dairy cattle farming; intermediate level of technology

In this LUT the cultivation of maize should be carried out on 50% to 60% of the area while 30% to 40% of the area should be devoted to dairy cattle. The pasture should be fertilized and rotated with maize after 4 to 5 years of grazing. The remaining 10% of the area may be devoted to minor components, e.g. rice, cotton and cassava.

Management specifications for maize in the simple LUT maize (section 5.4.2.1) should also be practised in this LUT. In addition, maize may be interplanted with legumes, e.g. cowpeas or groundnuts, cotton should be planted in pure stands but should be rotated with maize.

From the available maize yield data, the expected maize yields are above 2500kg per hectare, depending on the amount of rainfall during the growing season. Dairy cattle production estimates were not available.

The production costs for this LUT are expected to be very high (more than that of maize alone, viz. KSh. 1400/ha annually). The labour intensity is also expected to be very high (more than that of maize, viz. 90 mandays/ha annually). Due to pronounced labour demand peaks, family labour will generally not be adequate and therefore hired labour will have to be deployed during the peak labour demand periods, viz. during planting, weeding and harvesting. Farm power will be largely manual except for land preparation which will be mechanised.

The main infrastructural requirements for this LUT include an increased agricultural extension service, adequate and timely provision of tractor hire services, provision of input buying centres, e.g. for seeds and fertilizers. Credit facilities need to be expanded to provide bigger loans and to recruit more members. The infrastructural requirements for dairy cattle are provision of cattle dips, introduction of more fodder crops and artificial insemination services. The calf mortality rates are high and methods to effectively reduce these rates are needed. Soil conservation measures to reduce soil erosion are also needed in this LUT, contour ploughing, terracing, mulching, cut-off drains and avoiding overgrazing are some of the important measures towards the reduction of erosion.

5.4.2.2.4 Coconuts-cashewnut cultivation; intermediate level of technology

These tree crops should be planted in pure stands. The relative importance of each tree crop is expected to vary from one unit to another. However, coconuts are expected to be more predominant in the eastern part of the study area, where there is more rainfall. The management practices for the two tree crops are as specified in the simple land utilization types (section 5.4.2.1). Minor components in this LUT may include maize and other food crops which may be interplanted with the tree crops, rice and cotton in local depressions where rooting or drainage conditions are limiting for tree crops. Dairy cattle to produce milk for domestic consumption may also be a minor component of this LUT.

This LUT is an intergrade between the simple LUTs coconuts and cashewnuts therefore the production costs, labour intensity and yield estimates will range between those of the two constituent simple LUTs. However, where rice and dairy cattle are minor components in this LUT, the capital intensity, production costs and gross margins are expected to be slightly higher.

Farm power is expected to be exclusively manual except for the minor components for which land preparation may be partly mechanised.

In addition to the infrastructural requirements for cashew and coconuts, those of dairy cattle have to be provided to cater for this minor component.

5.4.2.2.5 Group ranching-cashewnuts; intermediate level of technology

The main component of this LUT is grazing beef cattle which should be devoted to 70% to 90% of the area under this LUT. Cultivation of cashewnuts and drought resistant annual food crops should then be devoted to the remaining 10-30% of the area. The pasture should consist of those grasses which can best withstand heavy grazing for long periods and conditions of low rainfall. The grass varieties *E. superba*, *C. ciliaris* and *Panicum maximum* appear to be suited to the ecological characteristics of the study area, and may be planted as pasture for ranching. Isolated or clumps of cashewnuts should be planted in the pastures to provide both shade and nuts. The shade tolerant *Panicum maximum*, should be planted under the cashewnut canopies. The management specification for cashewnuts (section 5.4.2.1) should generally be applied except planting in rows. Minor components of this LUT include cultivation of maize and cassava.

The relevant data for estimating carrying capacity and beef production was not available hence the production capacity of this LUT was not estimated. However, group ranching in Kwale for areas with similar ecological conditions has been successful and it is therefore assumed that it will also be viable in the study area. Local zebu cattle are well adapted for this environment and should therefore be kept for beef.

The initial capital intensity to establish group ranches (excluding the cost of animals) are expected to be low (less than KSh. 500/ha as of 1980). Labour intensity will also be low (less than 50 mandays /ha annually). Farm power is expected to be manual except for the construction of firebreaks, boreholes, dams and for pumping drinking water for the animals.

The infrastructural requirement of this LUT include provision of drinking water, cattle dips and veterinary extension services, to advise farmers on the management practices required to improve the health of animals.

5.5 SUITABILITY CLASSIFICATION OF THE SOILS FOR SELECTED SIMPLE AND COMPOUND LAND UTILIZATION TYPES

The relevance of a suitability classification in an area is dependent on the physical, and socio-economic context of the area being evaluated. Although the socio-economic conditions within the present study area were not a diagnostic criterion per se, it is necessary to describe briefly the socio-economic conditions under which the physical suitability has been assessed. The physical suitability was assessed using 'conversion tables' which were constructed for each of the alternative simple LUTs.

The socio-economic constraints to agricultural development and the construction of the conversion tables in this study are therefore discussed before assessing the suitabilities of the mapping units.

5.5.1 Socio-economic constraints to agricultural development

Scarcity of land, fragmentation and the distance between farms are becoming a constraint to agricultural development in parts of the study area. Farm sizes range from about 3 hectares in the eastern part to over 12 hectares in the western part of the study area. Given the present population growth rates of about 3.2 to 4.3% per annum, the pressure on the land is expected to increase considerably in the near future.

Land ownership is presently governed by complicated customary laws. Under these laws, although families have rights to use the land allocated to them, all the land is owned by the clan. Traditional borrowing of land, where a farmer may borrow land under tree crops, inhibits investments on the land by both the borrower and the land owner. Grazing rights are held by the community which encourages overgrazing and consequently soil erosion. The customary laws will however be replaced once the land adjudication, now in progress, is completed.

Farm incomes are low due to the low productive capacity of the land, for example, Mukabi et.al. (1980) estimated an income of between KSh. 700-1200 per hectare annually for a coconut farmer, assuming that 30% of the nuts are processed into copra. To earn the equivalent of the statutory minimum wages at the coast, the coconut farmer would need 4-7 hectares planted to coconuts.

The quality of produce is often low, notably so with copra. Poor copra processing methods employed by individual farmers are responsible for the poor quality. Low quality copra earns the farmers low prices which is discouraging. Cashewnuts of high quality (FAQ) are however produced but the prices are also low. Annual fluctuations in the prices are a further constraint. Furthermore, the overall price structure does not offer farmers adequate incentive to warrant their increased attention on tree crops.

Produce buying and input selling centres are localized in the main markets. Consequently farmers in remote areas encounter difficulties in transporting their produce and inputs. Furthermore, extension staff seldom visit farmers in remote areas. Improving minor roads would be highly beneficial for these remote farmers.

Credit facilities are another major constraint. Most farmers do not have title deeds for their farms, and therefore do not qualify for loans from the Agricultural Finance Corporation. The Integrated Agricultural Development Project offers too small annual loans (Ksh. 1500) moreover, only a small number of farmers are recruited into the program. Tractor hire services under this program are often insufficient to meet the demand during peak periods, consequently land preparation is often delayed.

Low yielding tree varieties are another constraint and thus inspite of improved agronomic practices, the yields are still low. Lack of effective means to control pests and diseases further accentuates the low yields obtained.

5.5.2 Conversion tables

The suitability of land for a given use is dependent on the 'conversion tables' used in the evaluation. Moreover, since there are no 'universal' conversion tables, the suitability obtained using a set of conversion tables is predominantly of local significance. It is therefore necessary to discuss how the conversion tables used in a given evaluation were constructed. The conversion tables used in this study were constructed using information on crop requirements obtained from the literature (section 2.3), other similar suitability classification studies and the author's judgement of how land qualities affected crop performance in the field. The construction of conversion tables for each alternative simple LUT is discussed below.

5.5.2.1 Coconuts

Availability of moisture, oxygen, rootability and availability of nutrients were used as the diagnostic criteria.

Average yields of coconuts in coastal Kenya are low compared to other coconut producing areas (van Eijnatten, 1980). These low yields have been attributed largely to marginal rainfall, (Child, 1964; van Eijnatten et.al., 1977; Floor, 1981). Availability of moisture was therefore 'weighted' heavily in the suitability rating. Soils in which moisture deficits are likely to cause more than 60% decline in yields, were considered not suitable, viz. rating 5. Soils experiencing moisture deficits likely to cause

30% to 60% decline in yields were considered marginally suitable to accommodate the aforementioned authors' 'suitability rating' of marginally suitable for areas 10 kilometres inland and north of Mombasa. Up to 30% yield declines were rated as highly to moderately suitable.

Coconut requires well drained soils. Fremond et. al. (1966), stated that "...the coconut palm demands soils that are aerated and correctly drained." However, these authors did not define the correct drainage. Purseglove (1976) on coconut's drainage requirement, stated that "low lying areas, subject to flooding, and which cannot be drained should be avoided". In the study area, coconuts were absent or unproductive (see Plates 6 and 8) in poorly drained soils. In view of these observations, poorly drained (rating 4) and imperfectly drained (rating 3) soils were considered not-suitable and marginally suitable, respectively. Well and moderately well drained soils were not considered limiting hence they are moderately to highly suitable.

Fremond et.al. (1966) gave the minimum depth requirement for adequate anchorage as 80-100cm. In the study area, some coconut growing in unit $LfLw_2$ with ironstone at 80-105cm depth were extremely tall and unproductive (Plate 9). In other units with less than 80cm rootable depth coconuts were absent or non-productive, see Plate 6. Soils with less than 80cm rootable depth (ratings 5 and 4) were therefore considered not suitable while 80-150cm depth was considered marginally suitable. Rootable depth greater than 150cm was not considered limiting.

Coconuts adapt well to soils with a wide range of chemical properties, consequently soil chemical analyses are not well correlated with yields. Manciot et.al (1979, 1980), quoted by Floor (1981) gave the following critical values of nutrients:-

Exchangeable K	0.15-0.2 me/100g
" Mg	0-2-0.5 "
Sum of exchangeable cations......	>1 me/100g
% organic carbon......	1%

The critical values of Manciot et.al. (loc.cit.) rated according to tables 16c and d in this study fall in class 4. Webb (1981) evaluated the suitability of the soils of Mangaia, Cook Island, for tree crops including coconuts and cashewnuts. A rating of the soils with very severe nutritional limitations in Webb's classification, according to table 16c and d in the present study placed them in class 4. Thus in view of Webb's study and Manciot's critical values, class 5 of tables 16c and d would be rated as not suitable. However, since some fertilizer application is assumed at the intermediate level of technology, soils falling in class 5 of Tables 16c, 16d and consequently class 5 of Table 16 will be considered marginally suitable, class 3 moderately suitable and classes 1 and 2 as highly suitable.

The land qualities susceptibility to soil erosion and workability of the soil were not considered very important for coconuts. This was so because a complete canopy cover will effectively reduce erosivity of the storms and enhance infiltration of rain into the soil. These two land qualities were therefore not used as diagnostic land qualities.

5.5.2.2 Cashewnuts

In general, the requirements of cashewnuts are similar to those of coconuts, therefore the conversion tables for the two crops are similar. However, there are some differences for example, in addition to the diagnostic criteria used for coconuts, the harmful effect of the August-December rainfall was also used as a diagnostic criterion for cashewnuts.

From section 2.3 it is clear that cashewnut requires less rainfall than coconuts, therefore the former is more tolerant to moisture deficits. However moisture deficits have been commensurated in terms of yields for the two crops. Similar moisture availability ratings were therefore used in assigning suitability classes for the two crops, except for the moderately suitable class which was equated to moisture availability rating 2 and 3 for cashews and to moisture availability class 2 for coconuts. This separation was necessary to make the resultant suitability for the two crops compatible to 'field suitability' as observed by the author. The assignment of August-December rainfall ratings to suitability classes was the same as the assignment of availability of moisture ratings. The rating classes used for availability of oxygen and rootability for coconuts were also used for cashews since the two crops appear to have similar requirements for these land qualities. The nutritional requirements of cashewnuts are poorly documented in the literature, furthermore, the few that exist relate cashew requirements to foliar analyses (Ohler, 1979) therefore the author's judgement was used. Availability of nutrient ratings were related to suitability classes as follows, ratings 1 and 2 as highly suitable, rating 3 as moderately suitable and ratings 4 and 5 as marginally suitable. Since no critical exchangeable cation values were found in the literature for cashewnuts and the assumption that application of fertilizers is part of the intermediate level of technology, all soils were considered to be at least marginally suitable.

5.4.2.3 Maize

The moisture availability was not calculated for maize, since, as stated earlier the major emphasis in this study was on coconuts and cashewnuts. In the absence of the moisture availability parameter for maize agroclimatic zones (defined in section 4.2.3) and available moisture storage capacity were used as a crude index of availability of moisture. Maize requires at least 375mm rainfall during the growing season (Purseglove, 1976) or 750-1250mm annual rainfall (Rubui, 1980). Although all stations in the study area have at least 750mm average annual rainfall, the (rainfall) distribution requirement (which is critical) is not met in all stations, and therefore some parts of the study area are not suitable for maize. In agroclimatic zone III, soils with an AMSC of more than 150mm, 80-150 mm, 40-80mm and less than 40mm were considered highly moderately, marginally and Not-suitable respectively. In zone IV, soils with more than 150mm, 80-150mm and less than 80mm were considered moderately, marginally and not-suitable, respectively. In zone V, the soils with an AMSC of more than 100mm were considered marginally suitable, but those with less than 100mm were considered not-suitable. The availability of nutrient rating classes 1, 2, 3, 4, 5 were considered highly, moderately and marginally suitable. Since fertilizer application is assumed to be part of the agronomic practise, all rating classes were considered at least marginally suitable. Maize is intolerant of poor drainage and consequently rating 4 of the availability of oxygen land quality was considered not suitable, unless the soils were to be artificially drained. Rating 3 was considered moderately suitable but ratings 1 and 2 were not considered limiting.

Sixty percent of roots (by weight) are in the top 75cm of the soil (Purseglove, 1976), therefore less than 30cm depth was considered not-suitable while 30-80cm depth was considered marginal for maize. A rooting depth of more than 80cm was not considered limiting for anchorage of maize. Susceptibility to soil erosion was not 'weighted heavily' since adequate and effective soil conservation measures are assumed at an intermediate level of technology. Workability of the topsoil was not 'weighted heavily', thus, rating 5 was considered marginally suitable, since land ploughing is partially mechanised.

5.4.2.4 Grass (pasture) for dairy cattle

Dairy cattle production is dependent on those land qualities which affect productivity of grazing land, its nutritive value, and other land qualities which directly affect dairy cattle e.g. climatic hardships, endemic pests and diseases, and the availability of drinking water. However, time did not permit all the land qualities to be considered, therefore the construction of the conversion table was based on the land qualities which affect the productivity of grass. All other land qualities were assumed not limiting.

Although grass varieties have different ecological requirements, it was not possible to construct conversion tables for each grass species, therefore a generalised conversion table was constructed. Unlike those for coconuts, cashew and maize, the conversion table for grass was not based on critical values of the relevant land qualities but on the basis of the generalized requirements of some grasses given in Table A1, section 2.3.5.

Dairy cattle require succulent pastures, therefore agroclimatic zones were 'weighted' heavily in the conversion table. The degree of suitability of a soil within a given agroclimatic zone will also depend on its available moisture storage capacity therefore the ranges of AMSC of soils in each agroclimatic zone were defined for each suitability class. The ranges in AMSC for each suitability class were chosen rather arbitrarily but reflect the decreasing suitability as the rainfall and the AMSC of a soil decreases.

Soil depth was considered with respect to availability of nutrients and foothold since the moisture storage capacity has already been considered. Ratings 1, 2 and 3 were not considered limiting but ratings 4 and 5 were considered marginal.

Different grasses withstand lack of oxygen to varying degrees. On reducing the availability of oxygen the number of suitable grass varieties are reduced. Consequently, ratings 1, 2 and 3 were not considered limiting but rating 4 will reduce the number of suitable grasses and was therefore considered marginally suitable. Where grasses, tolerant to poorly drained conditions are not present or planted, then class 4 becomes not-suitable.

Availability of nutrients determines both the rate of growth and the nutritive value of the grasses therefore it was weighted' heavily. Ratings 1 and 2 were considered highly suitable, rating 3 and 4, 5 moderately and marginally suitable, respectively. Since application of fertilizers is assumed no rating was considered not-suitable. The suitability ratings for dairy cattle are given in Table 24d.

5.4.2.5 Grass for beef cattle

The conversion table for grass for beef cattle was similar to that for dairy cattle. However, the requirements of dairy cattle may be more rigorous than those of beef cattle. Beef cattle are generally kept in areas which are either marginal or not-suitable for cultivation (Barret and Larkin, 1974). The area available for grazing beef cattle has to be much larger than that available for dairy cattle, thus beef cattle can tolerate lower pasture yields than dairy cattle. These facts were taken into account in the construction of the conversion table for grasses for beef cattle. Agroclimatic zones and AMSC were jointly used as an index of availability of moisture. The ranges in AMSC of soils in the three agroclimatic zones were arbitrarily defined for each suitability class. Lower ranges of AMSC's were used for beef cattle than those for dairy cattle.

Soil depth ratings were not 'weighted' heavily since the available moisture storage capacity has been considered but was nevertheless rated with respect to volume tapped for nutrients and foothold. Ratings 1, 2, 3 were not considered limiting but rating 4 and 5 were considered marginally suitable.

Availability of oxygen was 'weighted' more heavily than was the case for dairy cattle because for beef cattle no supplementary fodder crops are considered. Since lack of oxygen reduces the yields of most grass varieties, rating 4 was considered marginally suitable, rating 3 moderately suitable while ratings 1 and 2 were not considered limiting. Seasonality of grazing is not considered but it is worth mentioning. During the dry season the annual or perennial grasses tend to dry out, and under these circumstances grasses are better where the availability of oxygen is low, i.e. moisture availability is higher, hence the suitability of the ratings 4 and 3 would be higher than they have been accorded in this conversion table.

Availability of nutrients was rated the same way as for dairy cattle except for class 5 which was here considered not-suitable. Class 3 and 4 were considered moderately and marginally suitable, respectively while classes 1 and 2 were considered highly suitable. The conversion criteria discussed above are

Table 24. Conversion tables

24a. Coconuts

LAND QUALITY / SUITABILITY CLASS	AVAILABILITY of MOISTURE	AVAILABILITY of OXYGEN	ROOTABILITY	AVAILABILITY of NUTRIENTS
Highly Suitable S1	1	1,2	1,2	1,2
Moderately Suitable S2	2	1,2	1,2	3
Marginally Suitable S3	3,4	3	3	4,5
Not-Suitable NS	5	4	4,5	-

Table 24. cont'd.

24b. Cashewnuts

LAND QUALITY / SUITABILITY CLASS	AVAILABILITY OF MOISTURE	AUGUST-DECEMBER RAINFALL	AVAILABILITY of OXYGEN	ROOTABILITY	AVAILABILITY of NUTRIENTS
Highly Suitable S1	1	1	1,2	1,2	1,2
Moderately Suitable S2	2,3	2,3	1,2	1,2	3
Marginally Suitable S3	4	4	3	3	4,5
Not Suitable NS	5	5	4	4,5	-

Table 24. (cont'd.)

24c. Maize

LAND QUALITY / SUITABILITY CLASS	AGROCLIMATIC ZONE AND AVAILABLE MOISTURE STORAGE CAPACITY	AVAILABILITY of NUTRIENTS	AVAILABILITY of OXYGEN	ROOTABILITY	SUSCEPTIBILITY TO SOIL EROSION	WORKABILITY OF THE SOIL
HIGHLY SUITABLE S1	III; >150mm	1,2	1,2	1,2,3	1,2,3	1,2,3
MODERATELY SUITABLE S2	III; 80-150mm IV; >150mm	3	1,2,3	1,2,3,4**	4	4
MARGINALLY SUITABLE S3	III; 40-80mm IV; 80-150mm V; >100mm	4,5	3*	4	5	5
NOT-SUITABLE NS	III; <40mm IV; <80mm V; <100mm	-	4	5	-	-

* Applicable in areas which are imperfectly drained but receive water from lateral drainage

** applicable for those soils with high available nutrients, rating 1 and 2

Table 24. (cont'd.)

24d. Grass (pasture) for dairy cattle

LAND QUALITY / SUITABILITY CLASS	Agroclimatic Zone and AMSC	Soil Depth	Availability of Oxygen	Availability of Nutrients
HIGHLY SUITABLE S1	III; >150mm	1,2,3	1,2,3	1,2
MODERATELY SUITABLE S2	III; 80-150mm IV; >150mm	1,2,3	1,2,3	3
MARGINALLY SUITABLE S3	III; 40-800mm IV; 100-150mm V; >150mm	4,5	4	4,5
NOT-SUITABLE NS	III; <40mm IV; <100mm V; <150mm	5*	-	-

* Only applicable where shallow rooting grass varieties are not available

Table 24. (cont'd.)

24e. Grass for beef cattle

LAND QUALITY / SUITABILITY CLASS	Agroclimatic zone and Available Moisture Storage Capacity	Soil Depth	Availability of Oxygen	Availability of Nutrients
HIGHLY SUITABLE S1	III; >120mm IV; >150mm V; >150mm	1,2,3	1,2,3	1,2
MODERATELY SUITABLE S2	III; 80-120mm IV; 80-150mm V; 100-150mm	1,2,3	1,2,3	3
MARGINALLY SUITABLE S3	III; 30-80mm IV; 40-100mm V; 60-100mm	4,5	4	4,5
NOT-SUITABLE NS	III; <30 IV; <40 V; <60	5*	-	-

* Only applicable where shallow rooting grass species are not available

given in Tables 24 . In all the conversion tables discussed above the suitability of a mapping unit is determined by the suitability class of the most limiting diagnostic land quality.

5.5.3 Suitability of individual mapping units for the selected alternative simple and compound land utilization types

The 'current' suitability of each mapping unit for the alternative simple and compound LUTs was assessed using the rated land qualities (Table 21) and the conversion table for each alternative LUT. The suitability of an alternative compound LUT was derived from the suitability of the two main constituent simple LUTs. The suitability of each mapping unit is discussed in the following sections, first the alternative simple LUTs then the alternative compound LUTs.

5.5.3.1 Suitability for the simple land utilization types

The suitability ratings for the alternative simple LUTs cashewnuts and coconuts - the focal point of this thesis - was assessed in a greater detail than the suitability ratings for the alternative simple LUTs maize, grass for dairy cattle and grass for beef cattle (ranching).

$\underline{VcTi_1}$ is not suitable for coconuts and cashewnuts.

