Agricultural Research Department
The Winand Staring Centre for Integrated Land, Soil and Water Research

A Soil Suitability Appraisal of the Lake Kenyatta Extension and Witu Settlement Schemes (Lamu and Tana River Districts, Kenya)

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REPORT 62
Wageningen (The Netherlands), 1992

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Survey carried out for:

The German Assisted Settlement Programme (GASP), G.T.Z., Lamu, Kenya

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ABSTRACT

Touber, L. 1992. A Soil Suitability Appraisal of the Lake Kenyatta Extension and Witu Settlement Schemes (Lamu and Tana River Districts), Kenya. German Assisted Settlement Programme (GASP), GTZ, Ministry of Lands and Housing, Lamu, Kenya; Wageningen (The Netherlands), The DLO Winand Staring Centre. Report 62. 98 p.; 7 Figs.; 17 Tables; 4 Maps; 4 Annexes.

For land use planning purposes of the German Assisted Settlement Programme, situated in the lowland area along the northern Kenya coast, the soils of two planned settlement schemes have been inventorized at a semi-detailed scale. Their distribution is presented on two map sheets at scale 1:50.000. Soil properties have been qualitatively evaluated for a number of crops under rainfed, smallholders farming. Conclusions incorporate the recommended distribution of appropriate land use alternatives.

Keywords: Soil Survey, Land Evaluation, Physical Land Use Planning, Coastal Lowland, Kenya.

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The DLO Winand Staring Centre is continuing the research of: Institute for Land and Water Management Research (ICW), Institute for Pesticide Research, Environment Division (IOB), Dorschkamp Research Institute for Forestry and Landscape Planning (LB), and Soil Survey Institute (STIBOKA).

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CONTENTS

Page

1 INTRODUCTION

1.1 Background and objectives

The German Assisted Settlement Programme (GASP) strengthens the Department of Land Adjudication and Settlement in the Ministry of Lands, Housing and Physical Planning.
GASP supports the Ministry in its efforts to settle landless people on hitherto non-adjudicated state land, through the set-up of a physical and social infrastructure for rural communities. It concerns surroundings of Hindi-Magogoni, Mpeketoni (Lake Kenyatta) and Witu townships, in Lamu District.
The GASP programme includes advice, training and (financial) assistence in the fields of low technology agriculture, development of water supply systems, agro-forestry activities, farmers cooperative societies, primary education and health care improvements and community development

The previous Project Phases were largely concerned with assistance in the planning and implementation of the Lake Kenyatta and Hindi-Magogoni Settlement Schemes (LKSS and HMSS).
Presently (Third Phase: 1989-1992) the Project has started various studies in the Witu area to initiate the Witu Settlement Scheme (WSS).

Along with other resources studies, assessment of soil resources is required for proper physical land use planning (e.g. the identification of agriculturally suitable land; the subsequent layout of farm plots and feeder roads; the projection of village centres), as well as for advice on land and crop management matters.
To meet this requirement GASP invited the Winand Staring Centre (WSC) to carry out a soil suitability appraisal for smallholders rainfed farming. To this end a semi-detailed scale (1:50,000) soil survey was considered sufficiently informative.

Two study areas are concerned: the total of the WSS, which is an area stretching West and South of Witu, with an approximate size of 14,500 ha, and secondly a 6,000 ha planned extension of the already largely developed LKSS.
About half of the WSS area was previously surveyed by the author, at a scale of similar intensity, at the request of the United Nations High Commissioner for Refugees (UNHCR),in a period when this area was set aside for the settlement of Ugandan refugees (Touber, 1979). Results of this previous study have been incorporated in the present one.

The soil surveyor travelled to Lamu District in the end of March 1991. The field study of the Witu Settlement Scheme was about to be completed by the beginning of May, when weather conditions hampered further survey activities. The completion of the WSS survey as well as the study on the LKSS-II area were continued in August 1991. Field activities were completed by mid September 1991.

1.2 Acknowledgements

Field surveys need planning, organization, and certainly some endurance, to keep their progress at an acceptable pace. For these matters surveyors are for a good deal at the mercy of the organisation for whom the work is carried out. In the present case I have been extremely pleased with the seemingly effortless assistance in the provision of all necessary transport, personnel, equipment and administrative support without any form of delay.
I want to thank the GASP management and administrative staff for their logistic support, which indeed contributed greatly on the smooth survey progress.
Thanks are due to the Project's agronomist, who has devoted valuable time discussing priorities of the survey and the preliminary survey results with the author.
Special mention has to be made of driver Iason Mangeri, skilled in safe bush driving and mechanical trouble shooting, and of casual labourers Isaac Karanja, Faridi Famau, James Mugalu, and Delmas Mugalu, who all worked 7 days a week, carried out altogether 700 soil augerings and accurately performed 2,100 EC and pH sample measurements, without one single complaint, in spite of heat, insects and clothes-tearing thorn shrubs.

The Kenya Soil Survey (KSS), which is part of the Kenya Agricultural Research Institute (KARI), has by way of courtesy lent me all necessary soil augers, distilled water, and pF-rings. For this I am indebted to the Acting Head of KSS, Mr. W.W.Aore.

2 SUMMARY, CONCLUSIONS, RECOMMENDATIONS

2.1 Summary

A semi-detailed soil survey has been conducted of two areas, of 6,000 and 14,500 ha, eligible for infrastructural development for settlement of rural communities. The schemes are located along the Garsen - Lamu road, in Lamu and Tana River Districts. (See Fig. 1)

The area falls in the semi-humid to semi-arid coastal lowland zones according to the agro ecological zonification for Kenya by Jaetzold & Schmidt. Yearly rainfall averages 1100 mm. Rainfall distribution is bi-modal with most of the precipitation falling during the long rains. The short rains are unreliable. (See Fig. 3)
The area belongs to the Pleistocene marine terrace, which is an almost flat coastal plain, at a level of appr. 5-20 m a.s.l.
The geology consists for the greater part of coral limestone rock and sandy and clayey lagoonal deposits.

The average density of observations is about 1 per 20 ha. Approximately 700 augerholes were made, (apart from those of an earlier realised inventory within the area in 1979), together with 32 soil profile descriptions and -sampling, carried out in April/May and August/September 1991.
On the basis of these field checks, complemented with air photo interpretation, soil maps were compiled and presented on 1 : 50,000 scale maps.

The survey results have been evaluated for small scale, rainfed subsistence farming, with a low level of technology. A selected number of crops, relevant for the prevailing climatic conditions, were taken into consideration.

The system of land evaluation, based on "A Framework for Land Evaluation" (FAO, 1976) was used as a guideline for the interpretation of data. Modifications by the Kenya Soil Survey (KSS), and the recently upgraded version presented in "Soils of the Kilifi Area" (Boxem et al., 1987) were taken into account.
The inventory of agroecological zones in Kenya, by Jaetzold and Schmidt (1983), plays an important role in this land evaluation.

Distribution of major soil types and suitability:

An important distinction can be made between
- well drained yellowish red soils, developed over coral limestone rock (PL units);
- the mainly imperfectly drained, brown, mottled "sand over clay soils" (PA units);
- and the saline-sodic cracking clays (PJ units).

See figures 4[a] and 4[b] (p. 32 and 33).

PL-units
Soils of the PL-units are developed over coral limestone rock. They are yellowish red, well drained sandy clays and clays. These soils occur mostly between Witu and an area halfway Kipini. In the centre of this zone occur rock outcrops among soils of shallow depths (unit PL2). Elsewhere, the soils over limestone are deep and have a good moisture storage capacity (unit PL1). Topsoils are dark and well developed, although rather thin. Chemical fertility of these surface horizons is not high, but addition of mineral fertilizers will improve the fertility considerably. Apart from the areas with rock outcrops, these soils are the best of the scheme and pose little restrictions to agricultural practices.

PA-units
Well drained, very deep, yellowish red loamy sands, with loamy subsoils (units PA1-PA3) form an important transition between the red clays over coral rock and the sand-over-clay soils. The soils partly comprise complexes of older (Pleistocene) beach ridges.
These are also most common in a zone between Witu and Kipini, and as well widespread around Katsaka Kairu. Also these soils are worth considering for agricultural development: They have favourable rooting space and soil moisture storage capacities. However, chemical fertility is not high, and is likely to decline rather fast under annual crop cultivation. The area is regarded suitable for tree crops.

Soils developed over lagoonal deposits are mainly brown, mottled, imperfectly drained, loamy sands over (deeper or shallower) sandy clays (units PA4-PA7, C1, C2). They constitute the major part of the schemes (90% of LKSS-II; 50% of WSS). The drainage conditions vary, and in a number of cases will bring difficulties for crop cultivation, especially tree crops (units PA5p, PA5f, PA7, PA7f). Moreover the strong difference in texture between upper and lower subsoil is restricting to root development (units PA6, PA7). The very sandy top- and upper subsoils have a very low moisture storage capacity, and are very poor in minerals. These 'sand over clay' soils are regarded as marginally suitable for most annual crops and in a number of cases offer no possibilities for sustained agriculture.

PJ-units
West of Witu, between Witu and Katsaka Kairu, a broad strip of saline clay soils occur, originated in relatively recent clayey lagoonal deposits: units PJ1 and PJ2. They are regarded unsuitable for agriculture due to unfavourable physical and chemical properties.

Part of a seasonally flooded area, belonging to the Tana Delta, occurs within the proposed WSS boundaries (Unit AA). Also this land is rated unsuitable for rainfed farming, due to high salinity and adverse drainage conditions.

Both PJ- and AA-units have adequate potential for extensive cattle grazing, however.

2.2 Conclusions, recommendations

Major conclusions of this study are summarized in Fig. 5[a] and 5[b] (p. 56 and 59), which give the distribution of **recommended landuse**.
The following principles form the basis for this choice:

All land, rated suitable for annual crops, is recommended for development of plots for rainfed, small holders farming;

All land, rated moderately suitable for annual crops (but marginal for maize and cotton) is recommended for development of rainfed farming, with important livestock component (i.e. larger plots with opportunity of longer fallow periods and production of manure);

All land, rated marginally suitable or unsuitable for annual crops, but (moderately) suitable for tree crops, is recommended for the development of larger size plots for rainfed farming with dominant agroforestry and livestock components.

All land, rated marginal or unsuitable for both annual and tree crops, is recommended for development of livestock, communal grazing, i.e. grazing blocks, rather than family plots; **or**, in case of obviously poor grazing land, is recommended for wildlife protection / nature conservation / wildlife corridor

It remains the question, whether subsistence farming on the extensive areas of sandy soils, that are prone to a rapid fertility decline, is at all a sustainable form of agriculture. It is the question whether at all these areas should be developed for **agricultural** activities, and not be left for other forms of more sustained income generation, such as tourist development, wildlife viewing and/or extensive, communal grazing. This is especially valid for the LKSS-II area.

On **fertility degradation:**

For all sustained annual crop cultivation it is a prerequisite to maintain soil nutrient levels through the regular application of (animal) manure, ample fallow rotation, mulching by crop residues, green manuring, etc.

By far the largest part of the settlement schemes' sandy soils have a very low fertility level, which is largely contained in topsoil organic matter. When taken in cultivation, the current practice is to cut all natural vegetation including trees, in order to allow light and space to benefit annual crops, esp. maize. The subsequent working of the soil, the lack of shade, and the nutrient demanding maize crop depletes the sandy soil rapidly from organic matter, illustrated by the rapid and strong decline in yield levels after a few seasons of cultivation as experienced in the LKSS-I.
In spite of recommendations "to maintain levels of organic matter by applying manure and mulch through crop residues, etc." (Ali, 1985; A.H.T., 1985), it means in practice that the cultivation of high nutrient demanding crops, like maize and

cotton and sorghum, under this bush-fallow system is not a sustainable form of agriculture. The practice of wiping out the natural vegetation for the (limited) benefit of two or three modest harvests of maize, should be avoided on the sandy soils with low natural fertility status, in order to preserve fertility for better adapted, less demanding crops. (See crop groups and nutrient requirements, Tables 5-8)

Efforts to maintain levels of organic matter are most rewarding in the case of soils with loamy or clayey textures.

On **fertilizer application**:

The application of chemical fertilizers, in addition to proper soil organic matter management, will undoubtedly give response.

In view of the expected loss of fertilizers through leaching on the deeper, less well drained sandy soils (units PA4, PA5, PA6), it is recommended to apply minimal amounts of fertilizer, aiming at modest yield increase at these soils.

The application of fertilizers on the soils of more loamy and clayey textures, which also have a higher natural fertility (units PL1, PL2, PA1, PA2), brings about a relatively higher yield increase, compared to sandy soils. (see Table 5)

Fertilizer applications should follow the advice of AHT,1985, (see Table 10), untill results of field trials indicate otherwise. The reportedly adequate levels of Potassium, however, may turn out to be limiting, once N P - fertilizers have been applied.

On **erosion**:

It is recommended to practice checks on runoff and sheet erosion by contour plowing and manure/mulch application on the "steeper" parts of map units PL1, PL2, PA1, PA2 (between Witu and Kipini) and above all on soils of map unit PA3 around Katsaka Kairu.

On **wildlife**:

To minimize damage to crops by larger mammals (buffaloes, elephants, hippo's), avoiding an escalating conflict between agricultural activities and wildlife/nature conservation values, it is recommended to construct and maintain a game fence, rather than a "game road", along the side of the scheme, where most wildlife is expected to enter.

On **further studies**:

In order to enhance the knowledge of spatial variation in growing periods or Agro-Ecological Subzones (AESZ's, see Para 4.2), rainfall/temperature recordings need to be generated in the Katsaka Kairu area (gauges could be installed for example in villages with primary schools, such as Nyangore, Moa, Katsaka Kairu).

The GASP area, being well covered by sufficiently detailed soil inventory data, offers a good opportunity to select strategic locations for research and monitoring activities (crop yields, fertilizer response, etc), in both the operational scheme and the areas proposed for development. This enables the extrapolation of results over larger areas of the existing scheme, and facilitates the process of physical planning of the future schemes.

In this context it seems that the AHT-study, covering LKSS-I, is underutilized. This is partly due to a low user-friendliness of the rather unhandy set of 13 large scale soil map sheets with an outdated topographic base. It is therefor strongly recommended to transfer the soil boundaries onto a standard 1 : 25,000 scale updated topographic base map of the LKSS-I area, such as is in (daily) use by the GASP team, and which a.o. indicates farmers plot numbers.

Research/monitoring activities, located on representative plots, could encompass:

* The status and trend of organic matter content in sandy soils under various cropping systems;
* In cooperation with the Fertilizer Use and Recommendation Project (FURP), the response/recovery rates of chemical fertilizers on sandy soils versus loamy/clayey soils;
* Calibration/confirmation of the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model (see Para. 5.3.2);
* Production potential trials of "zero-grazing" systems on sandy soils, especially in the drier AESZ.

For the assessment of potential grazing, it is recommended to conduct carrying capacity studies on sample plots, representative for soil and vegetation types within recommended land use categories 4, 5 and 6 (see Table 17, figs 5[a] and 5[b]).

A (rough) inventory of livestock pests and diseases, such as Tsetse, East Coast Fever, Footrot, is recommended.

3 MATERIALS AND METHODS

Gathering of field data in a natural resources inventory comprises routine-wise the following three steps:

- Collection and examination of all existing data: topographic maps, remote sensing material and, above all, previous surveys of the area and its surroundings on climate, landforms, geology, hydrology, vegetation and landuse, etc.
- The actual field survey work.
- Elaboration of data: the compilation of maps and legends, and the interpretation of findings for the user.

3.1 Survey materials

Air photo's

Prior to fieldwork the available aerial photographs were studied stereoscopically. The photographs date from January 1989, and are at a scale of 1 : 20,000. This is sufficiently detailed and recent. They are of good quality, although some runs have been flown too late in the day, rendering part of open ground and lower vegetation obscured by shadows of nearby taller vegetation.

The technique of air photo interpretation comprises the following: Areas, appearing homogeneous in landforms, vegetation patterns and grey tones are delineated and separated from others on the aerial photographs. These photo-interpretation units reflect differences in appearance of the land surface: vegetation, landuse and topography; and hence they are indirectly an indication of rock type, hydrology and soils.
As there is a strong ecological relation among all these aspects of land, the photo-interpretation allows for the extrapolation of soil records over areas not observed in the field, once the connection between soil type and appearance of the land surface on the picture has been established. It depends wholly on the character of the land, however, how strong this connection is, and to what extent this connection has to be checked or established anew for each and every other part of the survey area. Also, with increasingly detailed scale of survey operations, reliability of extrapolation decreases.

In the schemes presently surveyed, the relation between photo image and soil type is not in all areas very clear. For example, the relation vegetation structure / soil texture and drainage is very strong in some areas, but seems absent in others. Consequently, the photo interpretation is of a limited value, and a relatively high density of observations was needed to arrive at a reliable soil map at the present scale.

A second asset of the photointerpretation is the plotting of representative observation points in accessible places, so that field days can be programmed in the office prior to field work.
In connection with this representativeness and the extrapolation exercise, it is a prerequisite that planned observation points are identified exactly in the field, and that one's whereabouts in the bush are continuously and exactly identified on the aerial photographs.

Topographic maps

The survey areas are covered by 1 : 25,000 scale topographic sheets, produced by GASP, after enlargements of the 1 : 50,000 topographic series by the Survey of Kenya. These feature infrastructure (updated to 1990), administrative boundaries, a 1 km^2 grid system (UTM grid), watercourses, the most important waterholes and ponds, and the 10 and 20 m contour lines.

3.2 Previous surveys, references

Part of the Scheme is covered by the 1 : 100,000 scale photo-interpretation map of the Tana Delta, by **Wokabi et al, 1976**, This information on soils, covering the scheme is, however, not sufficiently detailed to serve our purposes. The publication gives a good overview of the areas physiography and soil classification.

An area of 7900 ha, South of the Witu Forest and West of the Nairobi Ranch, (i.e. about half of the presently planned Witu Settlement Scheme) has been surveyed in 1979 (**Touber, 1979**). It concerns a suitability appraisal for smallholders, rainfed farming, at a semi-detailed scale, with an observation density of one to sixteen hectares. Use was made of 1 : 12,500 scale enlargements of aerial photographs of 1967(?) as field orientation and as topographic base. Results of this survey are suited to be incorporated in the present survey. To this end, part of the area was reviewed with the help of the 1989 aerial photography.

Sombroek et al., 1982 produced the exploratory soil map of Kenya, giving an excellent overview of soil types for the country as a whole (at 1 : 1,000,000 scale), but also not sufficiently detailed for the present purpose. Its data are used as modifiers in the suitability appraisal of Agroecological zones in Jaetzold and Schmidt (1983).

Map sheets at 1 : 50,000 scale of the coastal area were produced by the Japanese technical aid agency **JICA** in **1984**. It concerns topographical maps, and thematical maps on Surface Geology and Soils; Landform, Slope and Drainage; and Present Vegetation and Landuse. After the completion of the present survey, the extent of which is fully covered by these Jica maps, it became obvious that the thematic maps rely too much on inexperienced photointerpretation without the field checks that are so indispensable in these areas. Hence the soil information of these thematic maps is very unreliable, and, by its publication in full colour print, offers a confusing issue.

In an earlier stage of GASP, the Kenya Soil Survey carried out a site evaluation in the then proposed extension of the Lake Kenyatta Settlement Scheme, supplying a quick overview of the most salient limitations to rainfed farming (**Ali, 1985**). The presently surveyed Lake Kenyatta Settlement Scheme, Phase II (LKSS-II) is completely covered. Maps are presented at a 1 : 50,000 scale. However, the complex and short-distance changes of the soils in the area do not allow for a widely spaced observation network. This is the cause, that soil unit descriptions are too widely defined, such as "Well to poorly drained, very friable to firm, loamy sand to sandy clay"; and, consequently, soil boundaries have a limited meaning. However, the conclusions and recommendations concerning suitability levels and management aspects of individual soil types are certainly valid and useful.

Early 1985, the consulting engineers company Agrar und Hydrotechnik (A.H.T.) produced a detailed soil and land suitability appraisal of the Lake Kenyatta Settlement Scheme, Phase I (**A.H.T.,1985**). Maps are accurate (although the observation density of 1 per 10 ha does not justify publication at 1 : 10,000 scale maps), and soil units are well defined and comprehensively described. Unfortunately, however, the topographic base map is outdated, so that orientation (which plot has what soil?) becomes difficult. Also, the presentation of data on a set of 13 separate sheets does not add to the easy access for the user. The study nevertheless provides ample information on physical limitations to smallholders rainfed farming, advice on soil management practices and crop yield prognoses. This publication is very useful for the present survey area and its suitability assessment. An effort is made to correlate results of the present survey with those of the A.H.T. study, because, as farming in LKSS-I has been going on for about 15 years, a correlation of both surveys will, among others, enable us to predict farmers achievements on comparable land in the as yet undeveloped WSS and LKSS-II.

Simultaneously with the upgrading of the topographic maps, GASP produced "Present Land Use Maps" at 1 : 25,000 scale of the schemes proposed (**Speller, 1990**). These maps present the distribution of land under cultivation and five structural classes of natural vegetation (Forest; dense Bush; Wooded Grassland, etc.), all based on interpretation of the 1989 aerial photographs.

3.3 Field survey procedures

An average observation density of 1 per 20 hectares was regarded necessary to arrive at a reliable 1:50,000 scale soil map of the schemes.

Since available topographic maps (1 : 25,000) do not show enough detail in the extensive, featureless coastal plain, use has been made of the aerial photographs for orientation in the field.

Approximately 700 routine augerhole observations have been made. These were plotted on the aerial photographs. They were carried out with an "Edelman" type auger, or a narrow "riverside" auger, up to a depth of 1.20 m. Of each different horizon were recorded: depth; colour; mottling (if any); texture; consistence when moist and wet; concretions (if any); pH and electrical conductivity (1 : 2.5 suspension) at three standard depths (15, 40 and 90 cm).

Soil profile data from augerings were entered in a Lotus database. For this purpose, adapted fields sheets were designed. See Annex 3.

Together with every soil observation the vegetation was recorded in terms of physiognomy (according to Pratt et al., 1966), and species composition. The physiognomy describes the cover of trees, shrubs (woody vegetation, taller, resp. lower than 6m), herbs and grasses separately; of each of this vegetation "layer" the dominant species were mentioned as far as known.
Within the context of the survey it was not considered relevant to collect unknown species for determination in the East African Herbarium.