Extremely firm and cracking subsoil with a strong angular blocky structure (Plates 1 and 6) makes rootability the major limitation for the tree crops. The unit is however, moderately suitable for maize, dairy cattle and beef cattle. Although susceptibility to soil erosion would render this unit marginal for maize and beef cattle, it was not downgraded because adequate conservation measures are assumed at an intermediate level of technology.

$\underline{FrMw_2}$ is marginally and moderately suitable for coconuts and cashewnuts, respectively. Availability of moisture is the major limitation for coconuts resulting from low AMSC and probably from run-off losses on the steep slopes (up to 22%). The harmful effects of August-December rainfall is the major limitation for cashewnuts. Although susceptibility to erosion is rated high (due to steep slopes), the tree canopies effectively reduce erosivity, therefore, erosion would be low and is not considered the most limiting land quality. The unit is moderately suitable for maize and grasses for both dairy and beef cattle. For maize, susceptibility to soil erosion and availability of nutrients are the most limiting land qualities.

$\underline{AoCw_2}$ is moderately and marginally suitable for cashewnuts and coconuts, respectively. The harmful effect of August-December rainfall and availability of moisture are the most limiting land qualities for cashewnuts and coconuts. Availability of nutrients is a minor limitation for both tree crops. The unit is marginally suitable for maize and dairy cattle but is moderately suited for beef cattle. Availability of nutrients is the major limitation for maize and dairy cattle.

$\underline{LgAp_1}$ is not suitable for coconuts and cashewnuts because of low availability of oxygen, occasional water-logged conditions and restricted rootability. Availability of oxygen also makes the unit unsuitable for maize and marginal for both dairy and beef cattle. Workability of the soil and occasional flooding reduces the suitability rating of the unit for dairy and beef cattle.

$\underline{LfLw_2}$ is not suitable for tree crops due to the rooting restriction of ironstone in the subsoil. Coconuts in this unit grow very tall and unproductive (Plate 7). Maize and grass for dairy cattle are marginally suited but the unit is moderately suitable for beef cattle. Rootability, availability of nutrients and susceptibility to erosion are the main limitations.

$\underline{LcCw_1}$ is marginally and moderately suitable for coconuts and cashewnuts, respectively. Availability of moisture and the harmful August-December rainfall are the major limitations for coconuts and cashewnuts, respectively. The unit is moderately suitable for maize, dairy and beef cattle. Availability of nutrients is the main limitation for maize, dairy and beef cattle. Susceptibility to soil erosion also reduces the suitability for maize.

$NdLw_1$ and $LcMw_1$ have similar suitabilities for the alternative simple LUTs. The units are marginally suitable for coconuts and moderately suitable for cashewnuts, maize, dairy cattle but highly suitable for beef cattle. Availability of moisture is the major limitation for coconuts while availability of nutrients reduces their suitability for maize, dairy cattle. August-December rainfall is the main limitation for cashewnuts. Unit $NdLw_1$ is fairly rocky which severely reduces the possibility of mechanisation for maize.

Bv/Vp is not suitable for coconuts, cashewnuts and maize due to the availability of oxygen and very low rootability due to a very compact and cracking subsoils. The unit is marginally suitable for both dairy and beef cattle for which availability of oxygen, occasional waterlogged conditions are most limiting.

Lv/Vp/I is not-suitable for tree crops, maize and beef cattle due to low availability of oxygen and shallow rooting depth or cracking in the subsoil. The vertic LUVISOL and pellic VERTISOL members of this complex are moderately to marginally suitable for maize, beef and dairy cattle.

Lc/Lc/J has varying suitability for the alternative simple LUTs. The chromic LUVISOL member is marginally suitable for coconuts, cashewnuts, maize and dairy cattle with availability of moisture, August-December rainfall and availability of nutrients as the main limitations. The other two members of the association are not suitable for the tree crops due to low availability of oxygen and moisture. All the three members of this complex are moderately to marginally suitable for beef cattle. Where the ground water table is within 200cm of the surface moisture deficits are offset and coconuts can grow more vigorously.

Ao-Gd 3/1 is a soil association with different suitabilities for the alternative simple LUTs. Orthic ACRISOLS are marginally suitable for the tree crops. Although freely rootable (Plate 4), availability of moisture is the major limitation especially for coconuts. This member is also marginally suitable for maize and dairy cattle for which availability of nutrients and susceptibility to sheet erosion are the major limitations. The member is moderately suitable for beef cattle. The dystric GLEYSOLS are not suitable for tree crops due to availability of oxygen and rootability (see Plate 8). This member is marginally suitable for maize and dairy cattle due to availability of oxygen. The member is moderately suitable for beef cattle.

$QcFe_4$ is not suitable for coconut, maize and dairy cattle because of low availability of moisture. However the unit is marginally suitable for cashewnuts, and beef cattle for which availability of moisture is still most limiting. Low availability of moisture results from the low AMSC and low amount of rainfall.

$\underline{LvFi_2 \text{ and } LgAi_2}$ have similar suitabilities for the alternative simple LUTs. These units are not suitable for tree crops due to low availability of moisture and rooting restrictions in the subsoil. They are also not suitable for dairy cattle due to low availability of moisture. The units are not suitable for maize and dairy cattle but are moderately suitable for beef cattle.

$\underline{LcFw_1}$ is marginally suitable for coconuts, cashewnuts and maize with availability of moisture being the major limitation. The unit is not suitable for dairy cattle but is moderately suited to beef cattle.

5.5.3.2 Suitability for the compound land utilization types

The suitability of a compound LUT in a mapping unit is determined by the suitability of its constituent simple LUTs. As pointed out in section 2.2.3.2, the simple LUT with the least suitability is normally chosen to be the determinant of the overall suitability of a compound LUT but this downgrades the suitability of the less demanding simple LUT. In the present study the compound LUTs were defined as consisting of two main simple LUTs and the suitability of the two main component LUTs was used to define a range of suitability classes to represent the 'overall' suitability of the compound LUT. However, where one constituent simple LUT was not suitable the 'overall' suitability for the compound LUT was given as not suitable. The assignment of the 'overall' suitability of compound LUTs is illustrated in Table 25 below.

Table 25. <u>The suitability rating assignment for compound land utilization types</u>

Suitability rating of constituent simple LUT		Overall suitability of compound LUT
A	B	
high (S1)	high (S1)	high (S1)
high (S1)	moderate (S2)	high-moderate (S1-S2)
high (S1)	marginal (S3)	high-marginal (S1-S3)
high (S1)	not-suitable (NS)	not suitable (NS)
moderate (S2)	moderate (S2)	moderate (S2)
moderate (S2)	marginal (S3)	moderate-marginal (S2-S3)
marginal (S3)	marginal (S3)	marginal (S3)
marginal (S3)	not-suitable (NS)	not-suitable (NS)
not suitable (NS)	not-suitable (NS)	not suitable (NS)

The suitability of individual mapping units for the selected alternative compound LUTs is described as follows:

$\underline{VcTi_1}$ is not suitable for the LUTs cashew-dairy, coconut-dairy, coconut-cashewnut and ranching-cashew. The major limitation is rootability for tree crops, see Plate 1. The unit is moderately suitable for maize-dairy cattle. Susceptibility to soil erosion is the main limitation for this LUT.

$\underline{FrMw_2}$ is moderately suitable for cashew-dairy cattle, maize-dairy cattle and ranching-cashewnuts. The unit is moderately to marginally suitable for coconut-dairy cattle, and coconut-cashewnut. The availability of moisture and nutrients are the major limitations in this unit. For maize-dairy cattle susceptibility to soil erosion may also be limiting, however adequate conservation measures were assumed at the intermediate level of technology.

$\underline{AoCw_2}$ is moderately suitable for ranching-cashews. It is moderately to marginally suitable for cashew-dairy cattle, and coconut-cashewnuts. The unit is marginally suitable for maize - dairy and coconut-dairy. Availability of moisture, nutrients and the August-December rainfall are the major limitations in this unit.

$\underline{LgAp_1}$ is not suitable for all compound LUTs. Availability of oxygen, rootability and occasional flooding/ waterlogging are the most limiting land qualities in this unit.

$\underline{LfLw_2}$ is not suitable for cashew-dairy cattle, coconut-dairy cattle, coconut-cashewnuts and ranching-cashewnuts. However, it is marginally suitable for maize-dairy cattle. Rootability and availability of moisture are the limiting land qualities in this unit.

$\underline{LcCw_1}$ is moderately suitable for cashew-dairy cattle, maize-dairy cattle and ranching-cashewnuts. The unit is moderately to marginally suitable for coconuts-dairy cattle and coconuts-cashewnuts for which availability of moisture is the major limitation.

$\underline{NdLw_1 \text{ and } LcMw_1}$ have the same suitability for the compound LUTs. The units are highly to moderately suitable for ranching-cashewnuts and moderately suitable for cashewnuts-dairy cattle and maize-dairy cattle. The units are moderately to marginally suitable for coconut-cashewnuts and coconut-dairy cattle association. Availability of nutrients, moisture and August-December rainfall are the amjor limitations in this unit. Unit $NdLw_1$ is fairly rocky which reduces the possibility of mechanisation (tractors).

<u>Lv/Vp/I</u> is not suitable for any compound LUT except for maize-dairy cattle association for which it is moderately to marginally suitable. Rootability and availability of oxygen are the most limiting land qualities in this unit.

<u>Bv/Vp</u> is not suitable for any compound LUT. Roota-

bility and availability of oxygen together with occasional flooding/waterlogging are the major limitations in this unit.

Lc/Lv/J has different suitabilities for some compound LUTs. The vertic LUVISOLS of this complex are not suitable for tree crops due to the limiting availability of oxygen and rootability. Chromic LUVISOLS and FLUVISOLS are moderately to marginally suitable for ranching-cashew while they are marginally suitable for coconut-cashew, coconut-dairy, maize-dairy, cashew-dairy. Availability of moisture and the August-December rainfall are the major limitations in these two members of this complex.

Ao-Gd 3/1 has variable suitabilities for compound LUTs. The orthic ACRISOL member is marginally suitable for all the compound LUTs except for ranching-cashew which is moderately to marginally suitable. The major limitations here are availability of moisture and nutrients. The dystric GLEYSOLS are not suitable for the compound LUTs with tree crops as main components due to limiting availability of oxygen, rootability and availability of nutrients. This member however, is marginally suitable for maize-dairy cattle. The availability of nutrients and oxygen are the major limitations for maise-dairy cattle.

$QcFe_4$ is generally not suitable for compound LUTs with dairy cattle and coconuts due to low availability of moisture and nutrients. The unit is however marginally suitable for ranching-cashew for which availability of moisture and nutrients are most limiting. Some parts of this unit in zone IV are marginally suitable for coconut-dairy cattle.

$LvFi_2$ and $LgAi_2$ are not suitable for any compound LUT due to low availability of moisture and rootability for tree crops and grass for dairy cattle.

$LcFw_1$ is not suitable for cashew-dairy cattle, coconut-dairy cattle and maize-dairy cattle due to low availability of moisture and nutrients. However, the unit is marginally suitable for coconuts-cashewnuts and moderately to marginally suitable for ranching. Availability of moisture and rootability are the most limiting for tree crops and dairy cattle.

The suitabilities of the alternative simple and compound land utilization types are summarized in Table 26.

Table 26. Land evaluation key for selected alternative simple and compound land utilization types in the Chonyi-Kaloleni area

LUTs / MAPPING UNITS	coconuts	cashew	maize	grass for dairy cattle	grass for beef cattle	cashew -dairy cattle association	coconut-dairy cattle association	maize-dairy cattle association	coconut-cashew	beef cattle-cashew association
AGROCLIMATIC ZONE III										
$VcTi_1$	NS	NS	S2	S2	S2	NS	NS	S2	NS	NS
$FrMw_2$	S3	S2	S2	S2	S2	S2	S2-S3	S2	S2-S3	S2
$AoCw_2$	S3	S2	S3	S3	S2	S2-S3	S3	S3	S2-S3	S2
$LgAp_1$	NS	NS	NS	S3	S3	NS	NS	NS	NS	NS
$LfLw_2$	NS	NS	S3	S3	S2	NS	NS	S3	NS	NS
$LcCw_1$	S3	S2	S2	S2	S2	S2	S2-S3	S2	S2-S3	S2
$LcMw_1$	S3	S2	S2	S2	S1	S2	S2-S3	S2	S2-S3	S1-S2
$NdLw_1$	S3	S2	S2	S2	S1	S2	S2-S3	S2	S2-S3	S1-S2
Lv/Vp/I	NS	NS	S2+-NS	S2+-NS	S2-S3+	NS	NS	S2+	NS	NS
Bv/Vp	NS	NS	NS	S3	S3	NS	NS	NS	NS	NS
Lc/Lv/J	S3-NS	S3-NS	S3	S3	S2-S3	S3++	S3++	S3	S3	NS-S3++
AGROCLIMATIC ZONE IV AND V										
Ao-Gd 3/1	S3-NS	S3-NS	S3-NS	S3-NS	S2-S3	S3-NS	S3-NS	S3-NS	S3-NS	S2-NS
$QcFa_4$	NS	S3	NS	NS	S3	NS	NS	NS	NS	S3
$LvFi_2$	NS	NS	NS	NS	S3	NS	NS	NS	NS	NS
$LgAi_2$	NS	NS	NS	NS	S3	NS	NS	NS	NS	NS
$LcFw_1$	S3	S3	S3	NS	S2	S3-NS	S3-NS	S3-NS	S3	S2-S3

Key

S1 - highly suitable

S2 - moderately suitable

S3 - marginally suitable

NS - not suitable

\+ suitability rating does not include the LITHOSOLS

++ suitability rating for the Chromic LUVISOLS ONLY

6. LAND USE RECOMMENDATIONS

The most promising alternative LUT for a mapping unit depends not only on the physical suitability rating but also on other factors such as the present land use, particularly when tree crops are already established, and on the prevailing socio-cultural and economic conditions. Thus a mapping unit may be equally suitable for more than one alternative LUTs but the extent to which labour, input and minimum farm size requirements of different alternative LUTs are met, may vary considerably.

Alternative LUTs may also differ in the extent to which they satisfy the cultural needs, nutritional requirements and social acceptance, e.g. coconut may not be suited to agroclimatic zone V yet farmers repeatedly try to grow it for 'toddy' and 'madafu'. On the other hand food crops like sorghum and millet, which may be well suited in the study area, are not accepted by farmers as food and are therefore not grown. Moreover, the establishment of different alternative LUTs may involve changes of different magnitudes in the present land use. Finally, the alternative LUTs may have different relative profit margins. Due to these differences the physical suitability rating cannot be used as the only criterion for selecting the land use to be recommended for a given mapping unit.

An elimination procedure was used in the selection of the land use to be recommended for a given mapping unit. All alternative LUTs which are at least marginally suitable were considered. Those alternative LUTS whose labour and farm size requirements could not be met and those which do not satisfy the socio-cultural needs were eliminated. The alternative LUTs whose establishment involves unacceptable changes in the present land use were also eliminated. Of the remaining alternative LUTs the one with the highest suitability rating was recommended. In cases where more than one of the remaining alternative LUTs have similar suitability ratings, the one with the relatively higher profit margin was recommended. The recommended land uses of the adjacent or included mapping units were also taken into account. The land use recommendations for each mapping unit are discussed in the following section on the basis of the afore mentioned considerations and the physical suitability ratings given in Table 26.

$\underline{VcTi_1}$ occurs in an area under predominantly annual crops and is moderately suitable for the simple LUTs maize, grass for dairy and beef cattle and for the compound LUT maize-dairy cattle association. The farm size requirement for beef cattle cannot be met in this unit. Although the maize-dairy cattle association appears to have the highest profit margin and would satisfy the nutritional needs to a greater extent than other LUTs, there is a social difficulty limiting its establishment. Farmers owning land in this unit live in other mapping units and cattle would have to travel long distances to reach the pasture areas. Moreover, farmers prefer to build their houses where there are tree crops which are not present in this unit. Therefore it would be unlikely that farmers would erect homes in this unit. Therefore, cultivation of maize, fodder and other food crops is recommended for this unit. However, when the farmers' attitude changes and homesteads are built in this unit, the maize-dairy cattle association should be established.

$\underline{FrMw_2}$ occurs in an area predominantly under cashew and is moderately suitable for cashewnut-dairy association, maize-dairy cattle association and moderately to marginally suitable for coconut-cashew association. Dairy cattle with coconuts or maize would involve unacceptable changes in the present land use in this unit, i.e. the removal of existing cashew trees. Consequently these two LUTs can be eliminated. The cashew-dairy cattle association is therefore recommended for this unit. The units $VcTi_1$ and Lc/Lv/J which border this unit will provide fodder to supplement pastures in this unit.

$\underline{AoCw_2}$ occurs in an area under perennial tree crops, however the predominant tree crop varies from coconuts to cashews in different parts of the unit. The unit is moderately to marginal for coconut-dairy cattle, coconut-cashew and marginally suitable for cashew-dairy, maize-dairy cattle. The unit is moderately suitable for cashew-beef cattle but can be eliminated due to its high farm size requirement. To minimize the changes in present land use, dairy cattle with either coconuts or cashewnuts, whichever is already established in a given part of this mapping unit, is recommended. However, for tree crops, the level of technology must be gradually raised from low to intermediate.

$\underline{LgAp_1}$ occurs in a valley predominantly under grass but is only marginally suitable for grasses. Farm size requirement for beef cattle is not met in this unit and therefore pasture for dairy cattle is recommended. These pastures will supplement those in the neighbouring units $AoCw_2$ and $LcCw_1$.

$\underline{LfLw_2}$ occurs in an area under bush and annual crops dominated by maize and is moderately suitable for grass for beef cattle and marginally suitable for maize and grass for dairy cattle. Maize-dairy cattle association appears to have the highest profit margin, furthermore since this unit is an inclusion in unit $NdLw_1$ farms may extend into both units. Therefore the recommended land uses for both units should be complementary to each other. Maize-dairy cattle pasture is recommended in this unit.

$\underline{LcCw_1}$ occurs in an area predominantly under coconuts and is moderately to marginally suitable for all alternative LUTs. Coconut-dairy cattle involves the least changes in the present land use, and appears to have the highest profit margin. Moreover dairy cattle are recommended for the adjacent units $AoCw_2$ and $LgAp_1$. Therefore coconut-dairy cattle is recommended for this unit. The level of technology has to be elevated to intermediate.

$\underline{LcMw_1}$ is presently under coconuts and is at least marginally suitable for all alternative LUTs. Although coconut-dairy cattle does not have the highest suitability rating, its establishment involves the least changes in present land use. Moreover, this unit is an inclusion in unit $VcTi_1$ for which maize and fodder crops were recommended. The maize and fodder will satisfy the nutritional requirement of the people and supplement fodder for the cattle. Therefore coconut-dairy cattle association is recommended for this unit.

$\underline{NdLw_1}$ is predominantly under coconuts and is at least marginally suitable for all the alternative LUTs. Coconut-dairy cattle involves the least changes in the present land use and will be supplemented with fodder from the adjacent unit $VcTi_1$ and is therefore recommended for this unit.

<u>Lc/Vp/I</u> is predominantly under bush or annual crops dominated by maize. It is not suitable for tree crops but the most extensive members, i.e. vertic LUVISOLS

and pellic VERTISOLS are moderately to marginally suitable for maize grasses both dairy and beef cattle. Since dairy cattle has been recommended for the adjacent units $NdLw_1$ and $AoCw_2$, the simple LUT maize, other food and fodder crops are recommended for this unit.

<u>Bv/Vp</u> is in a minor valley under annual crops dominated by maize and is not suitable for any alternative LUT except grasses. In this unit are dams for animals, moreover dairy cattle and fodder crops were recommended for the adjacent units $VcTi_1$, $FrMw_2$, $NdLw_1$ and $LcMw_1$. Therefore pasture and fodder crops are recommended for this unit. Although not evaluated for in this study this unit is well suited for rice on account of the unit's poor drainage conditions.

<u>Lc/Lv/J</u> is a soil complex whose members have different suitability ratings for the same alternative LUT. Moreover, the unit forms part of the farms in the adjacent unit $FrMw_2$ and consequently, different alternative LUTs cannot be recommended for these two units. Maize, which is the predominant crop at present, is recommended together with other food and fodder crops, for this unit to supplement the nutritional requirements of both the farmers and dairy cattle in the adjacent unit $FrMw_2$.

<u>Ao-Gd 3/1</u> lies partly in agroclimatic zones III and partly in zone IV. Furthermore the two members of this unit have different suitability ratings for different alternative LUTs. The orthic ACRISOLS are at

least marginally suitable for all the alternative LUTs. Coconut is the predominant crop grown on the orthic ACRISOLS in agroclimatic zone III and the adjacent parts of zone IV while cashews are dominant in zone IV. Grass for both dairy and beef cattle are at least marginally suited. In view of the present LUT, coconut-dairy cattle and cashew-dairy cattle associations are recommended for the orthic ACRISOLS (depending on which tree crop is dominant in a given part of the unit) and grass and fodder crops are recommended for the dystric GLEYSOLS to supplement the pastures on the ACRISOLS.

$\underline{QcFe_4}$ occurs in an area currently under mixed farming with tree crops, i.e. coconut and cashew, while other parts are under extensive grazing. The unit is not suitable for most of the alternative LUTs except cashews and grass for beef cattle. On account of the physical suitability rating and the much larger farm sizes in this unit beef cattle-cashew association is recommended for this unit. To meet the farmer's food requirements, some maize may be cultivated especially in topographically lower areas where it would be better suited.

$\underline{LvFi_2 \text{ and } LgAi_2}$ occur in an area predominantly under extensive grazing. The two units are not suitable for the alternative LUTs except grass for beef cattle for which they are marginally suitable. Therefore on account of the physical suitability, grass for beef cattle is recommended to supplement the beef cattle in unit $QcFe_4$.