32 profile pits have been dug (100 - 150cm deep), of which for each horizon have been recorded, apart from the properties mentioned above: horizon boundaries; structure; features of clay illuviation (if any); pores; root distribution. Each horizon was sampled for standard survey analysis. A selection of horizons was also sampled for pF values and bulk density (undisturbed "ring" sampling).

See maps in folder for the location of these observations.
See Annex 2 for analytical data.

The results of the survey for a previously planned scheme for the UNHCR, within the present WSS area, have been incorporated. These were based on identical procedures, with around 500 routine soil observations and 6 soil profile pits. Location of these points and profile descriptions are contained in Touber, 1979.

Soil correlation trips were conducted, both to the UNHCR area and to the Lake Kenyatta Settlement Scheme.

3.4 Map and legend construction

During and after the field sampling programme, the field data were classified and grouped into soil mapping units, simultaneously re-interpreting the aerial photograhs with the now available "ground-truth" data. Thus the photointerpretation boundaries were transformed into soil boundaries.

Location of observations and final map boundaries were transferred from the aerial photographs to the 1 : 25,000 scale topomaps by hand drawing. To this end, use was made of a 1/4 km^2 grid of photo scale, on transparent material, oriented on the photographs in equivalence to that on the topographic map. The final 50,000 scale soil maps were obtained by photographic reduction of the 25,000 scale "interim" soil maps.

Surface area figures were obtained with the help of a dot-grid system, overlain over the 1 : 25,000 scale soil maps.

The design of the symbols indicating the mapping units, compromises between the system, established for Kenya by the KSS, and the system used in A.H.T., 1985:

Soil mapping units are separated at highest level according to landform; at second highest level according to parent material; at lowest level divisions are made following differences in important soil characteristics such as colour, drainage, depth, consistence, etc. The symbols of the mapping units are designed accordingly:

Landforms:
P - coastal plain
A - floodplain

Parent material:
L - coral rock, limestone
J - lagoonal deposits
A - various sediments (alluvial deposits, lagoonal deposits and beach ridges)

A simple numbering has been used for the lowest level of separation. A suffix **p** and **f** is used for soils that, for some time in the wet season, are poorly drained, and very poorly drained to waterlogged, respectively.

A capital **C** is used for the indication of a complex mapping unit, i.e. when various soil types occur in such a close pattern that they are not separable at the scale of mapping.

3.5 Laboratory methods

Analysis on soil samples has been carried out in the National Agricultural Research Laboratories (NARL), and partly in the Kenya Soil Survey (KSS) laboratory. Analytical methods were standard routine survey analyses, and, for selected samples, soil fertility analysis. The analytical methods are described in Annex 4.

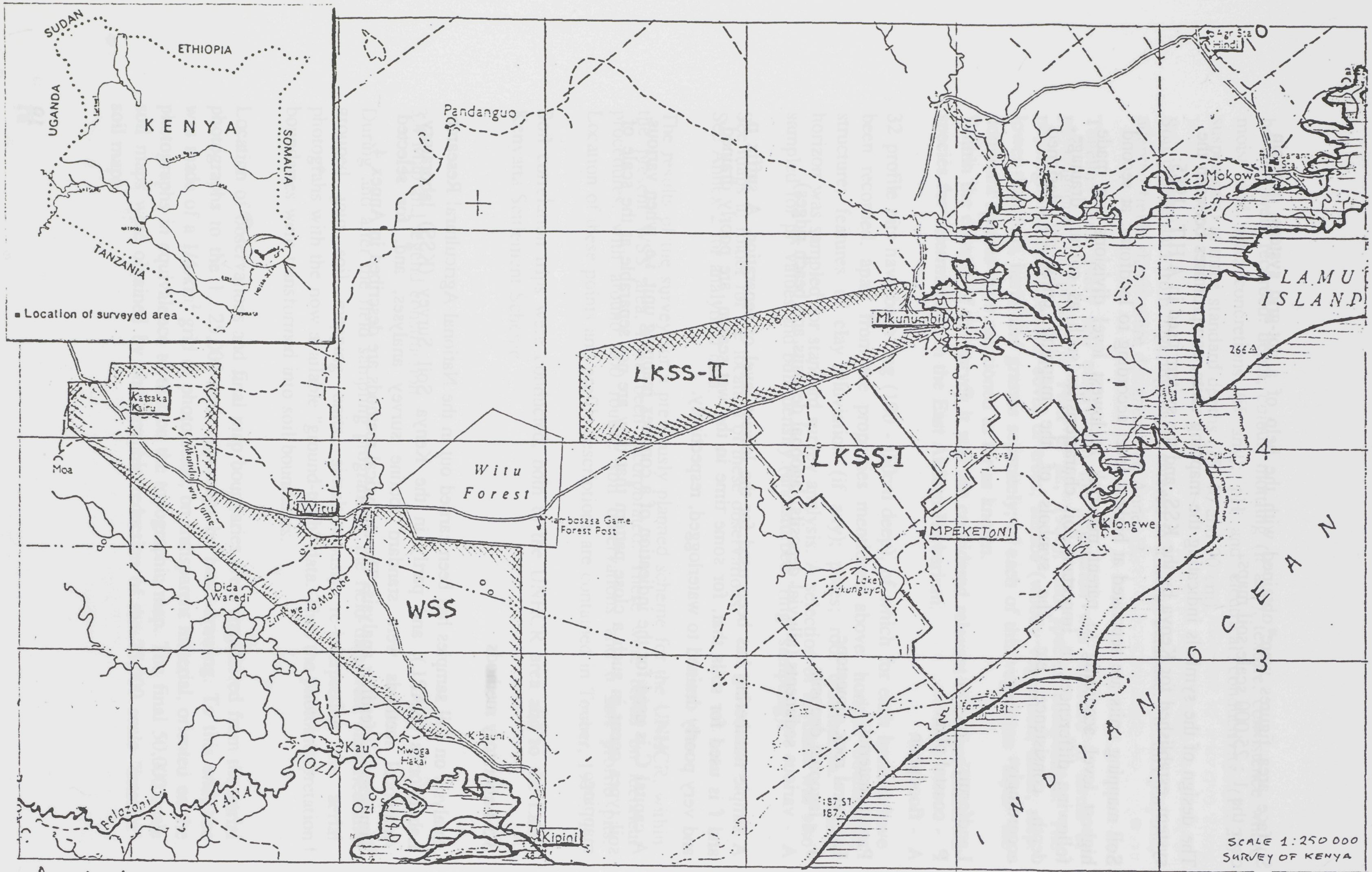


fig 1 LOCATION OF STUDY AREAS

WSS WITU SETTLEMENT SCHEME (PROPOSED)

LKSS-II LAKE KENYATTA EXTENSION AREA (PROPOSED)

LKSS-I LAKE KENYATTA SETTLEMENT SCHEME (IMPLEMENTED)

BOUNDARY OF SURVEY AREAS

4 ENVIRONMENT

4.1 Location of survey areas, accessibility

The schemes are located in the Coast Province, Lamu District, and partly in Tana River District.
Lake Kenyatta Extension (LKSS-II), with a size of about 6,000 ha, stretches along the main Garsen - Lamu road, opposite the already developed Lake Kenyatta Settlement Scheme (LKSS-I).
The Witu Settlement Scheme (WSS) has an extent of approximately 14,500 ha. It is situated between the Tana Delta and the Witu Forest, between Katsaka Kairu and Kipini. The boundary of Lamu and Tana River Districts runs through the scheme.
See Fig. 1

The areas appear on the 1 : 50,000 topographic sheets 179/4: *Witu* and 180/3: *Mkunumbi*.

The Garsen - Lamu main road has several side roads, running into the WSS, most important of which is the Witu-Kipini road. This is a well maintained all weather road, although some short stretches may be flooded upon excessive rainfall. Smaller motorable tracks lead to the villages of Moa, Dida Warede, Kau and Kilelengwani in the Tana floodplain.
During fieldwork for the UNHCR area, frequent use was made of two B.P. made cutlines that are clearly visible on the aerial photographs. These have been re-opened by GASP to enhance accessibility in that area. Other cutlines have been met in the field, but were not of much use for orientation or transport.

There is no road or motorable track in the Lake Kenyatta Extension area. At the request of the soil surveyor, two cutlines were made by GASP, with the purpose to provide acces into some especially densely vegetated areas.

Over 90% of the observation sites was reached by bush driving, using the configuration of trees, shrubs, grasslands and ponds on the aerial photographs for orientation.

4.2 Climate, agro-ecological zones

Extensive information on the climate of the area around Witu is given by Jaetzold (1972).
Braun (1978) deals with general aspects of the climate along the Kenyan coast, and Braun (1977) more specifically with rainfall probability.

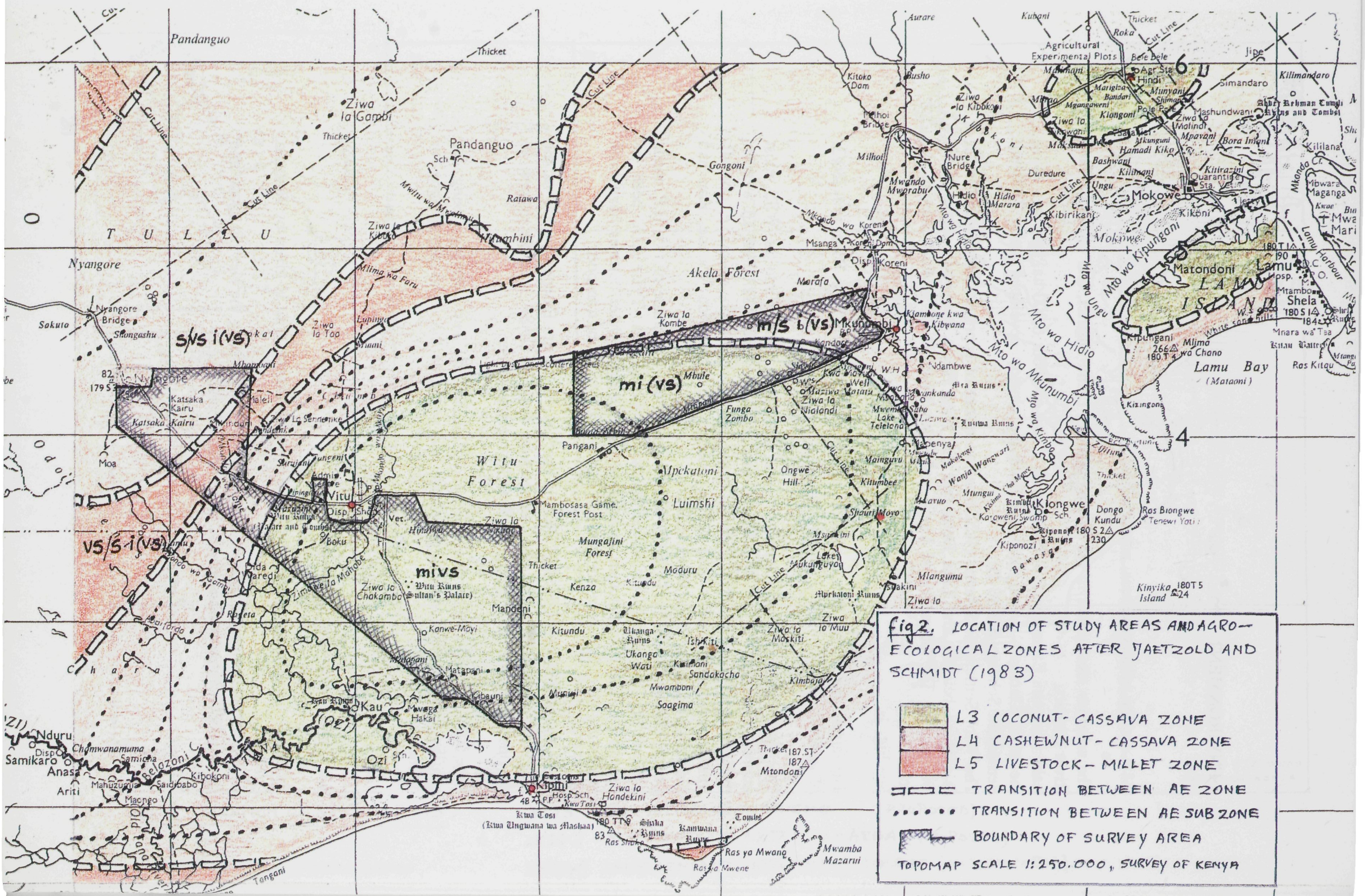


fig 2. LOCATION OF STUDY AREAS AND AGRO-ECOLOGICAL ZONES AFTER JAETZOLD AND SCHMIDT (1983)

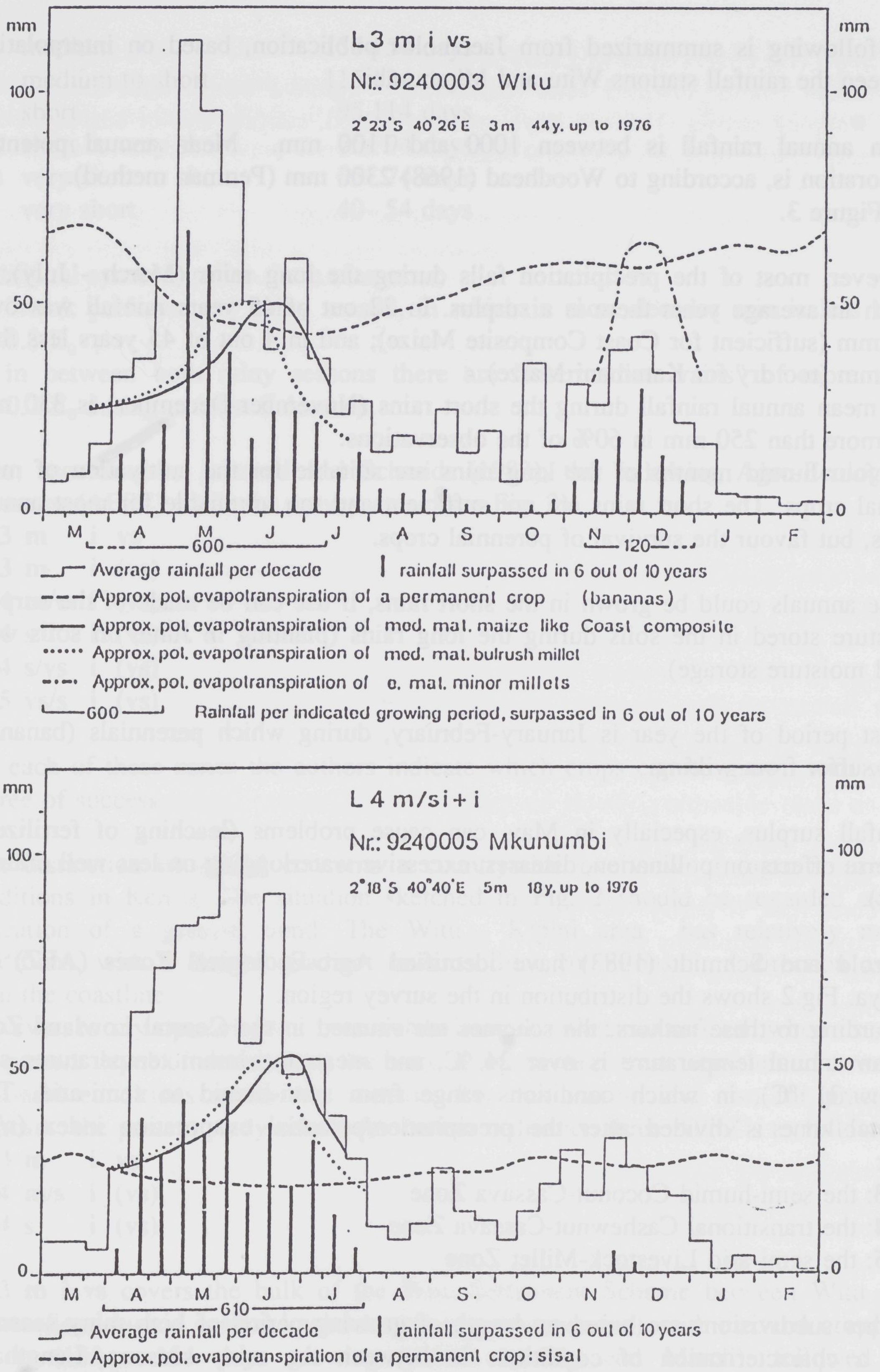


Fig. 3 Rainfall and some evapotranspiration data for Witu and Mkunumbi. Source: Jaetzold and Schmidt, 1983

The following is summarized from Jaetzholds publication, based on interpolation between the rainfall stations Witu and Mkunumbi.

Mean annual rainfall is between 1000 and 1100 mm. Mean annual potential evaporation is, according to Woodhead (1968) 2300 mm (Penman method). See Figure 3.

However, most of the precipitation falls during the long rains (March - July), of which in average years there is a surplus. In 22 out of 45 years rainfall was over 700 mm (sufficient for Coast Composite Maize); and in 4 out of 45 years less than 250 mm (too dry for Katumani Maize).
The mean annual rainfall during the short rains (November-December) is 330 mm and more than 250 mm in 60% of the observations.
The four humid months of the long rains are suitable for the cultivation of most annual crops. The short rains are not sufficient and too unreliable for most annual crops, but favour the survival of perennial crops.

Some annuals could be grown in the short rains, if use can be made of the surplus moisture stored in the soils during the long rains (planting in June, on soils with good moisture storage).

Driest period of the year is January-February, during which perennials (bananas) may suffer from wilting.

Rainfall surplus, especially in May, can cause problems (leaching of fertilizers, adverse effects on pollination, diseases, excessive waterlogging on less well drained soils).

Jaetzold and Schmidt (1983) have identified Agro-Ecological Zones (AEZ) for Kenya. Fig.2 shows the distribution in the survey region.
According to these authors, the schemes are situated in the Coastal Lowland Zone (mean annual temperature is over 24 °C, and mean maximum temperatures stay below 31 °C), in which conditions range from semi-humid to semi-arid. This coastal zone is divided after the precipitation/potential evaporation index (r/E_0) into:
CL3: the semi-humid Coconut-Cassava Zone
CL4: the transitional Cashewnut-Cassava Zone
CL5: the semi-arid Livestock-Millet Zone

Further subdivisions are based on length of growing period of both rainy seasons, and a characterization of conditions in between the rainy seasons. Length of growing periods are classified according to the number of days in which (in at least 6 out of 10 years) the rainfall + stored soil moisture (assumed at 60 mm) equals or exceeds four tenths of the Potential Evaporation ($0.4\ E_0$).

Lengths of cropping seasons of AE Subzones, that cover the survey areas, are classified as follows:

m	medium	135-154 days
m/s	medium to short	115-134 days
s	short	95-114 days
s/vs	short to very short	75- 94 days
vs/s	very short to short	55- 74 days
vs	very short	40- 54 days

Additional symbols refine these classes:

( ) "weak performance" rainy season, in which in most decades rain is less than 0.8 E_0

i in between both rainy seasons there are "intermediate rains" of more than 0.2 E_0 during at least 5 decades.

Thus, according to Jaetzold and Schmidt (1983), the following Agro-Ecological Subzones (AESZ) cover the survey areas (see Fig. 2):

CL3 m i vs
CL3 m i (vs)
CL4 m/s i (vs)
CL4 s i (vs)
CL4 s/vs i (vs)
CL5 vs/s i (vs)

For each of these zones the authors indicate which crops can be grown with what degree of success.

This distinction of AESZ concerns a countrywide overview of (agro-) climatic conditions in Kenya. The situation sketched in Fig. 2 should be regarded as an indication of a general trend: The Witu - Kipini area has relatively moist conditions, with a distinct gradient towards drier conditions in a direction away from the coastline.

However, to my opinion, the given subdivision is rather too refined, when used at the present level of detail; also the very sharp decline from semi-humid towards semi-arid conditions seems not realistic. For this reason, and also for practical purposes, the present study selects for further utilisation three AESZ's as follows:

CL3 m i vs
CL4 m/s i (vs)
CL4 s i (vs)

CL3 m i vs covers the bulk of the Witu Settlement Scheme between Witu and Kipini. Semi-humid coastal lowland zone (coconut-cassava), with medium cropping season (135 - 154 days growing period, starting end March), followed by intermediate rains and a very short cropping season (40-54 days growing period, starting mid October).

Good yield potential for most annual crops; also for Coconut, citrus, Banana, Mango, Cashew, Bixa.

Fair potential for sesame, Coconut, Banana, Citrus.

CL4 m/s i (vs) covers most of LKSS-II area.
Transitional coastal lowland zone (cashewnut - cassava zone): with medium to short cropping season (115-134 days growing period, starting end of March), with weak and erratic rains in the second season.

CL4 s i (vs) covers the Katsaka Kairu side of the WSS.
Transitional coastal lowland zone (cashewnut - cassava zone) with short cropping season (95-114 days growing period, starting end of March), followed by intermediate rains and a weak, very short second cropping season (40-54 days).
Good yield potential for early maturing Sorghum and Millet cultivars, also for Mango.
Fair yield potential for (Pioneer Hybrid) Maize, Finger Millet, Cowpeas, Simsim, early maturing Groundnuts.
Fair yield potential for Cashew, Cassava.

4.3 Geology, Landforms, Hydrology, Erosion, Vegetation and Wildlife

Geology

Geological information so far available is contained in a cyclostyled report by Matheson, 1962.

The parent materials, from which the soils have developed are coral rock (units PL), lagoonal sediments and in places beach ridge deposits (units PA)
The coral rock is partly very deeply weathered, partly present at shallow depths. The lagoonal sediments are mainly a shallow layer of sand over clay. Thick sand deposits are related with former beachridges. To the West alluvial clay sediments are found in the Tana River floodplain (unit AA).

Landforms

According to the above mentioned Geological report, the area can be divided into two geomorphological units: Pleistocene marine terrace and Recent floodplain.

The marine terrace is an almost featureless flat plain, at an altitude of about 10 - 20 m a.s.l. However, two NW-SE stretching terrain steps or minor escarpments, of about 3-6 m high, are clearly visible in the landscape between Witu and Kipini.
Around Katsaka Kairu a number of SW-NE stretching shallow ridges of reddish fine-sandy material dominate the area. These seem remnant beach ridges.
The mesotopography of this coastal plain has a relation to the geology. The relief over coral rock is very gently undulating (1-2%) to flat, with very few seasonal ponds (units PL1, -2 and -3), Only where coral rock is near to the surface, the topography consists of shallow long stretching depressions and low ridges, parallel to the "scarps" in the landscape (unit PL2).