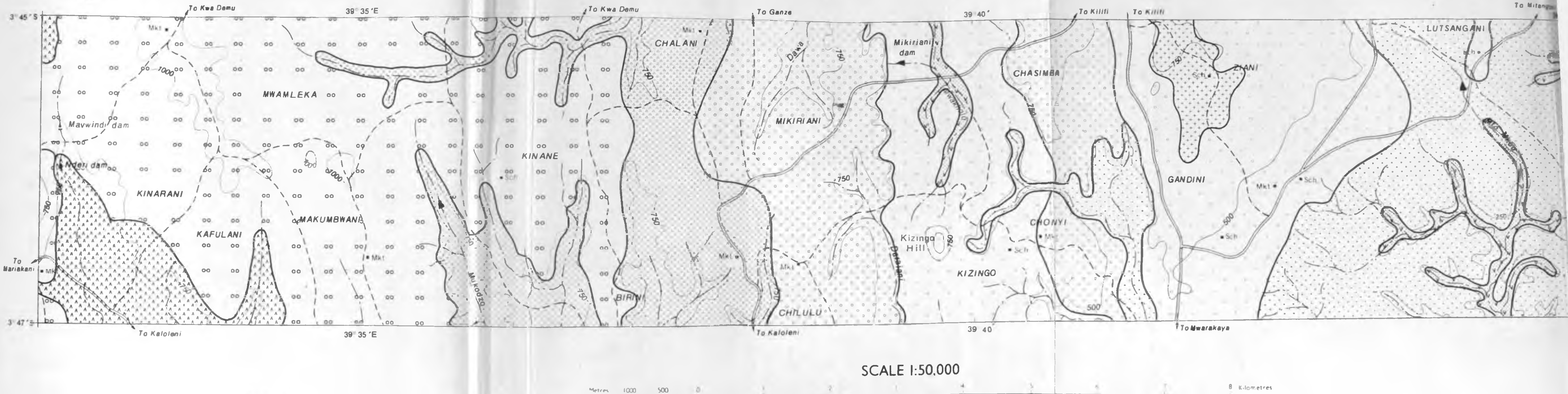
$LcFw_1$ is presently under cultivation and partly extensive grazing. It is marginally suitable for maize, cashews and coconuts, and moderately suitable for grass for beef cattle. On the basis of physical suitability, this unit is most suited to beef cattle-cashew association, moreover since this unit is small in areal extent, the alternative use to be recommended in this unit has to be complimentary to the uses recommended in the adjacent units $QcFe_4$ and $LgAi_2$. Beef cattle fulfils the above requirements therefore it was recommended in this unit.

These land use recommendations are summarized in Table 27 and their distribution is given in the recommended land use map, figure 9.

Table 27. Land use recommendations for each mapping unit

Mapping unit	Agroclimatic zone	Recommended alternative LUT	Remarks
$VcTi_1$		Maize + fodder and food crops	Maize-dairy cattle most suitable but disqualified on social grounds
$FrMw_2$		Cashewnuts-dairy cattle	-
$AoCw_2$		Coconut-dairy cattle association Cashew-dairy cattle association	Both cashew and coconut are already established
$LgAp_1$		Pasture for dairy cattle	Though not considered, rice may be well suited to this unit
$LfLw_2$		Maize-dairy cattle association	Pastures here will supplement those in $NdLw_1$
$LcCw_1$		Coconut-dairy cattle association	
$LcMw_1$		Coconut-dairy cattle association	-
$NdLw_1$		Coconut-dairy cattle association	-
Lv/Vp/I		Maize, other food and fodder for dairy cattle	To supplement the pastures in $NdLw_1$ and $AoCw_2$
Ao-Gd 3/1		Cashew-dairy cattle association Coconut-dairy cattle association (pasture grasses in the Gleysols)	
$QcFe_4$		Ranching-Cashewnuts	
$LgAi_2$		Grass for beef cattle	
$LvFi_2$		Grass for beef cattle	
$LcFw_1$		Beef cattle-Cashewnuts	

FIG. 9. RECOMMENDED LAND USE



LEGEND

- cashew – dairy cattle association
- coconut – dairy cattle association
- maize – dairy cattle association
- ranching – cashew – dairy cattle association
- coconut and or cashew-dairy cattle association
- maize plus other food and fodder crops
- pastures for dairy cattle
- pastures for beef cattle
- cashew and/or coconut– dairy cattle association and pasture for dairy cattle in the gleysols

KEY

- land use boundary
- road
- motorable track and footpath
- •Mkt. market
- •Sch. school
- river
- cattle dip
- 1,000 / 750 contours V.I. 250 ft

SUMMARY AND CONCLUSIONS

A reconnaissance soil survey of about 13,000ha at a scale of 1:50,000 was carried out to form the basis of a physical land evaluation study of the Chonyi-Kaloleni area. The suitability of land was evaluated following the guidelines outlined in the FAO framework for land evaluation, for selected land utilization types relevant to the area with an emphasis on the suitability for coconuts and cashew-nuts. Finally tentative land use recommendations were given for each mapping unit.

An elemental analysis of aerial photos was combined with a free traverse survey and with auger and pit inspection to delineate and describe the soil mapping units. The survey showed that the dominant soils in the area were Pellic and Chromic VERTISOLS, Albic and Cambic ARENOSOLS, Rhodic FERRALSOLS, Orthic ACRISOLS, Dystric NITOSOLS, and chromic, vertic and gleyic LUVISOLS. The soil types were greatly influenced by their parent material which ranges from shales, sandstones, sands, to limestones.

Two thirds of the study area (eastern part) occurred in agroclimatic zone III and the western part of the area in agroclimatic zones IV and V. The present LUTs ranged from ranching to the cultivation of annual food crops, cashews and coconuts, with the tree crops being the dominant land utilization types in the area. Most of the present LUTs were practised at a low level of technology.

The alternative LUTs, for which the land was physically evaluated, were the simple LUTs cashew, coconut, maize, and grass for beef and dairy cattle, and the compound LUTs cashew-dairy cattle, coconut-dairy cattle, maize-dairy cattle, coconut-cashew and beef cattle-cashew associations all at an intermediate level of technology.

The land qualities used to assess the suitability for cashewnuts and coconuts were the availability of moisture, nutrients and oxygen, rootability and in addition, the harmful effect of the August-December rainfall for cashews. The availability of moisture which was studied in greatest detail was assessed from moisture deficits. For maize and grasses the availability of moisture was determined by a combination of agroclimatic zones and available soil moisture storage capacity. Availability of nutrients was assessed from the soil CEC, base saturation and exchangeable cations, and the availability of oxygen was qualitatively determined by the presence and depth at which reducing mottles were found in the soil profile. Rootability was assessed from the depth of root penetration in the soil profile. The land qualities were rated and evaluated for each mapping unit in turn.

The suitability of each mapping unit was in the area. Most of the present LUTs were practised at a low level of technology.

The alternative LUTs, for which the land was physically evaluated, were the simple LUTs cashew, coconut, maize, and grass for beef and dairy cattle, and the compound LUTs cashew-dairy cattle, coconut-dairy cattle, maize-dairy cattle, coconut-cashew and beef cattle-cashew associations all at an intermediate level of technology.

The land qualities used to assess the suitability for cashewnuts and coconuts were the availability of moisture, nutrients and oxygen, rootability and in addition, the harmful effect of the August-December rainfall for cashews. The availability of moisture which was studied in greatest detail was assessed from moisture deficits. For maize and grasses the availability of moisture was determined by a combination of agroclimatic zones and available soil moisture storage capacity. Availability of nutrients was assessed from the soil CEC, base saturation and exchangeable cations, and the availability of oxygen was qualitatively determined by the presence and depth at which reducing mottles were found in the soil profile. Rootability was assessed from the depth of root penetration in the soil profile. The land qualities were rated and evaluated for each mapping unit in turn.

The suitability of each mapping unit was determined by matching the requirements of the alternative LUTs with the rated land qualities through the development of conversion tables. The most limiting land quality determined the final suitability classification for each mapping unit.

Well drained soils are in general moderately to marginally suitable for tree crops, maize and grass for dairy cattle but highly to moderately suitable for grass for beef cattle. Poorly and imperfectly drained soils, viz. Vertisols, Gleysols, gleyic and vertic Luvisols are generally not suitable for tree crops and annual food crops. The suitability of alternative compound LUTs is similar to that of their constituent simple LUTs.

Finally, tentative land use recommendations were made for each mapping unit taking into account the social and cultural factors, nutritional requirements, present land use, particularly presence of tree crops, physical suitability rating and the apparent relative profit margins. Interaction between one LUT and others in the adjacent mapping units was also taken into account in determining the land use to be recommended for a given mapping unit.

This study suggests that coconut-dairy cattle association should be recommended for Dystric NITOSOLS, chromic LUVISOLS and Orthic ACRISOLS; cashew-dairy cattle association for Rhodic FERRALSOLS and some

Orthic ACRISOLS; maize-dairy cattle association for Ferric LUVISOLS; beef cattle-cashew association for Cambic and Albic ARENOSOLS; maize, other food and fodder crops for Chromic VERTISOLS and Vertic LUVISOLS, and grass for dairy-beef cattle for gleyic and Vertic LUVISOLS, vertic CAMBISOLS, Pellic VERTISOLS and Dystric GLEYSOLS.

REFERENCES

ACLAND, J.D. (1971). East African crops, Longmans Ltd., LONDON.
*

ALBERS, H.T.M.P., KRUL, H.A. and van LANEN, H.A.J. (1975). Some existing West European Systems compared with recent FAO system; Land classification report, part 2. Dept. of Soils and Geology, Agricultural University Wageningen, the NETHERLANDS.

ARNON, I (1972). Crop production in dry regions, Vol. II - systematic treatment of principal crops. Published by LEONARD HILL, LONDON.

AVERLY (1970). Agricultural lands potential in Kwale and Kilifi districts. Ministry of Lands and Settlement, Town Planning Department, Coast Office, Mombasa.

BARRETT, M.A. and LARKIN, P.J. (1974). Milk and beef production in the tropics. Oxford University Press.

BEEK, J.K. (1977). The selection of soil properties and land qualities relevant to specific land uses in developing countries.

BEEK, J.K. (1978). Land evaluation for agricultural development, Publication No. 23, ILRI, Wageningen, the NETHERLANDS.

BEEK, J.K. and BENNEMA, J. (1972). Land evaluation for agricultural land use planning. An ecological methodology. Department of Soil Science and Geology, Agricultural University, Wageningen, the NETHERLANDS.

BENNEMA, J. (1978). Land evaluation for agricultural land use planning. in SWINDALE, D.L. (Ed) Soil Resource data for agricultural development. Hawaii Agricultural Experimental Station, College of Tropical Agriculture, University of HAWAII.

BIBBY, J.S. and MACKNEY, D. (1969). Land use capability classification. Technical Monograph No. 1. Soil Survey, HARPENDEN, UK.

BOGADAN, A.V. (1977). Tropical pasture and fodder plants (grasses and legumes). Publishers LONGMANS, LONDON.

BOUWMAN, L. (1980). Land utilization types in the Kaloleni East area in Southern Division. Training Project in Pedology, Kilifi Kenya.

* Addendum

BRAUN, H.M.H. (1977). Proposal for an agroclimatic classification, Kenya Soil Survey Internal Communication No. 9.

BRAUN, H.M.H. (1978). Climate in MICHIEKA, D.O., van der POUW, B.J.A. and VLEESHOUWER, J.J. (Ed). Soils of the Kwale-Mombasa-Lungalunga area. Reconnaissance Soil Survey report No. R3. Kenya Soil Survey, Ministry of Agriculture, Nairobi, Kenya.

BRAUN, H.M.H. and other staff of KSS (1980). Agroclimatic zones of Kenya.

BREMNER, J.M. (1965). Total Nitrogen in BLACK, C.A. (Ed) Methods of soil analysis part 2 - chemical and microbiological properties. Agronomy Monograph No. 9. Amer. Soc. of Agron. Inc. Madison, Wisconsin, USA.

BRINKMAN, R. and SMYTH, A.J. (Ed) (1973). Land evaluation for purposes. Publication No. 17, ILRI, Wageningen, the NETHERLANDS.

CANADA LAND INVENTORY (1969). Soil capability classification for agriculture. CLI report No. 2. Dept. of Regional Economic Expansion, Ottawa, CANADA.

CANADA LAND INVENTORY (1970). Objectives, scope and organisation. CLI report No. 1. Dept. of Regional Economic Expansion, Ottawa, CANADA.

CANADA LAND INVENTORY (1970). Land capability classification for forestry. CLI report No. 4. Dept. of Regional Economic Expansion, Ottawa, CANADA.

*CASWELL, P.V. (1956). Geology of the Kilifi-Mazeras area (with coloured map at scale 1:125,000). Report No. 34, Geological Survey of Kenya, NAIROBI.

CHAPMAN, D. (1965). Cation exchange capacity. In BLACK, C.A. (Ed) Methods of soil analysis. Agronomy No. 9. American Society of Agronomy INC.

CHILD, R. (1964). Coconuts. Longmans, LONDON.

DAGG, M. and TAPLEY, R.G. (1967). Cashewnut production in Southern Tanzania. V-water balance of cashew trees in relation to spacing. East African Agricultural and Forestry Journal. Muguga, KENYA.

DAY, P.R. (1956). Report on the committee on physical analysis, 1954-1955. Soil Science Society of America. Soil Science of Ame. Proc. 20: 167-199.

* Addendum

DAY, P.R. (1965). Particle fractionation and particle size analysis. In BLACK, C.A. (Ed) Methods of soil analysis Part I. Agronomy Monograph 9.

de JONG, C. (1977). Land utilization types of the medium potential areas of low altitude, the Kwale area. Miscellaneous Soil paper No. 4. Kenya Soil Survey, NAIROBI.

de GEUS, J. (1973). Fertilizer guide for tropical and subtropical farming. Centre d'ETUDE de l'AZOTE, ZURICH.

*
DOWKER, B.D. (1963). Sorghum and millet in Machakos District. E.A.A.F.R.O Journal Vol. XXIX No. 1 page 52. NAIROBI.

EDWARDS, D.C. and BELLIS, E. (1952). Settlement survey of South Kwale District (with map at scale 1:125,000). Pasture Research Station, Ruiru. Ministry of Agriculture, NAIROBI.

EDWARDS, R.D., RABEY, D.F. and KOVER, R.W. (1970). Soil survey of the Ventura area, California. USDA Soil Conservation Service and University of California Agricultural Experimental Station, Washington D.C., USA.

FAO (1967). Aerial photo-interpretation in soil survey, Soils Bulletin 6, FAO, Rome.

FAO (1967). Soil survey interpretation and its use. Soils Bulletin 8, FAO, ROME.

FAO (1974). Approaches to land classification. Soils Bulletin 22. FAO, ROME.

FAO (1975). Report on the AD HOC expert consultation on land evaluation. World Soil Resources Report No. 45. FAO, ROME.

FAO (1976). A Framework for Land evaluation. Soils Bulletin 32. FAO, ROME.

FAO (1977). Crop water requirements, FAO irrigation and drainage paper 24. FAO, ROME.

FAO (1978). Report on the Agro-ecological zones Project. Vol. I. Methodology and results for Africa. World Soil Resources report no. 48. FAO, ROME.

FAO (1977). Guidelines for soil profile description (2nd Edition) FAO, ROME.

FAO-UNESCO (1974). Soil Map of the World, 1:5,000,000. Volume 1 Legend. UNESCO-PARIS.

* Addendum

FISHER, N.M., (1977). Crop water use, rainfall and yield in Kenya. Technical Communication No. 20. Dept. of Crop Science. University of Nairobi, KENYA.

*
FREMOND, Y., ZILLER, R. and de LAMOTHE, M.N. (1966). The coconut Palm. International Potash Institute, BERNE, SWITZERLAND.

GACHENE, C.K.K. and BARBER, R.G. (1982). A preliminary report on an evaluation and detailed mapping of erosion susceptibility at Kaloleni, Kilifi district. Soil and Water Conservation Workshop. FACULTY OF AGRICULTURE, UNIVERSITY OF NAIROBI, NAIROBI.

GOLDSON, J.R. (1980). The effect and contribution of the cashew tree (ANACARDIUM OCCIDENTALE L.) in a cashew-pasture-dairy cattle association. In Procedings of Kenya National Seminar on Agroforestry. ICRAF, NAIROBI.

GOVERNMENT OF KENYA, (1981). National Food Policy. Sessional Paper No. 4. Government Printer, NAIROBI.

HENDRICKX, H (1981). Viability of the proposed oil-mill of the Kilifi District Co-operative Union. Marketing Research and Development Section, Ministry of Co-operative Development, NAIROBI.

HINGA, G., MUCHENA, F.N. and NJIHIA, C.M. (Ed) (1980). Physical and chemical methods of soil analysis. National Agricultural Laboratories. Ministry of Agriculture, NAIROBI.

HUDSON, N (1971). Soil Conservation, BATSFORD, LONDON.

HURRADINE Storie index rating for soils in the Ventura Area. In Soil Survey of Ventura Area, California.

HOOPER, L.J. (1974). Land use capability in farm planning in soil type and land capability. In MACKNEY, D. (Ed). Technical Monograph No. 4, HARDENPEN, UK.

KLINGEBIEL, A.A. and MONTGOMERY, P.H. (1961). Land capability classification, United States Department of Agriculture Handbook No. 210. Washington D.C., USA.

KMD Monthly and annual rainfall totals copied from the rainfall gazetter at the Kenya Meteorological Department HQ. at Dagoretti for various years between 1946 and 1980.

KOWAL, J.M. (1979). Rainfall regimes in Tropical Africa.

* Addendum

MAKIN, J (1968). The soils in the country around Shimba Hills Settlement, Kikoneni and Jombo mountain, Soil Survey Unit, National Agricultural Laboratories, NAIROBI.

MALETIC, J.T. (1966). Land classification survey as related to the selection of irrigable lands. Paper presented at the Pan American Soil Conservation Congress section III, Part 3. Sao Paulo, BRAZIL.

MALETIC, J.T. and HUTCHINGS, T.B. (1967). Selection and classification of irrigable land, in HAGAN, R.M. et.al. (Eds) Irrigation of agricultural lands, American Society of Agronomy, Madison, Wisconsin, USA.

MENON, K.P.V. and PANDALAI, K.M. (1958). The coconut Palm, a Monograph; Indian Central Coconut Committee, Ernakulam - India.

MICHIEKA, D.O., van der POUW, B.J.A. and VLEESHOUWER, J.J. (1978). Soils of the Kwale-Mombasa-Lungalunga area; Reconnaissance Soil Survey report R3, Kenya Soil Survey, NAIROBI (part 1 and 11).

*
MOORE, T.R. (1979). Rainfall erosivity in East Africa. Geogr. Ann. 61A (3-4).

MORGAN, R.P.C. (1978). Soil erosion. Longman LONDON and NEW YORK.

MUCHENA, F.N. (1980). Proposed criteria for land suitability classification for irrigation. KSS Internal Communication No. 23.

MUKABI, P. and HENDRICKX, H. (1980). Production and marketing of coconuts and copra in Kilifi District. Ministry of Co-operative Development, Marketing Research and Development Section. Communication Paper 1, NAIROBI.

MUMBA, N.E. and HEILMANN, P.G.F. (1978). Land evaluation in Zambia with reference to methodology and use of physical criteria. Department of AGRICULTURE, Lusaka ZAMBIA.

MUNSELL COLOUR Col, (1971). Munsell Soil Colour Charts. Munsell Colour Company Inc., Maryland, USA.

MURDOCK, G (1972). Views on land capability with bibliography 1923-70. Misc. report no. 132. Land Resources Division, Surbiton, Surrey, ENGLAND.

MUTURI, S.N. (Ed), 1981. Agricultural research at the Coast National Council for Science and Technology. Report No. 6. NAIROBI.

* Addendum

NORTHWOOD, P.J. and TSAKIRIS, A. Cashewnut production in Southern Tanzania. III Early yields from a cashew spacing experiment. E.A.A.F.R.O. Journal, Muguga, KENYA.

NYANDAT, N.N. (1969). The development of arable settlement scheme on the soils bordering Lake Mkunguya and Mapenya and stretching to the east. Soil Survey Unit, NAIROBI, KENYA.

NYANDAT, N.N. and OSWAGO, O. (1975). Soils of Ramisi sugar estates. Kenya Soil Survey, NAIROBI.

NYANDAT, N.N. and MUCHENA, F.N. (1978). Land evaluation in Kenya with an emphasis on the criteria used.

OHLER, J.G. (1979). Cashew. Communication No. 71, Dept. of Agricultural Research, Koninklijk Instituut voor de Tropen, AMSTERDAM, the NETHERLANDS.

OKOOLA, R.E.A. (1978). Spacial distribution of precipitation in the Mombasa area of Kenya. Meteorological Dept. Research report No. 1 /78, NAIROBI.

OLSON, G.W. (1974). Interpretative land classification in English speaking countries in Approaches to land classification, FAO. ROME.

PRATT, D.J., GREENWAY, P.J. and GWYNNE. M.D. (1966). A classification of East African Rangeland. Journal of Applied Ecology 3pp. 369-382.

PURSEGLOVE. J.W. (1976). Tropical Crops - Monocotyledons. Longmans, LONDON. pg. 300-333.

RIQUIER, J. (1974). A summary of parametric methods in land classification In Approaches to Land Classification Soils Bulletin 22. FAO, ROME.

RUBUI, A.M. (1980). Standard recommendations for maize at the coast. CARS. Mtwapa (*also referred to as 'CARS. 1980'in text).

SMITH. G.W. (1968). The relation between rainfall, soil water and yield of copra on a coconut estate in Trinidad. Journal of Applied ecology 3. pp. 117-125.

SMYTH, A.J. (1978). Contribution of soil survey interpretation in land appraisal. In SWINDALE, D.L. (Eds) soil resources data for agricultural development. College of Tropical Agriculture, HAWAII.

SOILS INSTITUTE OF IRAN (1970). Manual of land classification, Publication No. 205 of Soils Institute of Iran.

STATISTICS DIVISION (1970). Kenya Population Census 1969. Vol. I. Ministrv of Finance and Economic Planning. NAIROBI.

STEWART, G.A. (Ed) (1968) Land evaluation. MacMillan of Australia, Melbourne.

THOMPSON, O.A. (1956). Geology of the Malindi area. Geological Survey of Kenya report no. 36. Govt. Printer, NAIROBI pg. 21-28.

TSAKIRIS, A. and NORTHWOOD, P.J. (1967). Cashewnut production in Southern Tanzania. IV - The root system of the cashewnut tr-e. EAAFRO Journal, Muguga, KENYA.

USDA-Soil Survey Staff (1952). Soil Survey Manual. USDA, Agriculture Handbook No. 18, Washington D.C., USA.

USBR Staff, (1953). Land classification Handbook, USBR Publication V, part 2, Washington D.C., USA.

USBR Staff (1974). Irrigation suitability classification in Approaches to land classification, FAO, ROME.

van de WEG, R.F. (1974). Proposals for rating land qualities. KSS Internal Communication. (S269/OW/RFW).

van de WEG (1977). Proposals for rating land qualities. KSS Internal Communication No. 7. NAIROBI.

van de WEG, R.F. Conversion tables for land qualities. KSS Internal Communication No. 11. NAIROBI.

van EIJNATTEN, C.L.M., GURNAH, A.M. and NIEDERSTUCKE, K.H. (1977). A study of coconuts in Kenya's coastal strip, Technical Communication No. 19. Dept. of Crop Science, UNIVERSITY OF NAIROBI, NAIROBI.

van EIJNATTEN, C.L.M. (1979). Review of information on cashew in Kenya and suggestions for its further development as a cash crop in Coast Province. CARS Communication No. 3. KIKAMBALA, KENYA.

van EIJNATTEN (1979). Summary of information on coconuts in Coast Province and Proposals for future work. C.A.R.S. Communication No. 4. KIKAMBALA, KENYA.

van EIJNATTEN, C.L.M. (1979). Canopy development in cashew trees. CARS Communication No. 5. KIKAMBALA, KENYA.

van EIJNATTEN, C.L.M. (1980). Trunk and inflorescence characters and their variation in coconut palms at Mtwapa. Technical Communication II, KIKAMBALA, KENYA.

van EIJNATTEN. C.L.M. (1980). Improved productivity of coconut through fertilizers? CARS Communication no. 14, KIKAMBALA, KENYA.

van EIJNATTEN (1981). Coconut fertilizer trials at Mtwapa

van EIJNATTEN and ABUBAKER, A.S. (1981). Increased production of cashewnuts through new method of cultivation.

VELDKAMP, W.J. (1979). Land evaluation of valleys in a tropical rain area - a case study. PhD Thesis Agricultural University Wageningen, the Netherlands.

WARUI, C.M. (1979). Developments in cashew cultivation and Research in Kenya. CARS Comm. No. 2, KIKAMBALA, KENYA.

WOODE, R.P. (1981). We don't want soil maps, just give us land capability. The role of land capability surveys in ZAMBIA. Soil survey and land evaluation Vol. 1 No. 1.

WOODHEAD, T (1968). Studies on potential evaporation in Kenya. EAAFRO, NAIROBI, KENYA.

YOUNG, A (1980). Tropical Soils and Soil Survey. Cambridge University Press, Cambridge, pg. 382-423.

*Addendum

AGNOLONI, A.and HAEUSLER, G. (1980). A preliminary Study of the present and potential conditions of cashew cultivation in the Coast region of Kenya.

CARS. Annual Reports upto 1978.

DRAPER, N.R. and SMITH, H. (1966). Applied regression Analysis. John Wiley & Sons, Inc. pg. 163-177.

FLOOR, J. (1981). Coconuts around Kaloleni (Kilifi District, Kenya). Preliminary report No. 2, Kilifi Series. TPIP, Kilifi, KENYA.

MoA. Annual Reports for Kilifi District and Coast Province upto 1978.

Appendix A1. Water balance calculation sheet

WATER BALANCE FOR ....

ECOLOGICAL ZONE .... SOIL TYPE ....

AVAILABLE WATER CAPACITY .... YEAR OF STUDY ....

MONTH	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
EVAPORATIVE DEMAND Eo (PENMAN) (mm)													
CROP FACTOR Et/Eo													
INITIAL STORAGE S1 (mm)													
ET Crop (mm)													
RAINFALL (mm)													
FINAL STORAGE S2 (mm)													
DRAINAGE (mm)													
DEFICIT (mm)													

APPENDICES

APPENDIX 1. LETTER CODES FOR FIRST AND SECOND LEVEL FAO CLASSIFICATION SYSTEM (WITH REFERENCE CHONYI-KALOLENI AREA)

CODE		UNIT
I		LITHOSOLS
V		VERTISOLS
	Vp	pellic VERTISOLS
	Vc	chromic "
J		FLUVISOLS
	Jd	dystric FLUVISOLS
G		GLEYSOLS
	Gd	dystric GLEYSOLS
Q		ARENOSOLS
	Qa	albic ARENOSOLS
	Ql	luvic "
	Qc	cambic "
F		FERRALSOLS
	Fa	acric FERRALSOLS
	Fr	rhodic "
	Fo	orthic "
N		NITOSOLS
	Nd	dystric NITOSOLS
	Ne	eutric "
A		ACRISOLS
	Ao	orthic ACRISOLS
	Af	ferric ACRISOLS
L		LUVISOLS
	Lg	gleyic LUVISOLS
	La	albic "
	Lv	vertic "
	Lf	ferric "
	Lc	chromic "
	Lo	orthic "
B		CAMBISOLS
	Bg	gleyic CAMBISOLS
	Bv	vertic "
	Bd	ferralic "
	Bc	chromic "
	Be	eutric "

APPENDIX 2. PROFILE PIT DESCRIPTIONS

Observation	: 198/3-1; Kilifi district; E 817 N 836; 8/11/80.
Mapping unit	: VcTi.
Classification	: chromic VERTISOL
Agroclimatic zone	: III
Parent material	: Jurassic Shales
Physiography	: Upland
Relief	: Undulating
Vegetation/land use	: Cultivation of annual crops, maize, cassava, simsim, cotton and pulses.
Erosion	: Slight sheet erosion but prominent gullies are common on steeper slopes.
Surface stoniness/rockiness	: Nil.
Flooding	: Nil.
Slope angle and position	: 3%, upper slope.
Salinity/sodicity	: Nil.
Surface sealing	: Nil.
Internal drainage class	: Imperfectly drained.

Ap 0-17cm Very dark greyish brown (10YR 3/2, moist; 10YR 4/2,dry); clay; moderate, fine subangular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); many fine pores; many fine; common, medium and very few coarse roots; pH 6.3; clear and wavy transition to:

(Sample 198/3-1a)

AU 17-35 Dark yellowish brown (10YR 4/6, moist; 10YR 5/6, dry); clay; moderate, medium subangular blocky structure; very hard (dry), firm (moist), sticky and plastic (wet), many very fine to fine pores; common very fine to fine roots; pH 5.8; gradual and smooth transition to:

(Sample 198/3-1b)

C_1 35-56 Yellowish brown (10YR 5/8, moist and dry); few, fine faint olive brown (2.5Y 4/4) mottles; clay; weak coarse angular blocky structure; extremely hard (dry), very firm (moist), sticky and plastic (wet); many moderately thick slickensides, very few fine pores; common fine manganese and iron concretions; very few fine to very fine roots; pH 5.4; clear and smooth transition to:

(Sample 198/3-1c)

C_2 56-160+ Yellowish brown (10YR 6/8, moist); few medium faint dark brown (7.5YR 4/4) mottles; clay; moderate very coarse angular blocky structure; extremely hard (dry), very firm (moist), sticky and plastic (wet); common thick slickensides, slightly calcareous; very few, very fine pores; common fine manganese and $CaCO_3$ concretions, very few very fine roots; pH 8.2

(Sample 198/3-1c)

Note: + implies that the horizon extends beyond this depth

Remarks: 1) There are vertical cracks 1-3cm wide starting from 14cm below the surface to the bottom of profile.

2) Roots below 60cm are concentrated along the slickensides.

ANALYTICAL DATA FOR PROFILE 198/3-1 .....UNIT VcTi1 ......

Horizon	Ap	Au	Cg_1	Cg_2	
Depth (cm)	0-17	17-35	35-56	56-160	
pH H_2O (1:2.5 v/v)	6.3	5.8	5.4	8.0	
pH KCl (")	5.2	4.4	4.0	7.3	
EC (mmho/cm)	0.35	0.22	0.21	0.71	
% Carbon	2.39	0.76	0.29	0.26	
CEC (me/100g S) pH7.0	43	34	39	52	
Exch. Ca (me/100g S)	17.7	15.0	16.2	32.5	
" Mg "	8.24	9.04	10.84	11.44	
" K "	2.5	0.52	0.54	0.48	
" Na "	0.9	0.84	0.98	3.10	
Sum of cations	29.14	25.40	28.36	47.52	
Base saturation pH 7.0	68	75	73	91	
ESP at pH 8.2					
TEXTURE					
% Sand(2.0-0.05mm)	7	7	9	8	
% Silt(0.05-0.002mm)	25	20	9	19	
% Clay (<0.002mm)	68	73	82	73	
Textural class	C	C	C	C	

FERTILITY ASPECTS (0-30cm)

pH H_2O	6.1	AVAILABLE CATIONS (me/100g S)	
% Carbon	1.66	Ca	12.0
Nitrogen %	0.22	Mg	8.6
C/N ratio	7.55	K	0.58
P-Mehlich (ppm)	6	Na	0.62
P-Olson ppm	2	Mn	0.72

Observation	:	198/3-30; Kilifi district; E 661 N 834; 14/12/80
Mapping unit	:	QcFe4
Soil classification	:	cambic ARENOSOL
Agroclimatic zone	:	IV
Parent material	:	Fine grained Mariakani Sandstones
Physiography	:	Upland
Relief	:	Undulating
Vegetation/land use	:	Cultivation of tree crops, coconut and cashew and annual crops maize and cassava; some cattle also graze here
Erosion	:	Nil
Surface stoniness/rockiness	:	Nil
Slope angle and position	:	2% upper slope
Salinity/sodicity	:	Nil
Effective soil depth	:	Extremely deep (more than 160cm)
Surface sealing	:	Slight
Internal drainage class	:	Excessively drained

Ap 0-23cm Dark brown (10YR 3/3,moist; 10YR 5/3,dry); loamy fine sand; single grains; soft (dry), very friable (moist), non-sticky and non-plastic (wet); many fine pores- many fine to very fine, common medium to coarse roots; pH 6.3; gradual and smooth transition to:

(Sample 198/3-30a)

Au 23-83 Yellowish brown (10YR 5/6,moist; 10YR 6/4,dry); loamy fine sand; porous massive; soft (dry), very friable (moist), non-sticky and non-plastic (wet); many very fine, many medium to coarse roots; pH 5.8; gradual and smooth transition to:

(Sample 198/3-30 b and c)

Bu 83-112 Brownish yellow (10YR 6/6, moist); loamy fine sand; porous massive; hard (dry), friable (moist), non-sticky and non-plastic (wet); many fine pores; common medium to coarse roots; pH 5.5; with gradual and smooth transition to:

(Sample 198/3-30d)

C 112-160 Very pale brown (10YR 8/4,moist); loamy fine sand; porous massive; slightly hard (dry), friable (moist), non-sticky and non-plastic (wet); many fine pores; many medium to coarse roots; pH 5.7

(Sample 198/3-30e)

ANALYTICAL DATA FOR PROFILE 198/3-30....UNIT.QcFe4......

Horizon	Ap	Au	Bu	C	
Depth (cm)	0-23	23-83	83-112	112-160	
pH H_2O (1:2.5 v/v)	6.3	5.8	5.5	5.7	
pH KCl (")	4.9	4.2	3.8	3.8	
EC (mmho/cm)	0.05	0.03	0.04	0.02	
% Carbon	0.4	0.14	0.06	0.06	
CEC (me/100g S) pH7.0	4.0	3.1	3.6	1.8	
Exch. Ca (me/100g S)	1.9	1.5	1.2	0.7	
" Mg "	0.9	0.4	0.4	0.2	
" K "	0.37	0.09	0.08	0.06	
" Na "	0.18	0.18	0.33	0.23	
Sum of cations	3.15	2.17	2.01	1.19	
Base saturation pH 7.0	79	70	58	66	
ESP at pH 8.2					
T E X T U R E					
% Sand (2.0-0.05mm)	84	82	78	82	
% Silt (0.05-0.002mm)	12	16	14	14	
% Clay (<0.002mm)	4	6	8	4	
Textural class	LS	LS	LS	LS	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	5.9		
% Carbon	0.38	Ca	1.8
Nitrogen %	0.06	Mg	1.0
C/N ratio	6.0	K	0.18
P-Mehlich (ppm)	15	Na	0.15
P-Olson ppm	-	Mn	0.18

PROFILE DESCRIPTION No. 198/4-3

Observation	:	198/4-3; Kilifi district; E 865 N 841; 11/11/80
Mapping unit	:	FrMw
Soil classification	:	rhodic FERRALSOL
Agroclimatic zone	:	III
Parent material	:	Medium grained Magarini Sands
Physiography	:	Upland
Relief - macro	:	Hilly
" meso	:	Nil
" micro	:	Nil
Vegetation/land use	:	Cultivation of cashew, coconuts and annual crops; some parts left fallow
Erosion	:	Moderate to severe sheet and gully erosion
Surface stoniness	:	Nil
" rockiness	:	Nil
Slope - gradient	:	7% East (becoming steeper - 22% further East)
- position	:	Middle
Salinity/alkalinity	:	Nil
Effective soil depth	:	Extremely deep (more than 160cm)
Surface sealing	:	Nil
" cracking	:	Nil
Internal drainage	:	Well drained

Ap	0-10cm	Dark reddish brown (2.5YR 3/4, moist); sandy clay loam; weak fine subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and non-plastic (wet); many fine pores; common fine, few medium roots; pH 7.1; clear and smooth transition to: (Sample 198/4-3a)
AB	10-28	Dark to dusky red (2.5YR 3/2, moist); sandy clay loam; porous massive structure; slightly hard (dry), friable (moist), sticky and slightly plastic (wet); common fine, few medium to coarse roots; pH 6.5; gradual and smooth transition to: (Sample No. 198/4-3b)
BU_1	28-80	Dark reddish brown (2.5YR 2.5/4, moist); sandy clay loam; porous massive structure; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine to fine pores; common medium to coarse roots; pH 6.1; gradual and smooth transition to: (Sample No. 198/4-3c)
Bu_2	80-160	Dusky red (10R 3/4 moist); sandy clay loam; porous massive structure; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine to medium pores; common medium to coarse roots; pH 5.5. (Sample No. 198/4-3d)

ANALYTICAL DATA FOR PROFILE .198/4-3....UNIT.FrMw2......

Horizon	Ap	AB	Bu_1	Bu_2	
Depth (cm)	0-10	10-28	28-80	80-160	
pH H_2O (1:2.5 v/v)	7.1	6.5	6.1	5.5	
pH KCl (")	6.1	5.3	5.1	4.6	
EC (mmho/cm)	0.11	0.07	0.04	0.05	
% Carbon	0.61	0.38	0.23	0.18	
CEC (me/100g S) pH 7.0	6.2	3.6	2.4	1.8	
Exch. Ca (me/100g S)	3.0	1.6	1.1	0.9	
" Mg "	0.92	0.9	0.52	0.58	
" K "	0.41	0.23	0.25	0.07	
" Na "	0.32	0.18	0.20	0.15	
Sum of cations	4.65	2.91	2.07	1.7	
Base saturation pH 7.0	75	81	86	94	
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	72	72	71	68	
% Silt (0.05-0.002mm)	7	5	3	2	
% Clay (<0.002mm)	21	23	26	30	
Textural class	SCL	SCL	SCL	SCL	

FERTILITY ASPECTS (0-30cm)

pH H_2O	6.0	AVAILABLE CATIONS (me/100g S)	
% Carbon	0.44	Ca	3.0
Nitrogen %	0.06	Mg	1.2
C/N ratio	7.3	K	0.24
P-Mehlich (ppm)	5	Na	0.11
P-Olson ppm	-	Mn	0.86

Observation	:	198/3-8; Kilifi district; E 797 N 845; 13/11/80
Mapping unit	:	NdLw.
Soil classification	:	dystric NITOSOL
Agroclimatic zone	:	III
Parent material	:	Kambe Limestone
Physiography	:	Upland
Relief	:	Gently undulating
Vegetation/land use	:	Cultivation of tree and annual crops, coconuts, maize, pulses cassava
Surface stoniness	:	Nil
" rockiness	:	Rocky (rocks less than 10 metres apart)
Erosion	:	Nil
Flooding	:	Nil
Slope angle and position	:	2%, Middle
Salinity/alkalinity	:	Nil
Surface sealing	:	Very slight
" cracking	:	Nil
Effective soil depth	:	Extremely deep (more than 160cm)
Internal drainage class	:	Well drained

Ap 0-25cm Dusky red (2.5YR 3/2, moist ; 2.5YR 3/4, dry); sandy clay; moderate, fine to medium crumb structure; slightly hard (dry), friable (moist), sticky and plastic (wet); many fine pores; many very fine to fine, common medium roots; pH 5.6; gradual and smooth transition to:

(Sample 198/3-8a)

Bt_1 25-55 Dark red (10R 3/4, moist; 2.5YR 3/4, dry); sandy clay; moderate medium subangular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); few thin clay cutans; many fine, few medium to coarse pores; many fine to medium roots; pH 5.9; gradual and smooth transition to:

(Sample 198/3-8b)

Bt_2 55-200 Dusky red (10R 3/4, moist; 2.5YR 3/4 dry); sandy clay; weak to moderate, medium subangular blocky tending to prismatic structure; hard (dry), friable (moist), sticky and plastic (wet); many, moderately thin clay cutans; many fine pores; common medium roots; pH 6.2; abruptly overlying rock at 200cm depth

(Sample 198/3-8c and d)

Remarks:

1. The profile was augered at the bottom (160cm) to the rock at 200cm depth.
2. Coconut roots were found throughout profile upto 200cm.
3. The profile is not calcareous at all.

ANALYTICAL DATA FOR PROFILE ..198/3-8....UNIT.NdLw1......

Horizon	Ap	Bt_1	Bt_2		
Depth (cm)	0-25	25-55	55-200		
pH H_2O (1:2.5 v/v)	5.6	5.9	6.2		
pH KCl (")	4.9	5.1	6.2		
EC (mmho/cm)	0.09	0.04	0.03		
% Carbon	0.93	0.35	0.23		
CEC (me/100g S) $pH_{7.0}$	9.4	6.0	4.8		
Exch. Ca (me/100g S)	4.9	3.4	1.5		
" Mg "	1.4	0.45	0.15		
" K "	0.52	0.08	0.08		
" Na "	0.38	0.30	0.24		
Sum of cations	7.17	4.23	1.97		
Base saturation pH 7.0	76	71	41		
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	56	52	52		
% Silt (0.05-0.002mm)	6	4	4		
% Clay (<0.002mm)	38	44	44		
Textural class	SC	SC	SC		

FERTILITY ASPECTS (0-30cm)

pH H_2O	6.2	AVAILABLE CATIONS (me/100g S)	
% Carbon	1.02	Ca	3.6
Nitrogen %	0.16	Mg	2.0
C/N ratio	6.38	K	0.47
P-Mehlich (ppm)	6	Na	0.18
P-Olson ppm	-	Mn	0.9

Observation	: 198/3-16; Kilifi district; E 749 N851; 20/11/80
Mapping unit	: $AoCw_2$
Soil classification	: orthic ACRISOL
Parent material	: Coarse grained Mazeras Sandstone
Physiography	: Upland
Relief	: Undulating to hilly
Vegetation/land use	: Cultivation of cashew with bush undergrowth
Erosion	: Moderate sheet erosion. Some gully erosion is also evident.
Surface stoniness/rockiness	: Nil
Slope gradient and position	: 22%, upper middle slope
Salinity/sodicity	: Nil
Effective soil depth	: Extremely deep (more than 200cm)
Surface sealing	: Nil
Internal drainage	: Well drained

Ap	0-17cm	Reddish brown (5YR 4/3, moist); sandy loam; porous massive; loose (dry), very friable (moist), slightly sticky and slightly plastic (wet); many fine pores; many very fine to fine, common fine to medium, few coarse roots; pH 6.2; gradual and smooth transition to: (Sample 198/3-16a)
Au	17-33	Dark reddish brown (5YR 3/3, moist); sandy loam; weak fine to medium subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); common fine to medium pores; common very fine to fine, few medium to coarse roots; pH 6.4; gradual and smooth transition to: (Sample 198/3-16b)
Bt_1	33-75	Dark red (2.5YR 3/6, moist); sandy clay loam; moderate fine to medium subangular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); patchy thin clay cutans; common very fine to fine pores; few 2mm manganese concretions; common fine to medium roots; pH 5.9; gradual and smooth transition to: (Sample 198/3-16c)
Bt_2	75-160	Red (10R 4/6, moist) sandy clay loam; weak fine to medium subangular blocky structure; slightly hard (dry), friable (moist), sticky and plastic (wet); common very fine pores; few fine to medium roots; pH 5.0 (Sample 198/3-16d)

ANALYTICAL DATA FOR PROFILE 198/3-16....UNIT AoCw2......

Horizon	Ap	Au	Bt_1	Bt_2	
Depth (cm)	0-17	17-33	33-75	75-160	
pH H_2O (1:2.5 v/v)	6.2	6.4	5.9	5.0	
pH KCl (")	5.9	5.8	4.6	4.2	
EC (mmho/cm)	0.07	0.09	0.05	0.04	
% Carbon	0.8	0.46	0.29	0.34	
CEC (me/100g S) pH7.0	6.6	4.6	3.9	4.3	
Exch. Ca (me/100g S)	2.8	1.8	1.8	1.0	
" Mg "	0.82	0.57	0.32	0.3	
" K "	0.45	0.41	0.45	0.17	
" Na "	0.22	0.29	0.33	0.23	
Sum of cations	4.29	3.07	2.9	1.7	
Base saturation pH 7.0	65	67	74	40	
ESP at pH 8.2					
TEXTURE					
% Sand(2.0-0.05mm)	83	79	72	71	
% Silt(0.05-0.002mm)	3	6	2	2	
% Clay (<0.002mm)	14	12	26	27	
Textural class	SL	SL	SCL	SCL	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	6.4		
% Carbon	0.63	Ca	2.01
Nitrogen %	0.07	Mg	1.5
C/N ratio	9.0	K	0.29
P-Mehlich (ppm)	7	Na	0.12
P-Olson ppm		Mn	1.14

PROFILE DESCRIPTION No. 198/3-24

Observation	:	198/3-24; Kilifi district; E 601 N 816; 6/12/80
Mapping unit	:	$LqAi_1$
Soil classification	:	gleyic LUVISOL
Agroclimatic zone	:	IV to V
Parent material	:	Pleistocene Alluvial deposits
Physiography	:	Minor valley
Relief - macro	:	Flat
" meso	:	Nil
" micro	:	Nil
Land use/vegetation	:	Grazing of cattle and some isolated cultivation of annual crops
Erosion	:	Nil
Surface stoniness	:	Nil
" rockiness	:	Nil
Slope gradient	:	1% (East)
" position	:	Bottom
Salinity/sodicity	:	Slightly Saline
Effective soil depth	:	Deep (about 72cm)
Surface sealing	:	5mm thick and moderately strong crusts
" cracking	:	Few cracks (less than 1cm at the surface)
Internal drainage	:	Imperfectly drained

Au	0-15cm	Dark brown (10YR 4/3 moist; 10YR 4/3 dry); sandy clay loam; porous massive structure; very hard (dry), firm (moist), sticky and plastic (wet); few fine to medium pores; common fine, few medium roots; pH 5.8; with gradual and smooth transition to: (Sample 198/3-24a)
Bt	15-35	Dark brown (10YR 4/3, moist; 10YR 4/3, dry); sandy clay loam; moderate, fine to medium angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); patchy, thin clay cutans; common fine, few medium pores; few fine, very few medium roots; pH 5.7; clear and smooth transition to: (Sample 198/3-24b)
Bt_1g	35-72	Light olive brown (2.5Y 5/4, moist); few, faint, fine yellowish brown mottles; clay loam; weak medium angular blocky structure; extremely hard (dry), very firm (moist); slightly sticky and slightly plastic (wet); broken, moderately thick clay cutans; few fine pores; common manganese concretions; few fine roots; pH 5.9; with gradual and smooth transition to: (Sample 198/3-24c)
Bt_2g	72-190	Light olive brown (2.5Y 5/6, moist); common faint pale brown mottles; clay loam; weak coarse angular blocky structure; very hard (dry), very firm (moist), slightly sticky and plastic (wet); broken moderate clay skins, calcareous; very few fine pores; few manganese and/or iron concretions; pH 8.0; overlying solid rock. (Sample 198/3-24 d and e)

NB: The profile was 150cm deep while the rest was augered. Below 72cm the very few fine roots present were concentrated along vertical cracks.