The lagoonal deposits show a more irregular meso-topography, which is also very gently undulating, but with many shallow circular seasonal ponds, with a diameter of 100-250 m (units PA5, PA6, Cl, C2). These may be partly explained by dissolution of an underlying layer of coral limestone rock (Karst features).

More recent lagoonal clay deposits form an almost flat landform at a lower level of the marine terrace, probably not of Pleistocene, but of sub-recent age (units PJ). Its position is almost at the level of the floodplain (unit AA), mostly below 10 m a.s.l.

Hydrology

Land of the Witu Settlement Scheme drains largely towards the SW, into the Tana River floodplain system.
Apart from the Zimbwe la Mahobe River, that crosses the Witu scheme just SE of Witu township, no clear watercourses are present. This is also the case in the Lake Kenyatta Extension Area, where only along the main road, during very heavy rainfall, excess water can be seen flowing in southern direction.
It means that the otherwise reasonable amount of rainfall surplus during the long rains must largely and readily be absorbed by the soils, and that a good deal disappears through subsurface transport, laterally, through well permeated sand layers.
The numerous round depressions of the lagoonal deposits are seasonally waterlogged, to various extents, due to layers of slowly permeable clays in the deeper subsoil.
Between Katsaka Kairu and Witu an insignificant drainage line traverses the lagoonal clay deposits (units PJ), which is called the Mkondo wa Jame.

The SW side of the area, the Tana floodplain, is flooded twice a year.
Floodplain water has an electrical conductivity of around 2,000 micro-Mho (which is slight to moderately saline), whereas the almost pure rainwater from seasonal ponds has an EC of around 50-l50 micro-Mho (during the survey).

Erosion

Gullies, truncated top soils, runoff during heavy downpours, as most obvious features of erosion, were not observed in the area. This almost complete absence of erosion is due to the level topography, and the generally coarse textured topsoil that, together with the undisturbed, lush vegetation cover, allows for a well structured porous surface.

However, in the few situations, where some slope is combined with clayey or silty textures, runoff and sheet erosion does occur (see Para. 5.3.3).

How the present rapid infiltration rates will change under cultivation practices is rather unpredictable, but it is foreseen that no severe problems with erosion will develop.

Vegetation

The vegetation has been recorded as much as possible during the survey. Especially in non-cultivated areas, its spatial pattern may be closely related to variation in soil conditions.

Dense stands of woody vegetation are clearly recognisable on the aerial photographs. These stands are not forests in the sense of primary tropical rainforests. Considering climate and physiography, primary forests in this area thrive on groundwater, rather than on rainfall. They are in fact secondary tall shrub thicket, with scattered tall trees (original forest species?) and with many Doum palms (*Hyphaene coriacea*) intergrown. This dense woody vegetation is largely related to deep, excessively drained sandy soils of former beach ridges (unit PA3, PA4) but also cover less well drained deep sandy soils (partly unit PA5, Cl).

Dense bush of sclerophytic appearance (drought resistant) is common on (saline, calcareous) heavy clay soils of the lagoonal deposits (unit PJ1) in the Katsaka Kairu area.

Wooded bushed grasslands are commonly found on soils with coarse textured upper horizons. They consist of small patches of the above mentioned secondary forest, among wooded grassland of Doum palms (*Hyphaene coriacea*) over the perennial grasses *Hyparrhenia cymbaria* and *Panicum maximum* (unit PL3). *Panicum maximum* seems to be related to shade, not to a particular soil condition. Where temporary waterlogged conditions prevail, the grass layer is also occupied by *Digitaria diagonalis* (Unit PA5p, -f).

Wooded grasslands are typical of the "best" soils of the area (units PLl and PA1). They consist of Doum palms over *Hyparrhenia cymbaria*. The Hyparrhenia is partly replaced by *Brachiaria sp.* and *Andropogon sp.* in unit PL3, where the topsoils contain more clay and are less well drained.

Grasslands on well drained and more shallow soils (unit PL2) consist almost exclusively of *Hyparrhenia cymbaria* and *Heteropogon contortus*. Where the area is grazed, many leguminous and unpalatable herbs grow.

The seasonal ponds of the "sand-over-clay" soils (units PA6, and Cl) bear grasslands that consist of *Digitaria diagonalis* and *Dactyloctaenium aegyptiacum*. Bushed grasslands occur on unit PJ and consist of the salt-tolerant *Acacia seyal* (*zanzibarica*?) and *Ormocarpum kirkii* over *Digitaria diagonalis, Sporobolus spicatus* and others.

The short, salt-tolerant grass *Sporobolus spicatus* dominates the saline fringes of the Tana floodplain, (unit AA).

The woody vegetation of the units PA7, PA7p and PJ which form a broad strip along the Tana floodplain, and also SE of Katsaka Kairu, is markedly different from that of the rest of the area. It gives the land an appearance of semi-arid conditions, rather than the semi-humid one the doum palms render. This is certainly partly attributable to soil water retention conditions, and possibly also soil salinity.

Wildlife

Baboon have been met most frequently during the survey. They are present in vast numbers, and may turn out to be a most serious problem for successful cultivation.

Further, **Topi** and **Waterbuck** are commonly seen. Topi may form impressive large herds towards the end of the dry season, mainly in the Western end of the Lake Kenyatta Extension Area. They are commonly accompanied by small herds of (Burchell's) **Zebra**. **Warthogs** and **Buffaloes** are occasionally met. **Lions** are present.
A group of about thirty **Elephants** was seen repeatedly in August '91, in the stretches of dense wooded bush within the Lake Kenyatta Extension area.
Birdlife is magnificent, especially along the Tana river floodplain. **Hippo's** are present there as well.

Wildlife conservation practices should have a prominent place in the overall land use planning of the region. In such wider context, tourist development may be worth considering.

4.4 Land use

Quite a few acres are under cultivation, mainly along the main roads and minor bicycle paths. The cultivated area seems to increase rapidly, especially in the LKSS-II, near the existing scheme (comparing actual situation with the Present Land Use Map by Speller, 1990). Also in the southern corner of the Witu Scheme, between Kibaoni and Kipini the land is increasingly cleared for small farm plots. It concerns bush-fallow subsistence farming at a low level of technology: cultivation is done by hand; no fertilizers, pesticides or improved seeds are applied.
Bananas, maize, cotton, cashew, mangoes, bixa, sesame, cow peas, sweet potatoes, cassava and pawpaw are the main crops grown.

Some areas are used as grazing for beef cattle, eg. the Katsaka Kairu area, and obviously the seasonally flooded parts of the Tana Floodplain, insofar these are accessible. Cooperative ranches in the area are established west of Katsaka Kairu, and north of Mkunumbi.

4.5 Soils

An important distinction can be made between

- well drained yellowish red soils, developed over coral limestone rock (PL units);
- the imperfectly drained, brown, mottled "sand over clay soils" (PA units);
- the saline-sodic cracking clays (PJ units).

See figures 4[a] and 4[b]. The soil classification terminology follows that of the FAO-Unesco Soil Map of the World, revised Legend (FAO-Unesco, 1988).

Soils of the PL-units are developed over coral limestone rock. They are yellowish red, well drained, friable sandy clays and clays, with weak angular blocky to moderately coherent porous massive structures. These soils occur mostly between Witu and an area half-way Kipini.
The centre of this zone is characterized by the occurrence of rock outcrops among soils of shallow depths (unit PL2).
Elsewhere, the soils over limestone are deep and have a good moisture storage capacity (unit PL1): 10 mm/10 cm. Topsoils are dark and well developed, although rather thin. Chemical fertility of these surface horizons is not high (Cation Exchange Capacity (CEC) is 10-12 meq/100g; pH ranges between 6.0 and 7.0), but addition of mineral fertilizers may improve the fertility considerably. Apart from the areas with rock outcrops, these soils are the best of the scheme and pose little restrictions to agricultural practices.
All soils over coral rock show an increase in clay content with depth. These soils are classified as Chromic LUVISOLS, or Haplic LIXISOLS, where CEC is more, resp. less than 24 meq/100 g clay.

Well drained, very deep, yellowish red loamy sands, with loamy subsoils (units PA1-PA3) form an important transition between the red clays over coral rock and the sand-over-clay soils. The soils partly comprise complexes of older (Pleistocene) beach ridges.

These are also most common in a zone between Witu and Kipini, and as well widespread around Katsaka Kairu. Also these soils are worth considering for agricultural development: They have favourable rooting space. Soil moisture storage capacities are low to moderate in their sandy upper subsoils, but higher (up to 10 mm/10 cm) in the more loamy deeper subsoils. However, chemical fertility is not high, (Cation exchange capacities of 10-6 meq/100g soil); Top soil organic matter is likely to decline rather fast under annual crop cultivation (e.g. from 0.8% to 0.4% or less). The area is regarded particularly suitable for tree crops.

The classification unit of chromic LUVISOLS/haplic LIXISOLS (FAO-Unesco, 1988) applies also to map units PA1 and -2. In unit PA3, which is of sandier texture, a transitional form towards ARENOSOLS can be established.

Mapping units PA4 and PA5 have deep, sandy soils (classified as ARENOSOLS, which have less than 18% clay and more than 65% sand). PA5 shows hydromorphic features lower down in the profile (dark brown, rusty and bleached mottling).

Very low CEC figures are inherent to these sands. Most of its chemical fertility is contained in the organic matter of the top soils; this tends to decline considerably after some years of cultivation. Available water capacities are very low (around 5mm/10 cm). Rainwater infiltrates rapidly, is readily available for crops, but is partly lost due to throughflow beyond the root zone.

Features of presence of excess water, like in the deeper subsoils of unit PA5, occur much nearer to the soil surface in units PA5p and PA5f.

Soils developed over lagoonal deposits are mainly brown, mottled, imperfectly drained, (loamy) sands over (deeper or shallower) sandy clays (units PA4-PA7, C1, C2). They constitute the major part of the schemes (90% of LKSS-II; 50% of WSS). The drainage conditions vary, and in a number of cases will bring difficulties for crop cultivation, especially tree crops (units PA5p, PA5f, PA7, PA7f). Moreover the strong difference in texture between upper and lower subsoil is restricting root development (units PA6, PA7). The very sandy top- and upper subsoils have a very low moisture storage capacity, and are very poor in nutrients. These 'sand over clay' soils are regarded as marginally suitable for most annual crops and in a number of cases offer no possibilities for sustained agriculture.