ANALYTICAL DATA FOR PROFILE 198/3-24....UNIT.LgAi2.....

Horizon	Au	Bt	Bt_1g	Bt_2g	
Depth (cm)	0-15	15-35	35-72	72-190	
pH H_2O (1:2.5 v/v)	5.8	5.9	7.2	8.2	
pH KCl (")	4.7	4.1	6.0	7.0	
EC (mmho/cm)	0.12	0.09	0.55	1.30	
% Carbon	0.4	0.36	0.35	0.12	
CEC (me/100g S) pH 7.0	14.2	16.4	17.8	21.8	
Exch. Ca (me/100g S)	3.6	5.2	6.0	13.8	
" Mg "	5.9	7.5	11.0	11.0	
" K "	0.63	0.4	0.37	0.56	
" Na "	TRACE	0.5	2.0	1.88	
Sum of cations	9.13	13.2	19.4	27.2	
Base saturation pH 7.0	64	80	100	100	
ESP at pH 8.2			11.2	8.6	
TEXTURE					
% Sand(2.0-0.05mm)	52	46	38	38	
% Silt(0.05-0.002mm)	22	20	26	24	
% Clay (<0.002mm)	26	34	36	38	
Textural class	SCL	SCL	CL	CL	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	5.6		
% Carbon	0.96	Ca	3.7
Nitrogen %	0.15	Mg	3.6
C/N ratio		K	0.31
P-Mehlich (ppm)	12	Na	0.27
P-Olson ppm		Mn	0.62

REMARK : ECe (63% saturation extract) in Bt_1g and Bt_2g horizon is 4.5 mmho/cm. pH of extract was 7.9. Therefore soil is slightly saline.

Observation	:	198/3-17; Kilifi district; E 740 N 841; 20/11/80
Mapping unit	:	LgAp$_i$
Agroclimatic zone	:	III
Soil classification	:	gleyic LUVISOL
Physiography	:	Minor valley
Relief	:	Flat
Vegetation/land use	:	Grazing, formerly planted with rice
Erosion	:	Gully erosion severe where the valley is V-shaped
Surface stoniness	:	Nil
" rockiness	:	Nil
Slope gradient	:	1% (north)
Salinity/sodicity	:	Sodic
Surface sealing	:	Moderately strong
" cracking	:	Nil
Internal drainage	:	Poorly drained

Ap 0-15cm — Very dark greyish brown (10YR 3/2, moist); loam; fine crumb structure; slightly hard (dry), friable (moist), sticky and plastic (wet); very fine to fine, common medium pores; many fine roots; pH 5.8; clear and smooth transition to:

(Sample 198/3-17a)

Au 15-30 — Dark brown (10YR 4/3, moist); fine, faint yellowish brown mottles; clay loam; fine to medium subangular blocky structure; hard (dry), very firm (moist), sticky and plastic (wet); many fine, common medium pores; common fine roots; few manganese and/or iron concretions; pH 6.0; clear and wavy transition to:

(Sample 198/3-17b)

Bt$_1$g 30-70 — Brown (7.5YR 5/4, moist); common, fine, distinct, reddish yellow mottles; clay; fine to medium angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); few, fine to medium pores; continuous moderately thick clay cutans; few fine roots; pH 6.6; gradual and smooth transition to:

(Sample 198/3-17c)

Bt$_2$g 70-90 — Reddish brown (5YR 4/4, moist); mottled; clay; moderate fine to medium angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); common fine pores; continuous moderately thick clay cutans; strongly calcareous; few vertical cracks; very few fine roots; pH 8.2; abrupt and smooth transition to:

(Sample 198/3-17d)

Cg 90-140 — Light grey (7.5YR 7/0, moist); many, fine, prominent reddish yellow mottles; gravelly clay; moderate fine to medium angular blocky structure; very hard (dry), very firm (moist), very sticky and very plastic (wet); calcareous; pH 8.3; gradual and smooth transition to whitish green marls.

(Sample 198/3-17e)

ANALYTICAL DATA FOR PROFILE 198/3-17 ....UNIT LgAp1......

Horizon	Ap	Au	Bt_1g	Bt_2g	Cg
Depth (cm)	0-15	15-30	30-70	70-90	90-140
pH H_2O (1:2.5 v/v)	5.8	6.0	6.6	8.2	8.3
pH KCl (")	4.9	4.8	6.1	7.3	7.1
EC (mmho/cm)	0.1	0.24	1.3	2.05	1.85
% Carbon	0.97	0.2	0.57	0.37	0.29
CEC (me/100g S) pH8.2	11.8	10.8	15.9	15.5	14.7
Exch. Ca (me/100g S)	3.8	3.4	16.2	16.0	9.7
" Mg "	4.8	5.85	11.2	14.5	14.9
" K "	0.24	0.23	0.47	0.52	0.48
" Na "	0.6	1.31	4.13	4.2	4.9
Sum of cations	9.47	10.78	21.98	36.6	29.9
Base saturation pH 8.2	80	100	100	100	100
ESP at pH 8.2					
TEXTURE					
% Sand(2.0-0.05mm)	34	32	24	22	20
% Silt(0.05-0.002mm	40	36	32	30	32
% Clay (<0.002mm)	26	32	44	48	48
Textural class	L	CL	C	C	C

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	5.9		
% Carbon	1.1	Ca	3.0
Nitrogen %		Mg	4.7
C/N ratio		K	0.18
P-Mehlich (ppm)	7	Na	4.3
P-Olson ppm		Mn	0.5

Remark: ECe in Bt_1g (pH 7.7 and 54.2% saturation) is 5.50 mmho/cm
ECe in Bt_2g (pH 7.8 and 60.8% saturation) is 5.50 mmho/cm
ECe in Cg (pH 7.4 and 50.2% saturation) is 10.0 mmho/cm

PROFILE DESCRIPTION 198/3-33

Observation	:	198/3-33; Kilifi district; E 821 N 614; 18/12/80
Mapping unit	:	LvFi
Agroclimatic zone	:	IV-V[1]
Soil classification	:	vertic LUVISOL
Parent material	:	Fine grained Mariakani Sandstone
Physiography	:	Upland
Relief - macro	:	Undulating
" meso	:	Near to a small stream due west
" micro	:	Nil
Vegetation/land use	:	Bushed grassland currently under cultivation of annual crops maize and cassava. Grazing is done due south.
Erosion	:	Moderate sheet erosion
Surface stoniness	:	Nil
" rockiness	:	There is a rock outcrop of 20 metres upslope
Slope gradient	:	16% (South-west)
" position	:	Middle
Salinity/sodicity	:	Nil
Effective soil depth	:	Deep (70cm)
Surface sealing	:	Moderate
" crusting	:	2mm thick crusts
" cracking	:	Nil
Internal drainage	:	Imperfectly drained

Ap	0-20cm	Dark greyish brown (10YR 4/2, moist); sandy loam; porous massive structure; slightly hard (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine to fine pores; many very fine, common medium roots; pH 6.3; clear and smooth transition to: (Sample 198/3-33a)
AB	20-40	Very dark greyish brown (10YR 3/2, moist, 10YR 4/2, dry); fine sandy loam to sandy loam; weak, medium to coarse subangular blocky structure; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); many fine, common medium pores; many very fine to fine roots; pH 6.0; abrupt and smooth transition to: (Sample 198/3-33b)
Bt_1g	40-70	Dark yellowish brown (10YR 4/4 moist, 10YR 5/4, dry); many, faint, fine yellowish red mottles; sandy clay; moderate, fine to medium angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); broken, thin, clay cutans; few fine pores; common fine manganese concretions; few very fine to fine roots; pH 6.4; gradual and smooth transition to: (Sample 198/3-33c)
Bt_2g	70-125	Light olive brown (2.5Y 5/4, moist); many faint, fine brownish mottles; sandy clay; moderate fine to medium angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); continuous moderately thick slickensides; very few fine pores; slightly calcareous; common fine to medium manganese concretions; very few fine roots; pH 7.3; with abrupt and smooth transition to fine grained micaceous sandstone (or siltstone). (Sample 198/3-33d)

ANALYTICAL DATA FOR PROFILE 198/3-33...UNIT LvFi1......

Horizon	Ap	AB	Bt_1g	Bt_2g	
Depth (cm)	0-20	20-40	40-70	70-125	
pH H_2O (1:2.5 v/v)	6.3	6.0	6.4	7.4	
pH KCl (")	5.3	4.8	4.6	5.8	
EC (mmho/cm)	0.09	0.09	0.51	0.26	
% Carbon	0.77	0.57	0.51	0.26	
CEC (me/100g S) pH7.0	8.8	12.2	16.8	18.2	
Exch. Ca (me/100g S)	4.4	5.8	8.1	7.2	
" Mg "	2.0	3.3	6.7	8.5	
" K "	0.65	0.50	0.34	0.29	
" Na "	0.28	0.40	0.80	2.95	
Sum of cations	7.33	10.0	16.0	19.0	
Base saturation pH 7.0	83	83	95	100	
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	70	60	55	44	
% Silt (0.05-0.002mm)	12	16	9	14	
% Clay (<0.002mm)	18	24	36	42	
Textural class	SL	SCL/SL	SC	C	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	5.6		
% Carbon	0.5	Ca	2.3
Nitrogen %	0.07	Mg	1.7
C/N ratio	7.1	K	0.2
P-Mehlich (ppm)	8	Na	0.15
P-Olson ppm	–	Mn	0.5

PROFILE DESCRIPTION No. 198/3-11

Observation	:	198/3-11; Kilifi district; E 777 N 842; 14/11/80
Mapping unit	:	$LfMw_3$
Soil classification	:	ferric LUVISOL
Agroclimatic zone	:	III
Parent material	:	Kambe Limestone
Physiography	:	Upland
Relief - macro	:	Gently undulating
" meso	:	Nil
" micro	:	Nil
Vegetation/land use	:	Cultivation of tree crops, mainly coconut, cashew intercropped with annual crops.
Erosion	:	Very slight sheet erosion
Flooding	:	Nil
Slope angle and position	:	2% E
Surface sealing/crusting/cracking	:	Nil
Salinity/sodicity	:	Nil
Internal drainage	:	Well drained

Ap	0-10cm	Dark reddish brown (5YR 3/3, moist; 5YR 3/4, dry): sandy loam; moderate, fine to medium subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine to medium, common coarse pores; common very fine to fine, common coarse to very coarse roots; pH 5.9; clear and smooth transition to: (Sample 198/3-11a)
Bt	10-50	Dark reddish brown (2.5YR 3/4, moist); sandy clay loam; weak, medium subangular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); many fine pores; patchy thin clay cutans; common fine to coarse roots; pH 6.1; abrupt and broken transition to: (Sample 198/3-11b)
Bt_2	50-105	Reddish brown (2.5YR 4/4, moist); gravelly sandy clay loam; massive to weakly coherent; slightly hard (dry), friable (moist), slightly sticky and non-plastic (wet); many fine pores; common fine iron concretions; many fine roots; pH 6.2; abrupt and broken boundary to concretionary ironstones. (Sample 198/3-11c)

ANALYTICAL DATA FOR PROFILE .198/3-11...UNIT.LfLw2......

Horizon	Ap	Bt_1	Bt_2		
Depth (cm)	0-10	10-50	50-105		
pH H_2O (1:2.5 v/v)	5.9	6.1	6.2		
pH KCl (")	4.8	5.1	5.3		
EC (mmho/cm)	0.05	0.04	0.03		
% Carbon	1.22	0.29	0.18		
CEC (me/100g S) pH7.0	9.6	3.6	2.4		
Exch. Ca (me/100g S)	4.6	1.6	1.4		
" Mg "	1.55	0.8	0.45		
" K "	0.21	0.06	0.04		
" Na "	0.35	0.03	0.10		
Sum of cations	6.71	2.49	2.0		
Base saturation pH 7.0	71	69	83		
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	66	62	60		
% Silt (0.05-0.002mm)	6	6	6		
% Clay (<0.002mm)	28	32	34		
Textural class	LS	SCL	SCL		

FERTILITY ASPECTS (0-30cm)

pH H_2O	6.8	AVAILABLE CATIONS (me/100g S)	
% Carbon	1.02	Ca	5.0
Nitrogen %	0.13	Mg	1.3
C/N ratio	7.8	K	0.47
P-Mehlich (ppm)	5	Na	0.18
P-Olson ppm	-	Mn	1.08

Observation : 198/3-20; Kilifi district; E 736 N 828; 21/11/80.
Mapping unit : LcCw.
Soil classification : chromic LUVISOL
Agroclimatic zone : III
Parent material : Coarse grained Mazeras Sandstone
Physiography : Upland
Relief - macro : Undulating to hilly
" meso : Sparse termite mounds
Land use/Vegetation : Immediately around the profile annual crops are cultivated including maize, cassava and cowpeas in adjacent areas coconut and citrus trees are the major crops. In some parts grazing is done beneath the tree crops.
Erosion : Moderate sheet erosion
Surface stoniness : Nil
" rockiness : Nil
Slope gradient and position: 13%, middle
Salinity/sodicity : Nil
Effective soil depth : More than 160cm
Surface sealing : Moderate
" cracking : Nil
Internal drainage class : Well drained

Ap 0-14cm Brown (7.5YR 5/4, moist); sandy loam; porous massive; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine to medium pores; many very fine to fine, few medium to coarse roots; pH 6.2; clear and wavy transition to:

(Sample 198/3-20a)

Bu 14-36 Yellowish red (5YR 5/6, moist); sandy clay loam; weak to fine medium, subangular blocky structure; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine, common medium pores; common very fine to fine, few medium to coarse roots; pH 5.6 with gradual and smooth transition to:

(Sample 198/3-20b)

Bt_1 36-75 Red (2.5YR 4/6, moist); sandy clay; moderate medium to coarse subangular blocky structure; hard (dry), firm (moist), sticky and plastic (wet); common fine, few medium pores; patchy thin clay cutans; common fine to very fine, few medium roots; pH 5.3 with clear and smooth transition to:

(Sample 198/3-20c)

Bt_2 75-160 Yellowish red (5YR 5/8, moist); sandy clay; weak medium subangular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); many medium pores; patchy thin clay cutans; few fine to medium roots; pH 4.9.

ANALYTICAL DATA FOR PROFILE 198/3-20 ... UNIT LcCw1 ......

Horizon	Ap	Bu	Bt1	Bt2	
Depth (cm)	0-14	14-36	36-75	75-160	
pH H_2O (1:2.5 v/v)	6.2	5.6	5.3	4.9	
pH KCl (")	5.3	4.3	4.0	4.0	
EC (mmho/cm)	0.05	0.04	0.04	0.04	
% Carbon	0.74	0.54	0.34	0.26	
CEC (me/100g S) pH 7.0	7.84	6.59	5.69	5.87	
Exch. Ca (me/100g S)	3.4	3.4	1.9	2.0	
" Mg "	1.16	1.4	0.48	0.32	
" K "	0.45	0.48	0.41	0.30	
" Na "	0.21	0.35	0.26	0.29	
Sum of cations	5.22	5.63	3.05	2.91	
Base saturation pH 7.0	67	85	54	50	
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	68	56	51	55	
% Silt (0.05-0.002mm)	13	14	10	5	
% Clay (<0.002mm)	19	30	39	40	
Textural class	SL	SCL	SC	SC	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	6.3		
% Carbon	0.66	Ca	3.4
Nitrogen %	0.07	Mg	1.5
C/N ratio	9.4	K	0.35
P-Mehlich (ppm)	6	Na	0.16
P-Olson ppm	-	Mn	0.43

PROFILE DESCRIPTION No. 198/3-39

Observation	:	198/3-39; Kilifi district; E 818 N 849; 16/1/81
Mapping unit	:	$LcMw_1$
Agroclimatic zone	:	III
Soil classification	:	chromic LUVISOL
Parent material	:	Medium grained Magarini Sands
Physiography	:	Coastal Upland
Relief - macro	:	Undulating
meso	:	Nil
micro	:	Nil
Vegetation/land use	:	Cultivation of perennial crops, coconut and cashew. Maize and cassava interplanted with the trees. Citrus trees also present.
Surface stoniness	:	Nil
" rockiness	:	Nil
Slope gradient	:	4% (South)
" position	:	Middle
Salinity/sodicity	:	Nil
Surface sealing	:	Nil
" crusting	:	Nil
" cracking	:	Nil
Internal drainage	:	Well drained

Ap	0-8cm	Dark reddish brown (5YR 3/3, moist, 5YR 4/3,dry); sandy clay loam: moderate fine to medium subangular blocky structure; slightly hard (dry), friable (moist), sticky and plastic (wet); many very fine to fine, common medium to coarse pores, many fine to medium roots; pH 6.9; with gradual and wavy transition to: (Sample 198/3-39a)
AB	8-25	Reddish brown (2.5YR 4/4, moist, 5YR 4/4 dry); sandy clay loam; moderate medium subangular blocky structure; hard (dry), frible (moist), sticky and plastic (wet); many fine to very fine pores; many very fine to fine, common medium to coarse roots; pH 7.5; clear and smooth transition to: (Sample 198/3-39b)
Bt	25-98	Yellowish red (5YR 5/6,moist; 5YR 6/8,dry); clay; weak, coarse subangular blocky structure; very hard (dry), friable (moist), sticky and plastic (wet); many fine, common medium to coarse pores; common very fine to fine intense termite activities; many medium to coarse roots; common thin clay skins; pH 7.6, with gradual and smooth transition to: (Sample 198/3-39c)
BC	98-160	Yellowish red (5YR 5/8,moist; 10YR 6/8,dry); sandy clay: with a porous massive structure; slightly hard (dry), very friable (moist), sticky and plastic (wet); many fine, common medium pores; common fine to coarse roots; pH 7.5. (Sample 198-39d)

ANALYTICAL DATA FOR PROFILE 198/3-39....UNIT LcMw1.......

Horizon	Ap	AB	Bt	BC	
Depth (cm)	0-8	8-25	25-98	98-160	
pH H_2O (1:2.5 v/v)	6.9	7.5	7.6	7.5	
pH KCl (")	5.8	6.5	6.6	6.3	
EC (mmho/cm)	0.09	0.12	0.1	0.06	
% Carbon	0.66	0.51	0.31	0.34	
CEC (me/100g S) $pH^{7.0}$	10.8	13.7	8.4	6.2	
Exch. Ca (me/100g S)	5.4	9.6	4.4	2.6	
" Mg "	2.10	1.0	1.6	1.8	
" K "	1.02	0.76	0.38	0.85	
" Na "	0.18	0.23	0.33	0.06	
Sum of cations	8.7	11.59	6.71	5.31	
Base saturation pH 7.0	80	85	80	86	
ESP at pH 8.2					
TEXTURE					
% Sand(2.0-0.05mm)	56	52	43	49	
% Silt(0.05-0.002mm)	12	14	8	9	
% Clay (<0.002mm)	32	34	49	42	
Textural class	SCL	SCL	C	SC	

FERTILITY ASPECTS (0-30cm)

pH H_2O	7.1	AVAILABLE CATIONS (me/100g S)	
% Carbon	0.56	Ca	7.8
Nitrogen %	0.14	Mg	2.2
C/N ratio	4.0	K	0.76
P-Mehlich (ppm)	88	Na	0.23
P-Olson ppm	-	Mn	1.20

PROFILE DESCRIPTION No. 198/3-25

Observation	:	198/3-25; Kilifi district; E 601 N 832; 6/12/80
Mapping unit	:	$LcFw_1$
Agroclimatic zone	:	V
Soil classification	:	chromic LUVISOL
Parent material	:	Shales (Mariakani Sandstone)
Physiography	:	Upland
Relief - macro	:	Undulating
" meso	:	Nil
" micro	:	Active termite mounds
Vegetation/land use	:	Cultivation
Erosion	:	Moderate sheet
Surface stoniness	:	Nil
" rockiness	:	Nil
Slope gradient	:	5% (East)
" position	:	Middle
Salinity/sodicity	:	Nil
Effective soil depth	:	Very deep (110cm)
Surface sealing	:	Moderate
" cracking	:	Nil
Internal drainage	:	Well drained

Ap 0-8cm Dark yellowish brown (10YR 3/4, moist; 10YR 5/4,dry); sandy loam; porous massive; slightly hard (dry), friable (moist), sticky and slightly plastic (wet); common fine and very fine pores; common fine to medium roots; pH 6.1; clear and smooth transition to:

(Sample 198/3-25a)

Bu 8-25 Brown (7.5YR 4/4, moist; 7.5YR 5/4,dry); sandy clay loam; porous massive; hard (dry), firm (moist), sticky and plastic (wet); common fine, few medium pores; common fine to medium roots; pH 5.8; clear and smooth transition to:

(Sample 198/3-25b)

Bt_1 25-75 Reddish brown (5YR 4/4, moist); sandy clay loam; moderate fine to medium, subangular blocky structure; very hard (dry), firm (moist), sticky and plastic (wet); broken moderately thick clay cutans; few fine to medium pores; few, 2mm manganese concretions; few fine to very fine roots; pH 6.0; with gradual and smooth transition to:

(Sample 198/3-25c)

Bt_2 75-110 Dark reddish brown (5YR 3/3 moist); gravelly clay loam; weak coarse angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); many, moderately thick clay cutans; very few coarse pores; few, 2mm manganese concretions; very few very fine roots; pH 8.4; with abrupt and broken transition to rock.

(Sample 198/3-25d)

ANALYTICAL DATA FOR PROFILE 198/3-25....UNIT LCFW1.......

Horizon	Ap	Bu	Bt_1	Bt_2	
Depth (cm)	0-8	8-25	25-75	75-110	
pH H_2O (1:2.5 v/v)	6.1	5.8	6.0	8.4	
pH KCl (")	5.1	4.1	4.0	5.6	
EC (mmho/cm)	0.07	0.07	0.08	0.14	
% Carbon	0.78	0.35	0.63	0.29	
CEC (me/100g S) pH7.0	10.2	12.2	14.6	17.3	
Exch. Ca (me/100g S)	2.9	1.9	2.9	4.8	
" Mg "	4.0	5.0	6.0	8.6	
" K "	0.65	0.17	0.21	0.27	
" Na "	0.23	0.08	0.33	2.5	
Sum of cations	7.78	7.15	9.94	16.67	
Base saturation pH 7.0	76	59	65	96	
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	62	58	48	38	
% Silt (0.05-0.002mm)	26	18	20	24	
% Clay (<0.002mm)	12	24	32	38	
Textural class	SL	SCL	SCL	CL	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	5.7		
% Carbon	0.73	Ca	2.3
Nitrogen %	0.12	Mg	2.6
C/N ratio	6.1	K	0.29
P-Mehlich (ppm)	10	Na	0.19
P-Olson ppm	-	Mn	0.30

Observation	:	198/3-26; Kilifi district; E 665 N 822; 13/12/80
Mapping unit	:	Ao-Gd 3/1
Soil classification	:	orthic ACRISOL
Agroclimatic zone	:	IV
Parent material	:	Fine grained Mariakani Sandstone
Physiography	:	Coastal upland
Relief	:	Undulating
" micro	:	Termite mounds (on the flanks)
Land use/vegetation	:	Cultivation of both perennial and annual crops, coconuts, cashews, maize, cassava
Erosion	:	Moderate to severe sheet erosion. Gully erosion is severe on the steeper slopes
Surface stoniness	:	Nil
" rockiness	:	Few rock outcrops exposed in gullies
Slope gradient and position	:	11% middle
Salinity/sodicity	:	Nil
Effective soil depth	:	More than 160cm
Surface sealing	:	Moderately strong
" cracking	:	Nil
Internal drainage	:	Well drained

Au_1 0-4cm Dark brown (10YR 4/3, moist; 10YR 6/3- dry); fine sandy loam to loamy fine sand; porous massive weakly coherent; slightly hard (dry), friable (moist), non-sticky and non-plastic (wet); many fine pores; common very fine to fine roots; pH 6.3; clear and smooth transition to:

(Sample 198/3-26a)

Au_2 4-68 Dark yellowish brown (10YR 4/6, moist; 10YR 6/4 dry); loamy fine sand; porous massive; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine pores; common very fine to fine roots; pH 6.0; gradual and smooth transition to:

(Sample 198/3-26b and c)

Bt 68-160 Yellowish brown (10YR 5/6, moist); 10YR 6/6, dry); fine sandy loam; porous massive; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine to fine pores; very patchy, thin clay coatings on sand grains; few fine roots; pH 5.2.

(Sample 198/3-26d and e)

ANALYTICAL DATA FOR PROFILE 198/3-26.....UNIT.Ao-Gd 3/1..

Horizon	Au_1	Au_2	Bt		
Depth (cm)	0-4	4-68	68-160		
pH H_2O (1:2.5 v/v)	6.3	6.0	5.2		
pH KCl (")	5.6	4.8	3.6		
EC (mmho/cm)	0.11	0.17	0.12		
% Carbon	1.07	0.23	0.12		
CEC (me/100g S) pH7.0	10.19	6.12	6.79		
Exch. Ca (me/100g S)	4.4	1.5	1.3		
" Mg "	3.0	1.2	0.9		
" K "	0.56	0.23	0.25		
" Na "	TRACE	TRACE	0.08		
Sum of cations	7.96	2.93	2.53		
Base saturation pH 7.0	78	48	37		
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	74	76	70		
% Silt (0.05-0.002mm)	22	16	16		
% Clay (<0.002mm)	4	8	14		
Textural class	SL/LS	LS	SL		

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	6.1		
% Carbon	0.44	Ca	2.0
Nitrogen %	0.07	Mg	0.9
C/N ratio	6.3	K	0.2
P-Mehlich (ppm)	7	Na	0.11
P-Olson ppm	–	Mn	0.3

PROFILE DESCRIPTION No. 198/3-G

Observation	:	198/3-G; Kilifi district; E 676 N 812; 13/11/80
Mapping unit	:	Ao-Gd 3/1
Soil classification	:	dystric GLEYSOL
Agroclimatic zone	:	III and IV
Parent material	:	Alluvium derived from Mariakani Sandstone
Physiography	:	Upland
Relief - macro	:	Minor valley
" meso	:	Nil
" micro	:	Nil
Vegetation/land use	:	Grazing and cultivation of annual crops including maize and cassava.
Erosion	:	Nil
Surface stoniness	:	Nil
" rockiness	:	Nil
Slope gradient	:	3% (East)
" position	:	Middle
Salinity/sodicity	:	Nil
Effective soil depth	:	Deep (more than 150cm)
Surface sealing	:	Covered by grass and wet
" cracking	:	
Internal drainage	:	Poorly to imperfectly drained

Ap 0-12cm Light yellowish brown (10YR 6/4 moist); sandy clay loam; porous massive structure; loose (dry), friable (moist), non-sticky and non-plastic (wet); many fine to very fine pores, many very fine, few fine roots; pH 5.8; clear and smooth transition to:

(Sample 198/3-Ga)

ABg 12-54 Dark grey (N4 moist); many, distinct, yellowish red mottles; sandy clay loam; weak, fine to medium angular blocky structure; hard (dry), friable to firm (moist), slightly sticky and slightly plastic (wet); common very fine to fine pores; many very fine, common fine roots; pH 5.7; clear and smooth transition to:

(Sample 198/3-Gb)

Bug 54-87 Grey (10YR 5/1 moist); many, distinct, dark yellowish brown mottles; sandy clay loam; weak, medium to coarse subangular blocky structure; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine to very fine pores; many very fine common fine roots; pH 5.7; with clear and smooth transition to:

(Sample 198/3-Gc)

Btg 87-150 Grey (10YR 5/1 moist); brownish yellow mottles; sandy clay; weak, medium, subangular blocky structure; very hard (dry), firm (moist), sticky and plastic (wet); very few very fine to fine pores, few, moderate, clay and humus cutans; few manganese concretions; very few very fine roots; pH 6.0.

(Sample 198/3-Gd)

ANALYTICAL DATA FOR PROFILE 198/3-G.....UNIT Ao-Gd 3/1...

Horizon	Ap	ABg	Bug	Btg	
Depth (cm)	0-12	12-54	54-87	87-150	
pH H_2O (1:2.5 v/v)	5.8	5.7	5.7	6.0	
pH KCl (")	4.3	3.7	4.0	4.1	
EC (mmho/cm)	0.07	0.06	0.04	0.10	
% Carbon	0.62	0.72	0.47	1.08	
CEC (me/100g S) pH 8.2	4.3	8.0	6.3	12.2	
Exch. Ca (me/100g S)	1.5	1.8	2.0	2.9	
" Mg "	0.6	1.3	1.2	2.0	
" K "	0.59	0.07	0.11	0.17	
" Na "	0.05	0.25	0.38	0.73	
Sum of cations	2.74	3.42	3.69	5.8	
Base saturation (pH 8.2)	64	43	59	48	
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	68	56	68	56	
% Silt (0.05-0.002mm)	8	10	4	4	
% Clay (<0.002mm)	24	34	28	40	
Textural class	SCL	SCL	SCL	SC	

FERTILITY ASPECTS (0-30cm)

pH H_2O	4.9	AVAILABLE CATIONS (me/100g S)	
% Carbon	0.95	Ca	1.6
Nitrogen %	0.09	Mg	0.6
C/N ratio	10.55	K	0.24
P-Mehlich (ppm)	20.	Na	0.24
P-Olson ppm	-	Mn	0.20

Observation	:	198/3-31; Kilifi district; E 763 N 829; 18/12/80
Mapping unit	:	Lv/Vp/I
Agro climatic zone	:	III
Soil classification	:	vertic LUVISOL
Parent material	:	Oolitic Kambe Limestone
Physiography	:	Minor valley
Relief - macro	:	Undulating
" meso	:	Uneven topography
" micro	:	Gilgai microrelief in places
Vegetation/land use	:	Cultivation and natural fallow maize and cowpeas plus cashew in places.
Erosion	:	Nil to very slight
Surface stoniness	:	Nil
" rockiness	:	Very rocky in places
Slope angle	:	0-2% (South)
" position	:	Upstream
Effective soil depth	:	Very deep (more than 170cm)
Surface sealing	:	Nil
" crusting	:	Nil
" cracking	:	Some few cracks are present
Salinity/sodicity	:	Nil
Internal drainage	:	Imperfectly to poorly drained

Ap 0-18cm Dark brown (10YR 4/3 moist); clay loam; moderate fine to medium subangular blocky structure; hard (dry), friable (moist), slightly sticky and plastic (wet); common fine to medium pores; many fine, few medium roots; pH 5.9; clear and smooth transition to:

(Sample 198/3-31a)

Bu 18-39 Yellowish brown (10YR 5/6 moist); clay loam; porous massive breaking to weak, medium angular blocky structure; hard (dry), firm (moist), slightly sticky and plastic (wet); many fine, few medium pores; common medium roots; pH 5.9; clear and smooth transition to:

(Sample 198/3-31b)

Bt_1g 39-80 Yellowish brown (10YR 5/8 moist); many prominent, fine yellowish red mottles; clay loam; weak, medium angular blocky structure; hard (dry), firm (moist), slightly sticky and plastic (wet); few fine pores; continuous moderately thick clay cutans; few fine manganese concretions; common fine to medium roots; pH 6.2; gradual and smooth transition to:

(Sample 198/3-31c)

Bt_2g 80-194 Brownish yellow (10YR 6/6 moist); many prominent fine to medium yellowish red mottles; clay to clay loam; moderate, fine angular blocky structure; hard (dry), very friable (moist), sticky and plastic (wet); patchy moderately thin clay cutans; common very fine pores; few fine common fine to medium roots; pH 8.1

(Sample 198/3-31d)

<u>NB</u>: From 170cm depth the profile was augered to 194cm but the Bt_2 horizon was found to continue. There are however some limestone stones in the last horizon.

ANALYTICAL DATA FOR PROFILE 198/3-31....UNIT.IV/Vb/I....

Horizon	Ap	Bu	Bt_{1g}	Bt_{2g}	
Depth (cm)	0-18	18-39	39-80	80-194	
pH H_2O (1:2.5 v/v)	5.9	6.0	6.2	8.1	
pH KCl (")	5.1	4.5	4.8	6.8	
EC (mmho/cm)	0.15	0.06	0.08	0.55	
% Carbon	1.07	0.46	0.26	0.14	
CEC (me/100g S) pH 8.2	12.2	13.8	14.8	20.2	
Exch. Ca (me/100g S)	6.8	8.0	8.4	40.8	
" Mg "	2.0	2.7	2.2	4.2	
" K "	0.21	0.27	0.25	0.40	
" Na "	0.23	0.23	0.4	0.55	
Sum of cations	9.62	11.2	11.25	41.75	
Base saturation pH 8.2	81	81	76	100	
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	44	40	38	34	
% Silt (0.05-0.002mm)	36	24	24	26	
% Clay (<0.002mm)	20	36	38	40	
Textural class	CL	CL	CL	C/CL	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	5.8		
% Carbon	0.82	Ca	7.0
Nitrogen %	0.13	Mg	1.7
C/N ratio	6.3	K	0.17
P-Mehlich (ppm)	9	Na	0.25
P-Olson ppm		Mn	0.30

Observation	:	198/4-34; Kilifi district; E 855 N 816; 14/1/81
Mapping unit	:	Bv/Vp
Agroclimatic zone	:	III
Soil classification	:	pellic VERTISOL
Parent material	:	Jurassic Shales
Physiography	:	Minor valley
Relief - macro	:	Valley bottom and sides
" meso	:	Nil
" micro	:	Gilgai relief
Land use/vegetation	:	Cultivation of annual crops, e.g. maize, simsim cowpeas and rice. Coconuts are also planted but do not look healthy.
Erosion	:	Severe gully erosion on the steeper valley sides
Surface stoniness	:	Nil
" rockiness	:	Nil
Slope gradient	:	1% East
Salinity/sodicity	:	Saline in the C-horizon
Surface sealing	:	Nil
" crusts	:	Nil
" cracking	:	Cracks upto 2cm wide present on the surface
Internal drainage	:	Poorly drained

Ap 0-10 cm Very dark grey (10YR 3/1, moist, 10YR 4/2 dry); silty clay; moderate, medium, subangular blocky structure; hard (dry), firm (moist), sticky and plastic (wet); common fine to medium pores; many fine to medium, few coarse roots; pH 6.9; with diffuse and smooth transition to:

(Sample 198/4-34a)

AC_1g 10-75 Very dark grey (10YR 3/1 moist, 10YR 4/1 dry); common medium prominent olive yellow mottles; clay; moderate, coarse angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); common very fine pores; moderately thick, continuous slickensides; common very fine to medium roots; pH 7.2; gradual and smooth transition to:

(Sample 198/4-34b and c)

AC_2g 75-120 Dark grey (10YR 4/1,moist, 2.5Y 5/3,dry); common, fine prominent olive yellow mottles; clay loam; strong, coarse angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); moderate, continuous slickensides; very few fine pores; very few fine roots; pH 7.3; gradual and smooth transition to:

(Sample 198/4-34d and e)

Cg 120-220 Dark greyish brown (2.5YR 4/2,moist); many fine yellow mottles; sandy clay loam; weak, coarse, angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); common continuous slickensides; very few fine pores; few very fine roots; common medium manganese concretions; pH 7.8 over coarse sand.

Remark: Groundwater table was struck at a depth of 170cm.

ANALYTICAL DATA FOR PROFILE .198/4-34...UNIT..BV/VB.....

Horizon	Ap	ACg	ACg	Cg	
Depth (cm)	0-10	10-75	75-120	120-220	
pH H_2O (1:2.5 v/v)	6.9	7.2	7.3	7.8	
pH KCl (")	5.5	5.8	6.3	6.8	
EC (mmho/cm)	0.30	0.6	1.85	2.30	
% Carbon	2.0	1.26	0.51	0.17	
CEC (me/100g S) pH8.2	36.2	36.0	20.2	13.4	
Exch. Ca (me/100g S)	15.4	19.0	16.5	10.9	
" Mg "	9.5	8.50	6.3	5.1	
" K "	1.39	0.41	0.4	0.34	
" Na "	0.9	0.08	2.0	2.5	
Sum of cations	27.2	28.0	25.2	18.8	
Base saturation (pH 8.2)	75	78	100	100	
ESP at pH 8.2					
TEXTURE					
% Sand (2.0-0.05mm)	14	16	32	48	
% Silt (0.05-0.002mm)	42	38	38	26	
% Clay (<0.002mm)	44	46	30	26	
Textural class	SiC	C	CL	SCL	

FERTILITY ASPECTS (0-30cm)

		AVAILABLE CATIONS (me/100g S)	
pH H_2O	6.4		
% Carbon	2.31	Ca	15.0
Nitrogen %	0.25	Mg	7.0
C/N ratio	9.2	K	0.56
P-Mehlich (ppm)	68	Na	0.88
P-Olson ppm	-	Mn	1.18

Remark: ECe of ACg (pH 7.7, 50% saturation) is 7.0 mmho/cm
ECe of Cg (pH 7.9, 48.8% saturation) is 5.5 mmho/cm

APPENDIX 3. MONTHLY AND ANNUAL DEFICITS FOR COCONUTS AND CASHEWNUTS FOR VARIOUS AVAILABLE MOISTURE STORAGE CAPACITIES IN ZONES III AND IV

APPENDIX 3a. MOISTURE DEFICITS FOR CASHEWNUTS, AMSC 300mm ZONE III

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL
1946	-	-	-	-	0	0	0	0	0	0	0	0	0
1947	124	165	81	0	0	0	0	0	0	0	75	22	467
1948	166	151	117	0	0	0	0	0	0	0	47	10	491
1949	164	165	178	62	0	0	23	38	9	114	91	35	779
1950	133	160	20	0	0	0	0	0	0	57	118	124	612
1951	168	158	107	57	0	0	0	0	0	0	0	0	490
1952	0	42	128	0	0	0	0	0	0	78	0	12	260
1953	104	162	109	0	0	0	0	0	0	0	0	0	375
1954	15	149	167	0	0	0	0	0	60	117	101	41	650
1955	153	69	162	0	0	0	0	0	0	0	73	100	557
1956	50	133	144	96	0	0	0	52	96	119	15	65	770
1957	162	164	33	0	0	0	0	58	0	0	0	0	417
1958	159	163	141	108	0	0	0	0	0	62	30	106	769
1959	132	160	171	0	0	0	0	0	0	0	2	81	546
1960	154	165	40	15	0	0	0	16	118	45	156	144	855
1961	0	0	40	49	57	67	0	0	0	0	0	0	213
1963	0	34	84	0	0	0	0	0	0	2	0	58	178
1964	158	165	118	41	0	96	80	60	118	111	141	10	1098
1965	143	165	161	108	0	0	0	25	29	8	0	0	639
1966	119	161	166	0	0	0	0	0	0	0	0	92	538
1967	169	89	177	0	0	17	51	0	0	0	0	0	503
1968	19	123	81	0	0	0	0	0	0	0	0	0	223
1969	71	97	73	115	19	8	12	29	94	0	0	65	653
1970	156	165	148	39	0	1	13	75	69	139	50	0	855
1971	169	165	178	136	0	0	0	0	0	75	156	115	994
1972	144	151	127	128	0	0	0	0	0	0	0	0	450
1973	0	15	173	30	0	0	0	0	0	0	1	138	357
1974	169	152	175	103	46	9	31	100	98	103	119	144	1249
1975	156	165	178	31	0	0	24	79	83	122	160	144	1142
1976	169	165	178	64	0	17	0	0	0	91	146	86	1162
1977	155	165	170	46	19	31	55	0	65	0	0	0	592
1978	38	110	50	0	0	0	0	0	0	48	7	42	295
1979	19	115	15	100	0	0	0	0	0	0	41	117	407
1980	169	136	166	103	33	80	22	0	0	89	0	105	1006

APPENDIX 3a. MOISTURE DEFICITS; AMSC 218mm; ZONE III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	-	0	0	0	0	0	0	0	64	64
1947	139	165	81	0	0	0	0	0	0	41	116	22	564
1948	166	151	117	0	0	0	0	0	0	0	55	10	499
1949	164	165	178	62	0	0	23	38	9	114	91	35	779
1950	133	160	20	0	0	0	0	0	0	57	118	124	612
1951	168	158	107	57	0	0	0	0	49	0	0	0	539
1952	18	106	128	0	0	0	0	0	0	78	0	12	342
1953	104	162	109	0	0	0	0	0	0	0	0	0	375
1954	97	149	167	0	0	0	0	0	60	117	101	41	732
1955	153	69	162	0	0	0	0	0	0	43	112	100	639
1956	50	133	144	96	0	0	0	52	96	119	15	65	770
1957	162	164	33	0	0	0	0	0	58	0	0	0	417
1958	159	163	141	108	0	0	0	0	0	136	30	106	843
1959	132	160	171	0	0	0	0	0	0	0	122	81	666
1960	154	165	40	15	0	0	0	16	118	45	158	144	855
1961	0	0	40	49	57	67	0	0	0	0	0	0	213
1963	0	116	84	0	0	0	0	0	0	2	0	58	260
1964	158	165	118	41	0	96	80	60	118	111	141	10	1098
1965	143	165	161	108	0	0	0	25	29	8	0	0	639
1966	119	161	166	0	0	0	0	0	0	0	62	120	628
1967	169	89	177	0	0	17	51	0	0	0	0	0	503
1968	101	123	81	0	0	0	0	0	0	0	0	12	317
1969	141	97	73	115	19	8	12	29	94	0	0	65	653
1970	156	165	148	39	0	1	13	75	69	139	50	0	855
1971	161	165	178	136	0	0	0	0	0	107	156	115	1026
1972	144	151	127	128	0	0	0	0	0	0	0	0	450
1973	0	15	173	30	0	0	0	0	0	18	65	138	439
1974	169	152	175	103	46	9	31	100	98	103	119	144	1299
1975	156	165	178	31	0	0	24	79	83	122	160	144	1142
1976	169	165	178	64	0	17	0	0	0	91	146	86	1162
1977	155	165	170	46	19	31	55	0	65	0	0	0	592
1978	38	110	50	0	0	0	0	0	31	81	7	42	359
1979	19	115	15	100	0	0	0	0	0	25	119	117	510
1980	169	136	166	103	33	80	22	0	0	89	0	105	1006

APPENDIX 3a. MOISTURE DEFICITS FOR CASHEW· AWHC 150mm: ZONE III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	0	0	0	0	0	0	0	28	110	138
1947	139	165	81	0	0	0	0	0	0	109	116	22	632
1948	166	151	119	0	0	0	0	0	0	39	84	10	569
1949	164	165	178	62	0	50	35	38	9	114	91	45	951
1950	133	160	20	0	0	0	0	0	0	96	118	124	611
1951	168	158	107	57	0	0	0	0	117	0	0	0	607
1952	86	106	128	0	0	0	0	0	18	92	78	90	606
1953	104	162	109	0	0	0	0	0	0	0	0	0	375
1954	165	149	167	0	0	0	0	0	44	117	101	41	788
1955	153	69	162	0	0	0	0	9	121	81	112	100	807
1956	50	133	144	96	0	0	0	52	96	119	15	65	770
1957	162	164	33	0	0	0	0	0	58	0	0	0	417
1958	159	162	141	108	0	0	0	0	53	151	30	106	910
1959	130	160	171	0	0	0	0	0	0	60	129	82	732
1960	154	165	140	15	0	0	0	16	118	45	158	144	955
1961	154	86	169	49	57	67	0	0	0	0	0	0	582
1963	19	165	84	0	0	0	0	0	0	44	0	58	378
1964	158	165	118	41	0	96	80	60	118	111	141	10	1098
1965	143	165	161	108	0	0	0	25	29	8	0	1	639
1966	119	161	166	0	0	0	0	0	62	0	68	120	696
1967	169	89	177	0	0	17	51	0	0	0	0	0	503
1968	169	123	81	0	0	0	0	0	10	31	0	39	453
1969	141	97	73	115	19	8	12	29	94	0	0	59	647
1970	156	165	148	39	0	1	13	75	69	139	60	0	865
1971	169	165	178	136	0	0	0	0	25	154	156	115	1098
1973	144	151	127	128	0	0	0	0	0	0	0	0	550
1974	0	25	173	30	0	0	0	0	45	41	65	138	525
1975	156	165	178	31	0	0	24	79	83	122	160	144	1142
1976	169	165	147	64	0	17	0	0	0	91	146	86	885
1977	155	165	170	46	19	31	55	0	65	0	0	0	706
1978	94	110	50	0	0	0	0	0	99	81	0	35	477
1979	19	115	15	100	0	0	0	0	0	93	119	117	578
1980	169	136	166	133	33	90	22	0	0	90	0	105	944