"Sand over clay" soils are characterized by a slowly permeable horizon, that causes stagnation of water during some time of the year. The sandy upper subsoil shows a minimum percentage clay compared to the rest of the profile, and often bleached mottles and "white tonguing" at the transition to the more clayey and prominently mottled deeper subsoil. The transition between sandy and clayey horizons is not abrupt. This type of profile is typical of soils of mapping unit PA5 (parts), PA6, and PA7, with respectively a sand -clay transition at depth of over 70 cm, between 40 and 70 cm and at less than 40 cm depth. "Albic properties" (light coloured, bleached sands) become more prominent in this sequence also. Classification of these sand over clay soils leads to intergrades between LUVISOLS and PLANOSOLS. In unit PA7 PLANOSOL characteristic are more clearly present. They also show some salinity and sodicity inthe deeper profile. They form the transitions to the clay soils of the more recent lagoonal deposits.
West of Witu and between Witu and Katsaka Kairu occurs a broad strip of imperfectly to very poorly drained clays, indicated on the soil map by the symbols PJ1 and PJ2. PJ1 is located at somewhat elevated position, has a thin, lighter textured top soil, and bears mostly dense, woody, sclerophytic vegetation. The soils of these units show cracks in the dry season, have intersecting slickensides in the subsoil ("vertic" properties), and salinity and calcareousness that increase with soil depth. CEC ranges from 20-30 meq/100g soil. The vertic properties, poor drainage conditions, salinity and very heavy consistency, are all adverse conditions for low input farming.
Unit AA constitutes part of a seasonally flooded area belonging to the Tana Delta. It is also regarded unsuitable for agriculture, due to its drainage status and very high levels of salinity in the topsoils.
The land of units PJ1, PJ2 and AA have adequate potential for extensive cattle grazing, however.

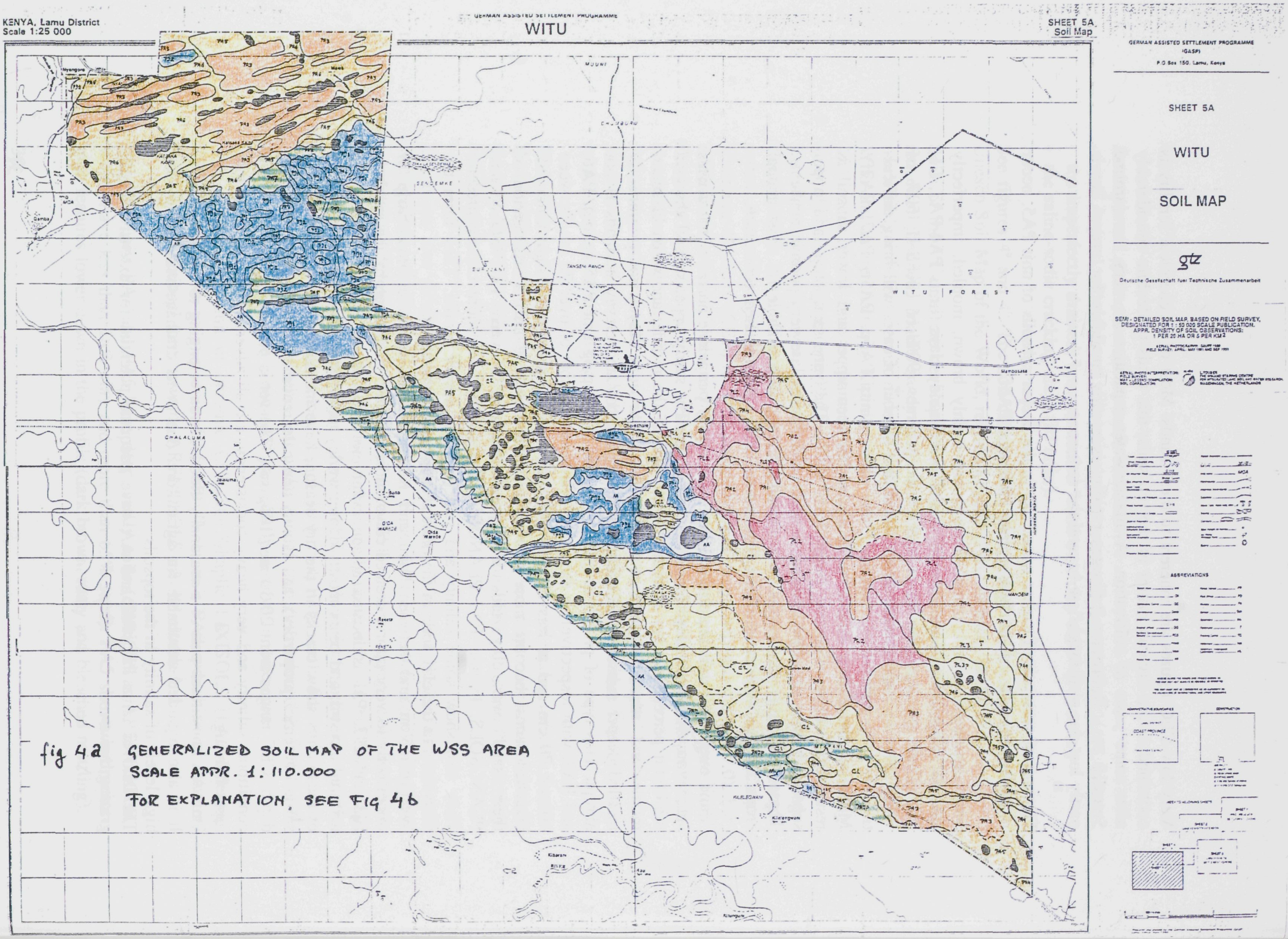


fig 4a GENERALIZED SOIL MAP OF THE WSS AREA
SCALE APPR. 1: 110.000
FOR EXPLANATION, SEE FIG 4b

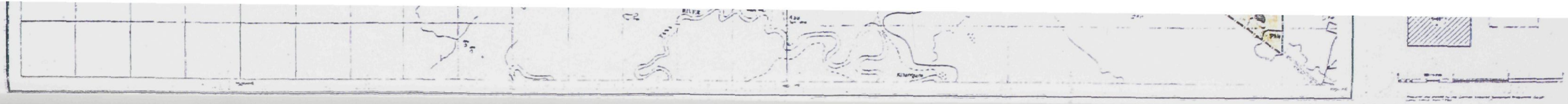


fig 4b GENERALIZED SOIL MAP OF THE LKSS-II AREA - SCALE APPR. 1:75.000

5 INTERPRETATION OF DATA: LAND EVALUATION PROCEDURES

5.1 General principles

Land evaluation procedures in Kenya follow the "Framework for Land evaluation", by FAO, 1976. The Kenya Soil Survey has adapted the system to Kenyan conditions. Reconnaissance soil survey reports of KSS contain this adapted system: The reader is referred to these reports. An adequate summary appears also in "Soil and land suitability of the Lake Kenyatta Settlement Scheme" (A.H.T.,1985).
It is useful in the present context, to mention some principles here.

Land is to be evaluated for a well defined use: there is no "suitable" or "unsuitable" land as such, if no mention is made of the land use envisaged. It is therefore necessary to identify and describe in an early stage the relevant Land Utilisation Types (LUTs).

A **Land Utilization Type** is defined by a number of standard attributes (Key attributes), such as (farm) produce, (farm) size, labour intensity, (recurrent) capital input, land tenure, level of technical know-how.
Land Use Requirements express the conditions for a successfull implementation. These have to be identified for each LUT (e.g growth requirements of certain tree crops; management requirements such as terrain conditions in view of soil degradation hazards).

Natural resources need to be inventorized to assess the physical conditions of the land in order to see whether the land use requirements can be fulfilled. These inventories result in the identification and delineation of tracts of land. These **Land Mapping Units** are described in terms of their specified Land Characteristics (or Attributes of Land) and are used in the land evaluation as the basis for spatial variation.

Land Characteristics are attributes of land that are measurable or can be estimated, eg. rainfall, evaporation, slope angle, slope length, rock outcrops, organic matter content, soil salinity, soil depth, soil texture, etc. These can be employed as a means of describing or distinguishing between mapping units. It is not always possible to compare such single land characteristics directly with the requirements of the relevant LUT in the area, because many interact in their influence. Hence the concept of **Land Quality** has been developed, which is defined as a "complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use" (FAO, 1976). Examples of Land Qualities and their composing Land Characteristics are: Moisture availability (rainfall/evaporation, infiltration/throughflow, soil water holding capacity); Nutrient availability (organic matter, cation exchange capacity, base saturation, pH, N, P, K etc.); Resistance to erosion (slope angle, vegetation cover, infiltration rate, soil consistence); Hazard of flooding, ponding (topographic position, river regime, depth of groundwater).

Comparison (or matching) of the land use requirements with the actual conditions of the land (or with land qualities) leads to a suitability classification for the specified land utilisation type.
This classification also enables us to compare (the predicted success of) potential land use alternatives.
Land Suitability Classes reflect degrees of suitability. Within the order Suitable, three classes are recognized: Highly, Moderately, and Poorly Suitable, indicated by the symbols **S1**, **S2**, and **S3**, respectively. Land Suitability Subclasses reflect the nature of the most limiting land quality, such as moisture deficiency, erosion hazard, shallow rooting conditions, etc. They are indicated by suffixes, eg. Subclasses S2m, S3e, S2r. Only the most important limitation(s) is (are) shown.

5.2 Land utilisation types

The kind of land use that is envisaged in the future GASP settlement schemes can be described as "rainfed, mixed farming, low level of technology". It is not possible in the scope of the present survey to completely define this LUT, as this would need a multi-disciplinary input of investigations.

The land utilisation type: "low level technology, rainfed farming" is defined as follows:

Produce	:	rainfed crops, annuals, perennials, as climatically feasible (maize, cotton, cashew, cassava, dolichos beans, cow peas, mango, coconut, vegetables, sesame, bixa); some small stock, such as chickens and goats.
Farm size	:	"family plots", appr. 4 ha (standard plot size); or, in case of less productive land, 6.5 ha (enlarged plot size)
Land tenure	:	own title-deed.
Level of technology	:	low level of technology: farm operations by hand tools; limited access to improved seeds, (occasional access to pesticides, fertilizers, tractor use).

A second LUT ("rainfed farming, improved level of technology") is considered relevant, which differs from the former in a higher level of technology and (capital) input. Farmers have access to improved seed varieties, use fertilizer and pesticides at a regular basis, and perhaps may employ animal traction. Obviously the requirements of this LUT on e.g. natural soil fertility are less strict than those of the low level technology farming.

As both types of LUTs are not clearly separable in space and time, whereas also the second seems somewhat hypothetic, it is considered more of practical value to evaluate the soil findings for a number of selected annual and tree crops under conditions of low management level (no fertilizer application).

Land which is considered not or only marginally suitable for rainfed agriculture could be recommended for extensive cattle grazing and/or reserved for wildlife. It is, however, beyond the scope of this survey to specify the requirements, land qualities and criteria for the latter two types of land use.

5.3 Land Qualities and Land Use Requirements

The land qualities which are considered of importance for subsistence farming in the natural environment of the study area are dealt with here:

* Moisture availability is most important in view of the almost marginal climatic conditions for rainfed agriculture in considerable parts of the settlement schemes.
* Natural soil fertility in the area is generally very low and poses obvious limitations to yields. Fertility decline was reported in existing schemes.
* Erosion hazard has to be considered in view of sustainability of land use envisaged.
* Oxygen availability, directly related to drainage conditions, varies strongly in time and space throughout the area. It is of influence to root development and crop performance.
* Workability of the surface soil is of importance in view of the low technology level of subsistence farming: soil consistence matters when working the land with handtools.

For the interpretation of the present survey, methodology and criteria used in the survey report on "Soils of the Kilifi Area" (Boxem et al., 1987) have been closely followed, as environmental conditions are comparable to those in the Witu-Mpeketoni Area; also because more recent developments in the interpretation of basic data have been incorporated here.