APPENDIX 3a. MOISTURE DEFICITS FOR CASHEW: AMSC 100mm: ZONE III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	-	0	0	0	0	0	0	78	110	188
1947	139	165	81	0	0	0	0	0	0	39	116	22	562
1948	166	151	119	0	0	0	0	0	16	60	84	10	606
1949	164	165	178	62	0	50	35	38	9	114	91	45	951
1950	133	160	20	0	0	0	0	0	0	117	118	124	672
1951	168	158	107	57	0	0	0	39	128	0	0	0	657
1952	136	106	128	0	0	0	32	41	59	92	78	90	762
1953	104	162	109	0	0	10	0	0	0	0	0	46	431
1954	169	149	167	0	0	0	30	22	87	117	101	41	883
1955	153	69	162	0	0	0	0	59	121	81	112	100	857
1956	50	133	144	96	0	0	0	69	96	119	15	65	787
1957	162	164	33	0	0	0	0	19	81	0	0	0	459
1958	159	162	141	108	0	0	0	23	100	151	30	106	980
1959	130	160	171	0	0	0	0	0	0	110	129	82	782
1960	154	165	140	15	0	0	0	26	118	45	158	144	956
1961	154	86	169	49	57	67	0	0	0	0	0	0	582
1963	69	165	84	0	0	0	0	0	10	84	0	58	470
1964	158	165	118	41	0	96	80	60	118	111	141	10	1098
1965	143	165	161	108	0	0	0	25	29	8	0	22	661
1966	119	161	166	0	0	0	0	0	112	0	68	120	746
1967	169	89	177	0	0	17	51	0	0	0	0	50	553
1968	169	123	81	0	0	0	0	0	60	31	0	39	503
1969	141	97	73	115	19	8	12	29	94	0	0	59	647
1970	156	165	148	39	0	1	13	75	69	139	60	0	865
1971	169	165	178	136	0	0	0	0	75	154	156	115	1148
1972	144	151	127	128	0	6	1	16	0	0	0	0	573
1973	0	52	173	30	0	0	0	0	95	41	65	138	594
1974	169	152	175	103	46	9	31	100	98	103	119	144	1249
1975	156	165	178	31	0	0	24	79	83	122	160	144	1142
1976	169	165	147	64	0	17	0	0	0	119	146	86	748
1977	155	165	170	46	19	31	55	0	65	0	0	0	706
1978	144	110	50	0	0	0	0	32	117	81	0	35	569
1979	19	115	15	100	0	.0	0	0	43	100	119	117	528
1980	169	136	166	133	33	90	22	0	5	127	0	105	985

APPENDIX 3a. MOISTURE DEFICITS FOR CASHEW: AMSC 50mm; ZONE III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	0	12	35	0	0	0	0	128	110	285
1947	139	165	81	0	0	21	21	0	47	120	116	22	732
1948	166	151	119	0	0	0	0	0	79	60	84	10	669
1949	164	165	178	62	0	50	35	38	9	114	91	45	951
1950	133	160	20	0	0	22	0	19	22	135	118	124	731
1951	168	158	107	57	0	24	0	65	128	0	7	42	756
1952	94	106	128	0	0	0	0	18	41	59	92	90	629
1953	104	162	109	0	0	60	0	0	0	0	0	96	531
1954	169	149	167	0	0	10	51	22	87	117	101	41	1001
1955	153	69	162	0	0	0	20	89	121	81	112	100	907
1956	50	133	144	96	0	0	46	73	96	[illegible]	15	65	837
1957	162	164	33	0	0	7	1	62	61	0	0	0	510
1958	159	[illegible]	141	108	0	0	0	53	100	151	30	106	1010
1959	130	160	171	0	0	0	0	0	40	120	129	82	832
1960	154	165	140	15	0	0	14	62	118	45	158	144	1015
1961	154	86	169	49	57	67	0	0	0	0	0	0	582
1963	119	165	84	0	0	0	0	0	60	84	0	58	570
1964	158	165	118	41	0	96	80	60	118	111	141	10	1098
1965	143	165	161	108	0	0	0	46	29	8	0	72	735
1966	119	161	166	0	0	0	0	23	139	0	68	120	796
1967	169	89	177	0	0	27	51	0	0	0	0	150	663
1968	169	123	81	0	0	0	0	0	110	31	0	75	589
1969	141	97	73	115	19	8	12	29	94	0	0	95	683
1970	156	165	148	39	0	16	13	75	69	139	60	0	880
1971	169	165	178	136	0	0	0	25	100	154	156	115	1376
1972	144	151	127	128	0	66	1	16	0	0	0	0	633
1973	0	100	173	30	0	0	41	0	108	41	65	138	696
1974	169	152	175	103	46	9	31	100	98	103	119	144	1249
1975	156	165	178	31	0	35	38	79	83	122	160	144	1190
1976	169	165	147	64	0	39	0	46	0	122	146	86	984
1977	155	165	170	46	19	31	55	0	65	0	0	38	744
1978	152	110	50	0	0	0	14	68	117	81	0	35	627
1979	19	115	15	100	0	0	0	42	51	100	119	117	678
1980	169	136	166	133	33	90	22	0	55	127	0	105	1036

APPENDIX 3b. MOISTURE DEFICITS FOR CASHEW: AMSC 295mm: ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	0	0	0	0	0	0	72	72
1951	171	153	163	42	0	0	0	0	0	0	0	81	610
1952	166	166	163	120	0	0	77	78	122	137	20	139	1188
1953	164	166	139	56	0	0	0	0	0	0	0	0	525
1954	11	154	168	0	0	0	16	93	95	129	66	98	830
1955	146	67	168	20	0	0	0	0	60	137	96	113	807
1956	114	163	118	52	0	0	0	0	0	21	89	143	700
1957	156	166	131	90	0	0	0	0	2	136	3	11	695
1958	171	166	0	37	0	0	0	0	0	87	158	89	708
1959	100	160	109	0	0	0	0	0	0	0	0	35	404
1962	94	156	169	73	37	77	63	52	85	123	125	64	1118
1963	157	166	42	0	0	0	0	0	75	41	8	102	591
1964	67	128	158	43	0	37	90	69	95	69	154	36	946
1965	63	166	170	96	0	0	47	61	37	11	23	156	830
1966	99	166	133	0	0	0	0	0	0	0	49	145	592
1967	171	95	177	0	0	0	20	0	0	0	0	0	463
1968	36	132	34	0	0	0	0	0	0	0	0	154	336
1969	171	92	160	146	91	81	107	32	141	48	0	101	1170
1970	123	166	160	135	14	85	51	71	113	132	142	103	1295
1971	169	166	172	69	0	0	0	87	121	158	148	85	1175
1973	158	77	178	0	0	0	0	0	0	41	145	132	731
1974	142	154	162	120	18	4	16	99	117	147	65	138	1182
1975	140	164	177	43	0	0	9	102	90	102	159	0	986
1976	136	152	116	73	0	0	0	56	28	111	118	143	933
1977	132	162	142	20	31	60	85	17	67	0	0	0	716
1978	109	120	113	0	0	57	67	94	125	113	0	94	840
1979	136	142	78	49	0	0	0	0	0	84	124	47	660

APPENDIX 3h. MOISTURE DEFICITS FOR CASHEWNUTS· AMSC 200mm: ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	0	0	0	0	0	0	0	0	71	71
1951	171	153	163	42	0	0	0	0	69	0	0	81	679
1952	166	166	163	120	0	0	77	78	122	137	20	139	1188
1953	164	166	139	56	0	0	0	0	0	0	0	65	590
1954	171	154	168	0	0	0	16	93	95	129	66	98	830
1955	146	67	168	20	0	0	0	0	90	137	96	113	837
1956	114	163	118	52	0	0	0	0	0	110	89	143	789
1957	156	166	131	90	0	0	0	0	2	136	3	11	695
1958	171	166	0	37	0	0	0	0	0	111	158	89	732
1959	100	160	109	0	0	0	0	0	0	0	57	73	499
1960	94	156	169	73	37	77	63	52	85	123	125	64	1118
1963	157	166	42	0	0	0	0	0	75	41	8	102	591
1964	67	128	158	43	0	37	90	69	95	69	154	36	946
1965	63	106	170	96	0	0	47	61	37	11	23	156	830
1966	99	166	133	0	0	0	0	0	6	0	64	145	607
1967	171	95	177	0	0	0	20	0	0	0	0	0	463
1968	131	132	34	0	0	0	0	0	0	21	68	160	546
1969	172	92	160	146	91	81	107	32	141	48	0	101	1170
1970	123	166	160	135	14	85	51	71	113	132	142	103	1295
1971	169	166	172	69	0	0	0	87	121	158	148	85	1175
1973	158	77	178	0	0	0	0	0	0	64	145	132	754
1974	142	154	162	120	18	4	16	99	117	147	65	138	1182
1975	140	164	177	43	0	0	9	102	90	102	159	0	986
1976	136	152	116	73	0	0	0	56	28	111	118	143	933
1977	132	162	142	20	31	60	85	17	67	0	0	0	716
1978	127	120	113	0	0	57	67	94	125	113	0	94	822
1979	136	142	78	49	0	0	0	0	74	103	124	47	753

APPENDIX 3b. MOISTURE DEFICITS FOR CASHEWNUTS· AWSC 13[illegible]. ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	0	0	0	0	96	0	100	196
1951	171	153	163	42	0	0	0	8	123	0	0	107	767
1952	166	166	163	120	0	0	77	78	122	137	20	139	1188
1953	164	166	139	56	0	0	0	0	0	0	0	0	525
1954	168	154	168	0	0	0	18	93	95	129	66	98	976
1955	146	67	168	20	0	0	0	18	134	137	96	113	899
1956	114	163	118	52	0	0	0	27	22	123	89	143	851
1957	156	166	130	90	0	0	0	0	13	136	1	11	706
1958	171	166	0	37	0	0	0	0	37	136	158	89	794
1959	100	160	109	0	0	0	0	0	0	41	78	73	561
1962	94	156	169	73	37	77	63	52	85	123	125	64	1118
1963	157	166	42	0	0	0	0	0	76	41	8	102	592
1964	67	128	158	43	0	37	90	69	95	69	154	36	946
1965	63	166	170	96	0	0	47	61	37	11	23	156	830
1966	99	166	133	0	0	0	0	0	68	0	64	145	675
1967	171	95	177	0	0	0	20	0	0	0	0	22	485
1968	171	132	34	0	0	0	0	0	3	80	68	160	648
1969	171	92	160	146	91	81	107	32	141	48	0	101	1170
1970	123	166	160	135	14	85	51	71	113	132	142	103	1295
1971	169	166	172	69	0	0	0	87	121	158	148	85	1175
1973	158	77	178	0	0	0	0	0	29	97	145	132	816
1974	142	154	162	120	18	4	16	99	117	147	65	138	1182
1975	140	164	177	43	0	0	9	102	90	102	159	0	986
1976	136	152	116	73	0	0	0	56	28	111	118	143	937
1977	132	162	142	20	31	60	85	17	67	0	0	51	767
1978	138	120	113	0	0	5	67	94	125	113	0	94	869
1979	136	142	78	49	0	0	5	54	77	103	124	47	815

APPENDIX 3b. MOISTURE DEFICITS FOR CASHEWNUTS; AMSC 100mm: ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	0	0	0	0	98	0	100	198
1951	171	153	163	42	0	0	0	46	123	0	0	107	805
1952	166	166	163	120	0	0	77	78	122	137	20	139	1188
1953	164	166	139	56	0	14	0	0	0	0	0	35	574
1954	168	154	168	0	0	0	23	91	95	129	66	98	978
1955	146	67	168	20	0	0	0	56	134	137	96	113	937
1956	114	163	118	52	0	0	0	65	22	123	89	143	889
1957	156	166	131	90	0	0	0	21	30	136	3	11	744
1958	171	166	0	37	0	0	0	0	75	136	158	89	932
1959	100	160	109	0	0	0	0	0	0	79	78	73	599
1962	94	156	169	73	37	77	63	52	85	123	125	64	1118
1963	157	166	42	0	0	0	0	0	88	41	8	102	604
1964	67	128	158	43	0	37	90	69	95	69	154	36	946
1965	63	166	170	96	0	0	47	61	37	11	23	156	830
1966	99	166	133	0	0	0	0	0	106	0	64	145	713
1967	171	95	177	0	0	0	20	0	0	0	0	60	523
1968	171	132	34	0	0	0	0	0	41	80	68	160	686
1969	171	92	160	146	91	81	107	32	141	48	0	101	1170
1970	123	166	160	135	14	85	51	71	113	132	142	103	1295
1971	169	166	172	69	0	0	0	87	121	158	148	85	1175
1973	158	77	178	0	0	0	0	0	67	97	145	132	854
1974	142	154	162	120	18	4	16	99	117	147	65	138	1182
1975	140	164	177	43	0	0	9	102	90	102	159	0	986
1976	136	152	116	73	0	0	0	56	28	111	118	143	937
1977	132	162	142	20	31	60	85	17	67	0	0	89	805
1978	138	120	113	0	0	5	67	94	125	113	0	94	869
1979	136	142	78	49	0	0	43	54	77	103	124	47	853

APPENDIX 3b. MOISTURE DEFICITS FOR CASHEWNUTS: AMSC 50mm: ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	39	0	0	0	148	0	100	287
1951	171	153	163	42	0	17	29	50	123	0	0	109	857
1952	166	166	163	120	0	0	77	78	122	137	20	139	1188
1953	164	166	56	0	64	0	0	0	0	0	0	85	535
1954	168	154	168	0	0	3	70	93	95	129	66	98	1041
1955	146	67	168	20	0	0	11	95	134	137	96	113	987
1956	114	163	118	52	0	0	27	27	88	123	89	143	944
1957	156	166	131	90	0	33	53	51	30	136	3	11	706
1958	171	166	0	37	0	0	2	41	92	136	158	89	892
1959	100	160	109	0	0	0	0	0	36	93	78	73	649
1962	94	156	169	73	37	77	63	52	85	123	125	64	1118
1963	157	166	42	0	0	0	6	41	91	41	8	102	648
1964	67	128	158	43	0	37	90	69	95	69	154	36	946
1965	63	166	170	96	0	0	47	61	37	11	23	156	830
1966	99	166	133	0	0	0	35	121	0	0	64	145	763
1967	171	95	177	0	0	0	62	0	0	0	0	110	615
1968	171	132	34	0	0	0	0	0	91	80	68	160	736
1969	171	92	160	146	91	81	107	32	141	48	0	101	1170
1970	123	166	160	135	14	85	51	71	113	132	142	103	1295
1971	169	166	172	69	0	0	0	87	121	158	148	85	1175
1973	158	77	178	0	0	0	42	0	77	97	145	132	906
1974	142	154	162	120	18	4	16	99	117	147	65	138	1182
1975	140	164	177	43	0	0	14	102	90	102	159	0	991
1976	136	152	116	73	0	0	0	85	28	111	118	143	962
1977	132	162	142	20	31	60	85	17	67	0	1	138	768
1978	138	120	113	0	0	5	67	94	125	113	0	94	869
1979	136	142	78	49	0	25	68	54	77	103	124	47	903

APPENDIX 3c. MOISTURE DEFICITS FOR COCONUTS; AMSC 200 ZONE III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	-	0	0	0	0	0	0	21	129	150
1947	161	194	103	0	0	0	0	0	0	138	136	42	774
1948	188	180	141	0	0	0	0	0	0	72	104	30	715
1949	186	194	200	80	9	67	49	52	27	133	111	65	1173
1950	155	189	42	0	0	0	0	0	14	152	138	144	843
1951	190	187	129	75	0	0	0	0	127	0	0	0	708
1952	98	135	150	0	0	0	0	0	76	111	98	110	776
1953	126	191	131	0	0	0	0	0	0	0	0	0	448
1954	177	178	189	0	0	0	0	24	103	136	121	61	892
1955	175	98	184	0	0	0	0	0	134	100	132	120	943
1956	72	162	166	114	0	0	19	87	114	138	35	85	992
1957	184	193	55	0	0	0	0	48	99	0	30	19	628
1958	191	191	163	126	0	0	0	0	49	170	50	126	1066
1959	154	189	193	0	0	0	0	0	0	45	149	101	831
1960	176	194	162	33	0	0	0	70	136	64	178	164	1177
1961	153	115	191	67	59	81	0	0	0	0	0	0	666
1963	0	189	106	0	0	0	0	0	8	103	5	93	504
1964	180	194	140	59	8	114	94	74	136	130	161	30	1320
1965	165	194	183	126	0	0	37	83	47	27	0	39	860
1966	142	190	188	0	0	0	0	0	58	0	107	140	825
1967	191	118	199	0	13	48	65	0	0	0	0	0	624
1968	161	152	103	0	0	0	0	0	0	42	0	79	537
1969	163	126	95	133	31	22	26	43	112	9	0	109	869
1970	178	194	170	57	0	27	27	89	87	158	79	20	1086
1971	191	194	200	154	0	0	0	0	7	173	176	135	1230
1972	166	180	149	146	0	0	0	17	0	0	0	0	658
1973	31	146	195	48	0	0	0	0	41	60	85	158	764
1974	191	181	197	121	58	23	45	114	116	122	139	164	1471
1975	178	194	200	49	0	20	52	93	101	141	180	164	1372
1976	191	194	169	182	0	43	0	0	0	156	166	106	1207
1977	177	194	192	64	41	45	69	5	92	0	0	0	879
1978	174	139	72	0	0	0	0	0	109	100	13	62	669

APPENDIX 3c. MOISTURE DEFICITS FOR COCONUTS; AMSC 150 ZONF III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	-	0	0	0	0	0	0	67	129	196
1947	161	194	103	0	0	0	0	0	49	139	136	42	824
1948	188	180	141	0	0	0	0	0	39	79	104	30	761
1949	186	194	200	80	9	67	49	52	27	133	111	65	1173
1950	155	189	42	0	0	0	0	0	23	152	138	144	843
1951	190	187	127	75	0	0	0	31	146	0	0	0	756
1952	148	135	150	0	0	0	0	1	77	111	98	110	830
1953	126	191	131	0	0	0	0	0	0	0	0	36	486
1954	80	178	189	0	0	0	0	24	103	136	121	61	892
1955	175	98	184	0	0	0	0	45	139	100	132	120	993
1956	72	162	166	114	0	0	19	87	114	138	35	85	992
1957	184	193	55	0	0	0	0	48	99	0	30	19	628
1958	191	191	163	126	0	0	0	<0	99	170	50	126	1116
1959	154	189	193	0	0	0	0	0	0	132	149	101	918
1960	176	194	162	33	0	0	0	70	136	64	178	164	1177
1961	153	115	191	67	59	81	0	0	0	0	0	0	666
1963	45	194	106	0	0	0	0	0	7	103	5	93	553
1964	180	194	140	59	8	114	94	74	136	130	161	30	1320
1965	165	194	183	126	0	0	37	83	47	27	0	39	860
1966	142	190	188	0	0	0	0	0	108	0	107	140	875
1967	191	118	199	0	13	48	65	0	0	0	0	20	654
1968	191	152	103	0	0	0	0	0	42	50	0	79	617
1969	163	126	95	133	31	22	26	43	112	9	0	109	869
1970	178	194	170	57	0	27	27	89	87	158	79	20	1086
1971	191	194	200	154	0	0	0	0	67	173	176	135	1290
1972	166	180	149	146	0	0	0	17	0	0	0	0	658
1973	55	146	195	48	0	0	0	0	91	60	85	158	838
1974	191	181	197	121	58	23	45	114	116	122	139	164	1471
1975	178	194	200	49	0	20	52	93	101	141	180	164	1372
1976	191	194	169	182	0	43	0	0	0	156	166	106	1207
1977	177	194	192	64	41	45	69	5	92	0	0	0	879
1978	156	139	72	0	0	0	0	24	135	100	13	62	701
1979	41	144	37	118	0	0	0	0	53	119	139	137	788

APPENDIX 3c. MOISTURE DEFICITS FOR COCONUTS; AMSC 100mm; ZONE III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	-	0	0	25	0	0	0	117	129	271
1947	161	194	103	0	0	0	20	5	74	139	136	42	874
1948	188	180	141	0	0	0	0	0	82	79	104	30	804
1949	186	194	200	80	9	67	49	52	27	133	111	65	1173
1950	155	189	42	0	0	0	0	33	40	152	138	144	893
1951	190	187	129	75	0	0	0	81	146	0	0	39	847
1952	159	135	150	0	0	0	0	51	77	111	98	110	891
1953	126	191	131	0	0	24	0	0	0	0	0	86	558
1954	80	178	189	0	0	0	13	36	105	136	121	61	919
1955	175	98	194	0	0	0	0	95	139	100	132	120	1043
1956	72	162	166	114	0	0	24	87	114	138	35	85	925
1957	184	193	55	0	0	0	0	61	99	0	30	19	641
1958	191	191	163	126	0	0	0	31	118	170	50	126	1166
1959	154	189	193	0	0	0	0	0	43	139	149	101	968
1960	176	194	162	33	0	0	0	70	136	64	178	164	1177
1961	153	115	191	67	159	81	0	0	0	0	0	0	666
1963	95	194	106	0	0	0	0	0	56	103	5	93	652
1964	180	194	140	59	8	114	94	74	136	130	161	30	1320
1965	165	194	183	126	0	0	0	80	47	27	0	42	864
1966	142	190	188	0	0	0	0	1	157	0	105	140	923
1967	191	118	199	0	13	48	65	0	0	0	0	70	704
1968	191	152	103	0	0	0	0	92	0	50	0	79	667
1969	163	126	95	133	31	22	26	43	112	9	0	109	869
1970	178	194	170	57	0	27	27	89	87	158	79	20	1086
1971	191	194	200	154	0	0	0	0	90	173	176	135	1313
1972	166	180	149	146	0	20	15	30	0	0	0	0	706
1973	55	146	195	48	0	0	1	0	140	60	85	158	888
1974	191	181	197	121	58	23	45	114	116	122	139	164	1471
1975	178	194	200	49	0	20	52	93	101	141	180	164	1372
1976	191	194	169	182	0	43	0	10	2	157	166	106	1220
1977	177	194	192	64	41	45	69	5	92	0	0	32	911
1978	174	139	72	0	0	0	0	74	135	100	13	116	823
1979	41	144	37	118	0	0	0	24	69	119	139	137	828

APPENDIX 3c. MOISTURE DEFICITS FOR COCONUT AMSC 50mm: ZONE III

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1946	-	-	-	-	0	26	49	0	0	0	167	129	371
1947	161	194	103	0	0	35	35	5	74	139	136	42	924
1948	188	180	141	0	0	0	0	32	107	79	104	30	963
1949	186	194	200	80	9	67	49	52	27	133	111	65	1173
1950	155	189	42	0	0	36	0	47	40	152	138	144	943
1951	190	187	129	75	0	38	5	88	146	0	27	62	947
1952	159	135	150	0	0	0	46	55	77	111	98	110	941
1953	126	191	131	0	0	74	0	0	0	0	0	136	658
1954	80	178	189	0	0	0	63	36	105	136	121	61	969
1955	175	98	184	0	0	0	42	103	139	100	132	120	1093
1956	72	162	166	114	0	0	74	87	114	138	35	93	1055
1957	184	193	55	0	0	20	15	76	99	0	30	19	691
1958	191	191	163	126	0	0	4	77	118	170	50	126	1216
1959	154	189	193	0	0	0	0	22	71	139	149	101	1018
1960	176	194	162	33	0	0	42	76	136	64	178	164	1225
1961	153	115	191	67	59	81	0	8	0	0	0	0	674
1963	145	194	106	0	0	0	0	3	103	103	5	93	752
1964	180	194	14C	59	8	114	94	74	136	130	161	30	1320
1965	165	194	183	126	0	0	0	80	47	27	0	92	914
1966	142	190	188	0	0	0	0	51	157	0	107	140	975
1967	191	118	199	0	13	48	65	0	0	0	0	120	754
1968	191	152	103	0	0	0	0	0	142	50	0	95	733
1969	163	126	95	133	31	22	26	43	112	9	0	115	875
1970	178	194	170	57	0	31	27	89	87	158	79	20	1089
1971	191	194	200	154	0	0	0	49	118	173	176	135	1390
1972	166	180	149	146	0	70	15	30	0	0	0	0	756
1973	44	146	195	48	0	0	51	0	140	60	85	158	927
1974	191	181	197	121	58	23	45	114	116	122	139	164	1471
1975	178	194	200	49	0	57	52	93	101	141	180	164	1409
1976	191	194	169	182	0	53	0	60	2	157	166	106	1280
1977	177	194	192	64	¯41	45	69	5	92	0	0*	82	961
1978	174	139	72	0	0	0	42	82	135	100	13	62	819
1979	41	144	37	118	0	0	18	66	69	119	139	137	888

APPENDIX 3d. MOISTURE DEFICITS FOR COCONUTS; AMSC 195mm; ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	0	0	0	0	85	9	132	226
1951	193	174	186	51	0	0	0	0	35	0	59	90	788
1952	188	187	186	139	0	21	98	93	139	157	41	159	1437
1953	186	187	162	75	0	0	0	0	0	0	0	0	610
1954	53	175	191	5	0	0	72	108	112	149	87	118	1070
1955	168	88	191	39	0	0	0	0	134	157	117	133	1027
1956	133	184	141	71	0	0	0	0	0	115	110	163	917
1957	178	187	154	109	0	0	0	29	47	56	24	30	814
1958	193	187	0	79	0	0	0	0	25	156	179	109	928
1959	122	181	132	0	0	0	0	0	0	0	20	93	575
1962	116	117	192	92	50	92	77	67	102	143	146	84	1338
1963	179	187	65	0	0	0	4	56	108	61	29	122	811
1964	89	149	181	62	0	65	104	84	112	89	175	56	1166
1965	85	187	193	115	0	0	89	76	54	31	44	176	1050
1966	121	187	156	0	0	0	0	0	78	14	91	165	812
1967	193	116	200	1	0	0	80	0	0	0	0	0	590
1968	78	153	57	0	0	0	0	0	0	0	52	180	520
1969	193	113	183	165	104	96	121	47	158	68	8	134	1390
1970	145	187	183	154	27	100	65	86	130	152	163	123	1515
1971	191	187	195	88	0	0	36	108	138	178	169	105	1395
1973	180	98	201	0	0	0	0	0	137	117	116	152	1051
1974	164	175	185	139	31	19	30	114	134	167	86	158	1402
1975	162	185	200	62	0	9	42	117	107	122	180	16	1202
1976	162	173	139	92	0	0	0	113	45	131	139	163	1137
1977	154	183	165	39	44	75	99	32	84	0	0	32	907
1978	158	163	101	68	0	0	0	0	55	123	145	67	880

APPENDIX 3d. MOISTURE DEFICITS FOR COCONUTS; AMSC 200; ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	0	0	0	0	115	9	132	256
1951	193	174	186	51	0	0	0	0	130	0	59	90	883
1952	188	187	186	139	0	21	98	93	139	157	41	159	1437
1953	186	187	162	75	0	0	0	0	0	0	0	0	610
1954	148	175	191	5	0	0	72	108	112	149	87	118	1070
1955	168	88	191	39	0	0	0	0	136	157	117	133	1029
1956	133	184	141	71	0	0	0	0	0	119	110	163	1021
1957	178	187	154	109	0	0	0	29	47	56	24	30	814
1958	193	187	0	79	0	0	0	0	25	156	179	109	928
1959	122	181	132	0	0	0	0	0	0	16	99	93	643
1962	116	177	192	92	50	92	77	67	102	143	146	84	1338
1963	179	187	65	0	0	0	4	56	108	61	29	122	811
1964	89	149	181	62	0	65	104	84	112	89	175	56	1166
1965	85	187	193	115	0	0	89	76	54	31	44	176	1050
1966	121	187	156	0	0	0	0	0	78	14	91	165	812
1967	193	116	200	1	0	0	80	0	0	0	0	0	590
1968	173	153	57	0	0	0	0	0	0	58	89	180	710
1969	193	113	183	165	104	96	121	47	158	68	8	34	1390
1970	145	187	183	154	27	100	65	86	130	152	163	123	1515
1971	191	187	195	88	0	0	36	108	138	178	169	105	1395
1973	180	98	201	0	0	0	0	0	137	117	166	152	1051
1974	164	175	185	139	31	19	30	114	134	167	86	158	1402
1975	162	185	200	62	0	9	42	117	107	122	180	16	1202
1976	162	173	139	92	0	0	0	113	45	131	139	163	1157
1977	154	183	165	39	44	.75	99	32	84	0	0	32	907
1979	158	163	101	68	0	0	0	41	94	123	145	67	960

APPENDIX 3d. MOISTURE DEFICITS FOR COCONUT· AMSC 150mm; ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	0	0	0	0	0	0	165	9	132	306
1951	193	174	186	61	0	0	0	40	140	0	59	90	943
1952	188	187	186	139	0	21	98	93	139	157	41	159	1408
1953	186	187	162	75	0	0	0	0	0	0	0	5	615
1954	193	175	191	5	0	0	72	108	112	149	87	118	1210
1955	168	88	191	39	0	0	0	35	151	157	117	133	1079
1956	136	184	141	71	0	0	0	44	39	143	110	163	1031
1957	178	187	154	109	0	0	0	29	47	156	24	30	914
1958	193	187	0	79	0	0	0	0	71	156	179	109	972
1959	122	181	132	0	0	0	0	0	0	64	99	93	691
1962	166	177	192	92	50	92	77	67	102	143	146	84	1338
1963	179	187	65	0	0	0	4	56	108	61	29	122	811
1964	89	149	181	62	0	65	104	84	112	89	175	56	1166
1965	85	187	193	115	0	0	89	76	54	31	44	176	1050
1966	121	187	156	0	0	0	0	102	102	14	91	165	836
1967	193	116	200	1	0	0	80	0	0	0	0	32	622
1968	191	153	57	0	0	0	0	0	8	100	89	180	772
1969	193	113	183	165	104	96	121	47	158	68	8	134	1390
1970	145	187	183	154	27	100	65	86	130	152	163	123	1515
1971	191	187	195	88	0	0	36	108	138	178	169	105	1390
1973	180	98	201	0	0	0	0	19	144	117	166	152	1077
1974	164	175	185	139	31	19	30	114	134	167	86	158	1402
1975	162	185	200	62	0	9	42	117	107	122	180	16	1202
1976	162	173	139	92	0	0	0	113	45	131	139	163	1157
1977	154	183	165	39	44	75	99	32	84	0	0	80	955
1978	·160	141	136	0	10	42	81	109	142	133	8	127	1089
1979	158	163	101	68	0	0	22	69	94	123	145	67	1010

APPENDIX 3d. MOISTURE DEFICITS FOR COCONUTS; AMSC 100mm; ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	4	0	0	35	176	9	132	356
1951	193	174	186	51	0	0	25	65	140	0	59	90	983
1952	188	187	186	139	0	21	98	93	139	157	41	159	1408
1953	186	187	162	75	0	29	0	0	0	0	0	55	665
1954	193	175	191	5	0	0	72	108	112	149	87	118	1210
1955	168	88	191	39	0	0	0	85	151	157	117	133	1129
1956	133	184	141	71	0	0	0	91	39	143	110	163	1075
1957	178	187	154	109	0	68	67	66	47	56	24	30	986
1958	193	187	0	79	0	0	0	41	109	156	179	109	1053
1959	122	181	132	0	0	0	0	0	3	113	99	93	743
1962	116	177	192	92	50	92	77	67	102	143	146	84	1338
1963	179	187	65	0	0	0	4	56	108	61	29	122	811
1964	89	149	181	62	0	65	104	84	112	89	175	56	1166
1965	85	187	193	115	0	0	89	76	54	31	44	176	1050
1966	121	187	156	0	0	0	0	14	138	14	91	165	886
1967	193	116	200	1	0	0	80	0	0	0	0	80	670
1968	191	153	57	0	0	0	0	0	58	100	89	180	825
1969	193	113	183	165	104	96	121	47	158	68	8	134	1390
1970	145	187	183	154	27	100	65	86	130	152	163	123	1515
1971	191	187	195	88	0	0	36	108	138	178	169	105	1395
1973	180	98	201	0	0	0	6	63	114	117	166	152	1097
1974	164	175	185	139	31	19	30	114	134	167	86	158	1402
1975	162	185	200	62	0	9	42	117	107	122	180	16	1202
1976	162	173	139	92	0	0	0	113	45	131	139	163	1157
1977	154	183	165	39	44	75	99	32	84	0	0	130	1005
1978	158	163	101	68	0	0	72	69	94	123	145	67	1060

APPENDIX 3d. MOISTURE DEFICITS FOR COCONUT; AMSC 50mm; ZONE IV

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1950	-	-	-	-	0	54	0	28	46	176	9	132	445
1951	193	174	186	61	0	32	43	65	140	0	41	90	1025
1952	188	187	186	139	0	21	98	93	139	157	41	159	1408
1953	186	187	162	75	0	79	0	0	0	0	0	105	794
1954	193	175	191	5	0	18	84	108	112	149	87	118	1240
1955	168	88	191	39	0	0	0	106	151	157	117	133	1150
1956	136	184	141	71	0	0	41	103	39	143	110	163	1131
1957	178	187	154	109	0	0	49	66	47	156	24	30	1000
1958	193	187	0	79	0	0	6	56	109	156	179	109	1074
1959	122	181	132	0	0	0	0	0	53	113	99	93	793
1962	116	177	192	92	50	92	77	67	102	143	146	84	1338
1963	179	187	65	0	0	0	34	56	108	61	29	122	841
1964	89	149	181	62	0	65	104	84	112	89	175	56	1166
1965	85	187	193	115	0	0	89	76	54	31	44	176	1050
1966	121	187	156	0	0	0	21	51	138	14	91	165	944
1967	193	116	200	1	0	11	80	0	0	0	0	130	731
1968	193	153	57	0	0	0	0	0	108	100	89	180	880
1969	193	113	183	165	104	96	121	47	158	68	8	134	1390
1970	145	187	183	154	27	100	65	86	130	152	163	123	1515
1971	191	187	195	88	0	0	37	108	138	178	169	105	1396
1973	180	98	201	0	0	0	56	63	144	117	166	152	1177
1974	164	175	185	139	31	19	30	114	134	167	86	158	1402
1975	162	185	200	62	0	9	42	117	107	122	180	16	1202
1976	162	173	139	92	0	0	5	124	45	131	139	163	1173
1977	154	183	165	39	44	75	99	32	84	0	22	158	1055
1978	160	141	136	0	10	42	81	109	142	133	8	127	1089
1979	158	163	101	68	0	40	82	69	94	123	145	67	1110

APPENDIX 4. MOISTURE DEFICITS (mm) FOR COCONUTS AND CASHEWNUTS FOR VARIOUS A.M.S.C's

APPENDIX 4a. AUGUST-DECEMBER MOISTURE DEFICITS FOR CASHEWNUTS (Zone IV)

YEAR \ AMSC's mm	50	100	138	200	295
1950	248	198	196	71	72
1951	282	276	238	150	81
1952	496	496	496	496	496
1953	85	35	0	65	0
1954	481	479	481	481	481
1955	575	536	498	436	406
1956	470	442	404	342	253
1957	231	201	163	163	149
1958	516	458	420	358	334
1959	280	230	192	130	35
1962	449	449	449	449	449
1963	283	239	227	226	226
1964	423	423	423	423	423
1965	288	288	288	288	288
1966	330	315	277	215	194
1967	110	60	22	0	0
1968	399	349	311	249	154
1969	322	322	322	322	322
1970	561	561	561	561	561
1971	599	599	599	599	599
1973	451	441	403	341	318
1974	566	566	566	566	566
1975	453	543	453	453	453
1976	485	456	356	356	356
1977	223	173	135	84	84
1978	426	426	426	426	426
1979	405	405	405	348	255
MEAN	387	372	345	318	299

APPENDIX 4b. AUGUST-DECEMBER MOISTURE DEFICITS FOR CASHEWNUTS (ZONE III)

YEAR \ AMSC's mm	100	150	218	300
1946	188	138	64	0
1947	177	247	179	97
1948	170	133	65	57
1949	297	297	287	287
1950	359	338	299	299
1951	167	117	49	0
1952	360	278	90	90
1953	46	0	0	0
1954	368	303	319	259
1955	473	423	255	173
1956	364	347	347	347
1957	100	58	58	58
1958	410	340	272	198
1959	321	271	203	83
1960	491	481	481	481
1961	0	0	0	0
1963	152	102	60	60
1964	440	440	440	440
1965	84	63	62	62
1966	300	250	182	92
1967	50	0	0	0
1968	130	80	12	0
1969	182	182	189	188
1970	343	343	333	333
1971	500	450	378	346
1972	16	0	0	0
1973	339	289	221	139
1974	564	564	564	559
1975	588	588	588	588
1976	351	323	323	323
1977	65	65	65	65
1978	265	215	161	65
1980	237	195	194	194
MEAN	270	233	206	179

APPENDIX 4. (cont'd.)

APPENDIX 4c. 24 MONTHS DEFICITS FOR COCONUTS (ZONE IV)

AMSC (mm) / YEAR	295	200	150	100	50
1950-51	1014	1141	1249	1339	1470
1951-52	2225	2320	2351	2391	2433
1952-53	2047	2047	2023	2073	2002
1953-54	1680	1680	1825	1835	2034
1954-55	2097	2099	2289	2339	2390
1955-56	1944	2050	2110	2204	2281
1956-57	1731	1835	1945	2061	2131
1957-58	1742	1742	1886	2039	2074
1958-59	1503	1571	1663	1796	1867
1959-62	1913	1981	2029	2081	2131
1962-63	2149	2149	2149	2149	2179
1963-64	1977	1977	1977	1977	2007
1964-65	2216	2216	2216	2216	2216
1965-66	1862	1862	1886	1936	1994
1966-67	1402	1402	1458	1556	1675
1967-68	1110	1300	1394	1495	1611
1968-69	1910	2100	2170	2215	2270
1969-70	2905	2905	2905	2905	2905
1970-71	2110	2110	2910	2910	2911
1971-73	2446	2446	2472	2492	2573
1973-74	2453	2453	2479	2499	2579
1974-75	2604	2604	2604	2604	2604
1975-76	2339	2359	2359	2359	2375
1976-77	2044	2064	2112	2162	2228
1977-78	1787	1867	2044	2065	2144
MEAN	2000	2043	2100	2154	2211

APPENDIX 4. (cont'd.)

APPENDIX 4d. 24 MONTHS DEFICITS FOR COCONUTS (ZONE III)

AMSC (mm) / YEAR	200	150	100	50
1947-48	1489	1585	1678	1863
1948-49	1888	1934	1977	2136
1949-50	2007	2016	2066	2505
1950-51	1542	1599	1740	1890
1951-52	1484	1586	1738	1888
1952-53	1224	1316	1449	1599
1953-54	1340	1378	1478	1627
1954-55	1835	1885	1962	2062
1955-56	1935	1985	1968	2148
1956-57	1620	1620	1566	1666
1957-58	1694	1744	1807	1907
1958-59	1897	2034	2134	2234
1959-60	2008	2095	2145	2243
1961-63	1169	1219	1318	1426
1963-64	1824	1873	1977	2072
-964-65	2180	2180	2184	2234
1965-66	1686	1776	1787	1889
1966-67	1449	1529	1627	1729
1967-68	1661	1271	1371	1487
1968-69	1406	1486	1536	1608
-969-70	1955	1955	1955	1964
1970-71	2316	2376	2399	2479
1971-72	1888	1948	2019	2146
1972-73	1422	1496	1594	1683
1973-74	2235	2309	2359	2398
1974-75	2843	2843	2843	2880
1975-76	2579	2579	2540	2689
1976-77	2086	2086	2131	2241
1977-78	1548	1580	1734	1780
MEAN	1785	1838	1897	2006

APPENDIX 5. COPRA AND CASHEW YIELDS, RAINFALL AND MOISTURE DEFICITS DURING SELECTED PERIODS.

Appendix a. Coconut yields, rainfall and deficits 29 and 24 months before the year of harvest in zone III (AMSC - 297mm)

YEAR (OF HARVEST)	YIELD (IN KG/HA)	RAINFALL (in mm)		DEFICITS (in mm)	
		29 MONTHS BEFORE HARVEST	24 MONTHS BEFORE HARVEST	29 MONTHS BEFORE HARVEST	24 MONTHS BEFORE HARVEST
1956	55	2877	2026	1738	1738
1957	102	2401	2039	2283	1838
1958	90	2369	2134	2009	1620
1959	146	2496	2134	2087	1628
1960	158	2682	2085	1963	1767
1961	164	2188	1908	2275	1946
1962	126	2987	2663	2074	1843
1964	150	3364	3140	1683	1071
1965	203	3164	1832	1725	1725
1970	137	3877	2716	1222	1212
1971	131	2396	1896	1961	1937
1972	41	2093	1545	2567	2294
1973	95	2302	1915	2299	1866
1974	108	2766	2636	1818	1349
1975	71	2694	1882	2179	2162
1976	63	1395	1017	3090	2843
1977	46	1547	1381	3234	2579
1978	132	2073	1931	2765	2086
1979	122	2701	2421	1923	1496
1980	166	3355	2576	1355	1258

Appendix 5b. Coconut yields, rainfall and moisture deficits 29 and 24 months before the year of harvest in agroclimatic zone IV (AMSC - 297mm)

YEAR OF HARVEST	YIELD (Kg/Ha)	RAINFALL (mm)		DEFICITS (mm)	
		29 MONTHS BEFORE HARVEST	24 MONTHS BEFORE HARVEST	29 MONTHS BEFORE HARVEST	24 MONTHS BEFORE HARVEST
1956	55	2675	1600	2097	2097
1957	102	2192	1936	2518	1944
1959	146	2410	2138	2130	1742
1958	90	2311	2149	2272	1713
1960	158	3267	2740	1689	1503
1964	150	-	1731	-	2149
1965	203	2191	1903	2519	1977
1970	137	3132	2110	1910	1910
1971	131	1294	975	1337	2905
1972	41	1388	973	3325	2910
1975	71	1559	1427	3151	2453
1976	63	1464	1276	3176	2604
1977	46	1692	1521	3018	2359
1978	132	2104	1816	2606	2064
1967	166	2332	2018	2378	1862

Appendix 5c. Cashew yields and the corresponding rainfall and deficits for selected periods of the year. For agroclimatic zone III (AMSC - 218mm)

YEAR	YIELD Kg/ha	RAINFALL (mm) IN THE YEAR OF HARVEST				DEFICITS (mm) IN THE YEAR OF HARVEST			
		ANNUAL	JAN-JUNE	JULY-DEC	AUG-DEC	ANNUAL	JAN-JUNE	JULY-DEC	AUG-DEC
1952	786	839	676	410	370	342	260	80	80
1953	249	1884	847	1037	861	372	375	0	0
1956	834	934	556	378	362	770	423	347	347
1957	346	1297	595	702	597	417	359	58	58
1959	897	926	745	-	280	666	-	-	272
1963	258	1226	642	584	503	260	200	60	60
1964	410	606	290	316	290	1098	578	520	440
1965	391	1066	362	704	687	639	577	62	62
1966	257	1165	729	436	364	628	346	182	182
1967	282	1132	416	1216	1161	503	452	51	0
1969	374	1057	415	642	548	653	453	200	188
1970	700	839	359	480	387	855	509	346	333
1971	413	706	466	240	130	1026	648	378	375
1972	247	1289	372	917	812	450	450	0	0
1973	275	1425	1028	397	378	439	218	221	221
1974	607	455	214	241	166	1249	654	595	564
1975	434	562	352	210	142	1142	530	612	588
1976	667	819	306	513	280	916	593	323	323
1977	232	1112	282	830	729	706	586	120	65

Appendix 5d. Cashew yields and the corresponding rainfall and moisture deficits for selected periods of the year for zone IV (AMSC - 200mm)

YEAR	YIELD (Kg/ha)	RAINFALL (in mm)				DEFICITS (in mm)			
		ANNUAL	JAN-JUNE	JULY-DEC	AUG-DEC	ANNUAL	JAN-JUNE	JULY-DEC	AUG-DEC
1952	786	532	268	264	241	1188	615	573	496
1953	249	1839	568	1271	1032	525	525	0	0
1956	834	1020	718	302	272	700	447	253	253
1957	347	1025	465	560	506	695	543	152	152
1959	897	1012	726	286	221	708	374	334	334
1963	258	1129	612	517	454	591	365	226	226
1964	410	774	443	331	314	946	433	513	423
1965	391	890	412	478	449	830	495	335	288
1966	257	1128	699	429	371	592	398	194	194
1967	282	1542	479	1063	1022	463	443	20	0
1969	374	550	135	415	415	1170	741	429	322
1970	700	425	193	232	176	1295	683	612	561
1971	413	545	379	166	132	1175	576	599	599
1972	247	-	-	-	-	-	-	-	-
1973	275	989	686	303	288	731	413	318	318
1974	607	538	276	262	171	1182	600	582	556
1975	434	737	371	367	288	986	524	462	453
1976	667	783	455	328	228	933	477	456	456
1977	232	1033	329	704	682	716	547	169	84