5.3.1 Moisture availability and moisture requirements

In Ecological land evaluation the land use requirements (needs of crops) are compared with land qualities (climate and soil properties). Moisture availability is the most important land quality in the presently prevailing climatic conditions.
The Agro-ecological subzones (AESZ) of Jaetzold and Schmidt (1983) (J&S) refer to a 1 : 1 Million scale overview of climatic conditions in Kenya. This distribution of AESZ should be taken as a general trend of prevailing conditions in the survey area (see Section 4.2 and Fig. 1). Thus, for practical purposes it is preferred to use J&S data in generalized form and have these reduced to:

CL3 m i vs Witu - Kipini area
CL4 s/m i (vs) LKSS-II area
CL4 s i (vs) Witu - Katsaka Kairu area

This tentative land suitability rating of J&S classifies the land quality **moisture availability**, using length of growing period. This is determined by the number of days in which rainfall exceeds 0.4 of the potential evaporation, expanded with a

period in which an average crop can survive on a fixed amount of stored soil moisture (90 mm).
This has been compared to **moisture requirements** of crops, expressed in the number of days of the growth cycle during which the crop does not suffer from water stress. This is a function of potential evapotranspiration, modified by crop coefficients, and based on a fixed rooting depth of 60 cm.

Table 1 gives tentatively a theoretical performance of crops, when only comparing moisture availability of the AESZ with crop water requirements. It expresses in fact the limitations to crop performance, caused by climatic moisture shortage. Table 1 summarizes crop performance of a number of annual crops during the first rains cropping seasons as mentioned in J&S(83), as well as the performance of perennial crops under conditions of the related AESZ's.
Each of these AESZ's has been assigned a suitability level.

Table 1 Crop performance according to length of cropping season in some AESZ (1st rains growing period)

	Tentative suitability	**S1**	**S2**	**S3**	**S3-N**	**N**
	Length of cropping season (days)	**135-154**	**115-134**	**95-114**	**75-94**	**<75**
Tree crops, Perennial crops	**Coconut, Banana**	**2**	**3**	**-**	**-**	**-**
	Citrus	**2**	**-**	**-**	**-**	**-**
	Pawpaw	**1**	**2**	**3**	**-**	**-**
	Bixa	**1**	**2**	**-**	**-**	**-**
	Cassava	**1**	**1**	**2**	**2***	**-**
	Cashew	**1**	**1**	**2**	**-**	**-**
	Mango	**1**	**1**	**1**	**3**	**-**
Annual crops	**Sesame**	**2**	**2**	**2**	**-**	**-**
	Cotton	**1**	**2**	**3**	**-**	**-**
	Tomato	**1**	**2**	**2**	**-**	**-**
	Green Gram	**1**	**2**	**2**	**2**	**2**
	Chinese Cabbage	**1**	**1**	**-**	**-**	**-**
	Maize	**1**	**1**	**2**	**3***	**-**
	Cow Pea, Dolichos Bean	**1**	**1**	**2**	**2**	**2**
	Onion	**1**	**1**	**2**	**3***	**-**
	Sweet Potatoe	**1**	**1**	**2**	**-**	**-**
	Millet, Sunflower, Sorghum	**1**	**1**	**1***	**2***	**-**

1 "good yield potential", i.e. over 60% of "optimum"(=normative yield?)
2 "fair yield potential", i.e. 40-60% of "optimum"
3 "poor yield potential", i.e. 20-40% of "optimum"
- no data; largely unsuitable (<20% of "optimum")
*** applies only to drought resistant and/or early maturing cultivars**

Source: Jaetzold and Schmidt, 1983, adapted

This classification makes use of the assumption that the average available moisture storage capacity is 15 mm/10 cm of soil and that crops have an average rooting space of 60 cm. It means that growing periods are based on r/E_0 data, added with

90 mm stored soil moisture. Thus, the suitability rating of J&S has to be modified with the actual soil moisture storage capacity data of the present survey.

Modifications concern the measured/estimated moisture storage capacities, rooting space, runoff losses, and presence of shallow groundwater.
The estimated rooting space takes in consideration the soil density and (abrupt) textural changes. The available moisture per textural layer is given according to analytical results, complemented with some interpolation.
Water holding capacity is calculated for root systems with a potential reach of 60 cm depth for annuals, and of 120 cm for tree crops/perennials. See Tables 2a and b.

Table 2a Calculated/estimated water holding capacities for crops with potential rooting depth of 60 cm (annual crops)

mapping unit	Rooting depth[1] USS+DSS	AWC (%)[1] USS+DSS	Water holding capacity	No. of days soil moisture evapotranspires[2]	
				at 2.5 mm/day	at 3.0 mm/day
1 PL1	60	12	72	29	24
2 PL2	60/10	12	72/6	24/3	20/2
3 PL3	25	(10?)	25	10	8
4 PL3p	25	(10?)	25	10	8
5 PA1	40+20	8+10	52	21	17
6 PA2	60	6	36	14	12
7 PA3	60	6	36	14	12
7 PA3*	60	9	54	22	18
8 PA4	60	5	30	12	10
9 PA5	60	5	30	12	10
10 PA5p	50	5	25	10	8
11 PA5f	40	5	20	8	7
12 PA6	50	5	25	10	8
12 PA6*	50	9	45	18	15
13 PA7	40	5	20	8	7
14 PA7f	30	5	15	6	5
15 PJ1	25	(5?)	12	5	4
16 PJ2	25	(5?)	12	5	4
17 AA	-	-	-	-	-
18 C1	60/50	5	30/25	12/10	10/8
19 C2	50/25	5/(10?)	25	10	8

*** Katsaka Kairu area**

[1] cm of prevailing texture/consistence in upper subsoil (USS) and deeper subsoil (DSS), and corresponding Available Water Capacity (AWC) in % or mm/10 cm soil, according to lab analyses results, partly estimated

[2] Water Holding Capacity expressed in No. of days, calculated for evapotranspiration rates of 2.5 and 3.0 mm/day, for AESZ CL3 (medium growing period) and CL4 (medium to short and short growing period) respectively

Table 2b Calculated / estimated water holding capacities for crops with potential rooting depth of 120 cm (tree crops, perennials)

Mapping unit	Rooting depth[1] USS+DSS	AWC (%)[1] USS+DSS	Water holding capacity	No. of days soil moisture evapotranspires[2] at 2.5 mm/day	at 3.0 mm/day
1 PL1	120	12	144	58	48
2 PL2	120/5	12	144/6	58/5	48/2
3 PL3	60	(10?)	60	24	20
4 PL3p	30	(10?)	30	12	10
5 PA1	40+80	8+10	104	42	35
6 PA2	60+60	6+10	96	38	32
7 PA3	90+30	6+10	84	34	28
7 PA3*	90+30	9+12	117	47	39
8 PA4	120	5	60	24	20
9 PA5	90	5	45	18	15
10 PA5p	60	5	30	12	10
11 PA5f	30	5	15	6	5
12 PA6	50+35	5+10	60	24	20
12 PA6*	50+35	9+11	81	32	27
13 PA7	40+40	5+10	60	24	20
14 PA7f	30	5	15	6	5
15 PJ1	40	(7?)	28	11	9
16 PJ2	40	(7?)	28	11	9
17 AA	-	-	-	-	-
18 C1	90/50+35	5/5+10	45/60	18/24	15/20
19 C2	50+35/40	5+10/10	60/40	24/16	20/13

*** Katsaka Kairu area**

[1] cm of prevailing texture/consistence in upper subsoil (USS) and deeper subsoil (DSS), and corresponding Available Water Capacity (AWC) in % or mm/10 cm soil, according to lab analyses results, partly estimated

[2] Water Holding Capacity expressed in No. of days, calculated for evapotranspiration rates of 2.5 and 3.0 mm/day, for AESZ CL3 (medium growing period) and CL4 (medium to short and short growing period) respectively

Per AESZ the number of days is given that crops survive on stored soil moisture, setting daily evapotranspiration rates at 2.5 mm per day for AEZ CL3, and 3 mm for AEZ CL4 (Boxem et al., 1987). This period is fixed at 36 and 30 days in J&M, respectively. In Table 3 this period is given for each land mapping unit, based on the actual water holding capacity figures.
Further correction on the growing period has been given by subtraction of an estimated percentage due to loss of rain by runoff and/or throughflow. The period has been prolonged where presence of a capillary fringe over groundwater poses an obvious advantage. See Tables 3a and b.

The resulting modified (i.e. actual) growing periods have to be compared ("matched") with the growing periods that crops require for a certain performance, as is indicated in Table 1. Thus, for each soil mapping unit under three different climatic conditions, a suitability rating for crops can be indicated as far as moisture availability of the land in question is concerned. The last column of Tables 3a and 3b gives these ratings, which appear in the table with final ratings; see Table 16.

Table 3a Land units and modified 1st rains growing period (adapted from Jaetzold and Schmidt, 1983) and tentative suitability for annual crops (average potential rooting depth of 60 cm)

Soil mapping unit	Location[1]	AESZ (J.& S.'83) 1st rains growing period (days)	Reduction[2] due to runoff, through-flow	Extension[3] period ground-water	Modification[4] due to WHC: see Table 2	Modified growing period 1st rains	Tentative suitability: see Table 1
1 PL1	WSS: W.-Kip.	m : 135-154			- 7	123-142	S1-2
1 PL1	LKSS-II	m/s: 115-134			- 6	105-124	S2-3
2 PL2	WSS: W.-Kip	m : 135-154			-12/-33	116-135/95-114	S2/S3-N
3 PL3	WSS: W.-Kip.	m : 135-194			-26	109-128	S2-3
3 PL3	LKSS-II	m/s: 115-134			-22	93-112	S3
4 PL3p	WSS: W.-Kip.	m : 135-154		+ 7	-26	116-135	S2
4 PL3p	LKSS-II	m/s: 115-134		+ 6	-22	99-118	S3
5 PA1	WSS: W.-Kip.	m : 135-154			-15	120-139	S1-2
6 PA2	WSS: W.-Kip.	m : 135-154			-22	113-132	S2
6 PA2	LKSS-II	m/s: 115-134			-18	97-116	S3
7 PA3	WSS: W.-Kip.	m : 135-154	-7		-22	106-125	S2
7 PA3	WSS: Kats.K.	s : 95-114	-5		-12	78- 97	S3*-N
8 PA4	WSS: W.-Kip.	m : 135-154	-7		-24	104-123	S3
8 PA4	LKSS-II	m/s: 115-134	-6		-20	89-108	S3*
9 PA5	WSS: W.-Kip	m : 135-154	-7		-24	104-123	S3
9 PA5	LKSS-II	m/s: 115-134	-6		-20	89-108	S3*
9 PA5	WSS: Kats.K.	s : 95-114			-20	75- 94	S3*-N
10 PA5p	WSS: W.-Kip.	m : 135-154		+ 7	-26	116-135	S2
10 PA5p	LKSS-II	m/s: 115-134		+ 6	-22	99-118	S3
11 PA5f	LKSS-II	m/s: 115-134		+12	-23	104-123	S3
12 PA6	WSS: W.-Kip.	m : 135-154			-26	109-128	S2
12 PA6	LKSS-II	m/s: 115-134			-22	93-112	S3
12 PA6	WSS: Kats.K.	s : 95-114			-15	80- 99	S3*-N
13 PA7	WSS: W.-Kip.	m : 135-154			-28	107-126	S2
13 PA7	LKSS-II	m/s: 115-134			-23	92-111	S3*
13 PA7	WSS: Kats.K.	s : 95-114			-23	72- 91	S3*-N
14 PA7f	WSS: W.-Kip.	m : 135-154		+ 7	-28	114-133	S2
14 PA7f	LKSS-II	m/s: 115-134		+ 6	-23	98-117	S3
15 PJ1	WSS: Kats K.	s : 95-114			-26	69- 88	S3*-N
16 PJ2	WSS: W.-Kip.	m : 135-154		+ 7	-31	111-130	S2
16 PJ2	WSS: Kats K.	s : 95-114		+ 5	-26	74- 93	S3*-N
17 AA	WSS: W.-Kip.	m : 135-154			-	-	-
17 AA	WSS: Kats.K.	s : 95-114			-	-	-
18 C1	WSS: W.-Kip.	m : 135-154			-24/-26	111-130/109-128	S2
19 C2	WSS: W.-Kip.	m : 135-154			-26	109-128	S3

1 WSS: Witu Settlement Scheme; W.-Kip.: Witu-Kipini area; Kats.K.: Katsaka Kairu area; LKSS-II: Lake Kenyatta Extension area

2 Reduction of 5% in case of gently undulating relief (runoff) and in case of (somewhat) excessive drainage conditions

3 Extension of 5% in case of temporary high groundwater table; 10% for prolonged water logging

4 Data from Table 2a, last column: difference with fixed No. of days used in Jaetzold and Schmidt's AESZ growing periods: 36 days for m: medium growing period, and 30 days for m/s and s: medium to short and short growing periods

* applies to drought resistant and/or early maturing cultivars

Table 3b Land units and modified 1st rains growing period (adapted from Jaetzold and Schmidt, 1983) and tentative suitability for annual crops (average potential rooting depth of 120 cm)

Soil mapping unit	Location[1]	AESZ (J.& S.'83) 1st rains growing period (days)	Reduction[2] due to runoff, through-flow	Extension[3] period ground-water	Modification[4] due to WHC: see Table 2	Modified growing period 1st rains	Tentative suitability: see Table 1
1 PL1	WSS: W.-Kip.	m : 135-154			+22	157-176	S1
1 PL1	LKSS-II	m/s: 115-134			+18	135-152	S1
2 PL2	WSS: W.-Kip	m : 135-154			+22/-33	157-176/95-114	S1/S3
3 PL3	WSS: W.-Kip.	m : 135-194			-12	123-142	S1-2
3 PL3	LKSS-II	m/s: 115-134			-10	105-124	S2-3
4 PL3p	WSS: W.-Kip.	m : 135-154		+ 7	-24	118-137	S2
4 PL3p	LKSS-II	m/s: 115-134		+ 6	-20	101-120	S3
5 PA1	WSS: W.-Kip.	m : 135-154			+ 6	141-160	S1
6 PA2	WSS: W.-Kip.	m : 135-154			+ 2	137-156	S1
6 PA2	LKSS-II	m/s: 115-134			+ 2	117-136	S2
7 PA3	WSS: W.-Kip.	m : 135-154	-7		- 2	126-145	S1-2
7 PA3	WSS: Kats.K.	s : 95-114	-5		- 2	88-107	S3
8 PA4	WSS: W.-Kip.	m : 135-154	-7		-12	116-135	S2
8 PA4	LKSS-II	m/s: 115-134	-6		-10	99-118	S3
9 PA5	WSS: W.-Kip	m : 135-154	-7		-18	110-129	S2
9 PA5	LKSS-II	m/s: 115-134	-6		-15	94-113	S3
9 PA5	WSS: Kats.K.	s : 95-114			-15	80- 99	S3-N
10 PA5p	WSS: W.-Kip.	m : 135-154		+ 7	-24	118-137	S2
10 PA5p	LKSS-II	m/s: 115-134		+ 6	-20	101-120	S3
11 PA5f	LKSS-II	m/s: 115-134		+12	-25	102-121	S3
12 PA6	WSS: W.-Kip.	m : 135-154			-12	123-142	S2
12 PA6	LKSS-II	m/s: 115-134			-10	105-124	S2-3
12 PA6	WSS: Kats.K.	s : 95-114			- 3	92-111	S3
13 PA7	WSS: W.-Kip.	m : 135-154			-12	123-142	S2
13 PA7	LKSS-II	m/s: 115-134			-10	105-124	S2-3
13 PA7	WSS: Kats.K.	s 95-114			-10	85-104	S3-N
14 PA7f	WSS: W.-Kip.	m 135-154		+ 7	-30	112-131	S2-3
14 PA7f	LKSS-II	m/s: 115-134		+ 6	-25	96-115	S3
15 PJ1	WSS: Kats K.	s : 95-114			-21	74- 93	N
16 PJ2	WSS: W.-Kip.	m : 135-154		+ 7	-25	117-136	S2
16 PJ2	WSS: Kats K.	s : 95-114		+ 5	-21	79- 98	N
17 AA	WSS: W.-Kip.	m : 135-154			-	-	-
17 AA	WSS: Kats.K.	s : 95-114			-	-	-
18 C1	WSS: W.-Kip.	m : 135-154			-18/-12	117-136/123-142	S2/S1-2
19 C2	WSS: W.-Kip.	m : 135-154			-12/-20	123-142/115-134	S1-2/S2

[1] WSS: Witu Settlement Scheme; W.-Kip.: Witu-Kipini area; Kats.K.: Katsaka Kairu area; LKSS-II: Lake Kenyatta Extension area

[2] Reduction of 5% in case of gently undulating relief (runoff) and in case of (somewhat) excessive drainage conditions

[3] Extension of 5% in case of temporary high groundwater table; 10% for prolonged water logging

[4] Data from Table 2b, last column: difference with fixed No. of days used in Jaetzold and Schmidt's AESZ growing periods: 36 days for m: medium growing period, and 30 days for m/s and s: medium to short and short growing periods

* applies to drought resistant and/or early maturing cultivars

5.3.2 Soil fertility and nutrient requirements

Boxem et al.(1987) have established, through field trials and soil and plant analyses, soil fertility classes for the Kilifi area. Use has been made of the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS: Guiking et al, 1982; Janssen et al, 1986), a calculating model, based on interrelations between N,P,K uptake of maize; corresponding yield levels in crop monocultures; and analytical data of unmanured soil samples.

The resulting fertility classification for the Kilifi area has been used for appraisal of soil fertility in the GASP area. The system was applied unmodified, as results seem within a reasonable order of magnitude, and also because data and scope of the present survey do not allow a calibration in the GASP areas, however worth the effort would be.
Classes are given in Table 4; Table 5 gives corresponding yield levels of maize, and nutrient uptake, under otherwise "ideal" conditions, i.e. in monoculture, with proper spacing, and control of weeds, pests and diseases. All map units of the GASP area are classified according to this system in Table 6. In view of the "real" conditions, the figures presented are optimistic. Soil map units have been grouped according to soil fertility classes of the QUEFTS system.

Table 4 Fertility classes for the Kilifi Area

Diagnostic properties				Additional properties		Combinations of nutrient available class			Fertility class
org. C (g/kg)	P-Olsen[1] (mg/kg)	exch. K (mmol/kg)	$pH\text{-}H_2O$ (-)	CEC(pH 8.2) (mmol/kg)	P-total (mg/kg)	N	P	K	
>17	>6	>6	>5.5	>100	>300	2	2	2	C1
>8	>6	>6	>5.5	>100	>300	3	2	2	C2
>8	>3	>6	>5.0	>100	>300	3	3	2	D2
>8	>3	>2	>5.0	>100	>300	3	3	3	D3
≤8	>6	≥2	>5.0	>50	>200	4	2	3	E1
≤8	>6	<2	>5.0	>50	>300	4	2	4	E1
≤8	>3	≥2	>5.0	>50	>300	4	3	3	E2
≤8	>3	<2	>5.0	>50	>200	4	3	4	E2
≤8	≤3	≥2	>5.0	<50	<200	4	4	3	E3
≤8	≤3	<2	>5.0	<50	<200	4	4	4	E3

[1] The corresponding values for P-Mehlich are 18 and 9.

Source: Boxem et al, 1987.

There is a clear division as to fertility level between the more clayey and loamy soils on the one hand, and the sandy and loamy sand soils on the other. This is of course related to the levels of organic carbon, which is better preserved in the more clayey soils, and to which (acc. to the QUEFTS model) an amount of N is related. Within the group of sandy soils, those with poor drainage conditions tend to be lowest in nutrients.
Levels of available P seem less dependent on content of organic matter and clay.
Potassium is strongly dependent on cation exchange capacity. Levels are moderately low, and tend to be higher in soils over coral rock.

Table 5 Relationship between fertility class, nutrient uptake and maize yield levels in the Kilifi Area. Maize varieties are coast composite and pioneer Hybrid.

Fertility class (Table 4)	Nutrient uptake (kg/ha) N	P	K	Maize yield level (kg/ha)
C1	75	10	90	2750
C2	55	9	80	2250
D2	40	7	70	1600
D3	35	6	50	1300
E1	25	8	40	1000
E2	20	5	30	700
E3	10	3	20	400

Source: Boxem et al, 1987

Table 6 Fertility classes according to QUEFTS, and corresponding maize yield levels for mapping units, based on findings in the Kilifi Area (Boxem et al, 1987)

Mapping unit	Org. C (g/kg)	P_{Mehlig} (mg/kg)	Exch. K (mmol/kg)	pH-H_2O	CEC 8.2 (mmol/kg)	Nutrient Av. class (Table 4) N	P	K	Fert. class	Maize yield level (kg/ha)	Nutrient uptake (kg/ha) by maize N	P	K
1 PL1	10	12	7	6.5	100	3	3	2	D2	1600	40	7	70
2 PL2	10	12	10	6.4	140	3	3	2	D2	1600	40	7	70
3 PL3													
4 PL3p													
5 PA1	8	12	5	6.8	90	4-3	3	3	D3	1300	35	6	50
6 PA2	5	11	4.8	6.5	60	4	3	3	E2	700	20	5	30
7 PA3	4		3	6.7	34	4		3	E2	700	20	5	30
7 PA3*	5		3	6.3	58	4		3	E2	700	20	5	30
8 PA4	(4)	11				4							
9 PA5	4	10	2-3	6.0	35	4	3	3	E2	700	20	5	30
10 PA5p	(4)					4			E3	(400)	10	3	20
11 PA5f	(3)					4			(E3)	(400)	10	3	20
12 PA6	4	(10)	1.4	6.5	50	4	3	4	E2	700	20	5	30
12 PA6*	4		1.6	6.5	55	4		4	E2	700	20	5	30
13 PA7	4-5		2.5	6.0	55	4		3	E2	700	10	3	20
14 PA7p	2		1.8	6.0	45	4		4	(E3)	(400)	10	3	20
15 PJ1	6		1.4	6.5	265	4		4	E2	700	20	5	30
16 PJ2	10		5	6.5	275	3		3	D3	1300	35	6	50
17 AA	(12)												

*** Katsaka Kairu area**

The soil fertility classes and their potential **nutrient supply** labeled to map units have to be compared now to **nutrient requirements** of crops to be grown, in order to establish soil limitations. Table 7 gives nutrient requirements for normative yields of a number of crops, calculated per growing period. Criteria for fertility suitability classes appear in Table 8. Suitability ratings with respect to nutrient availability for crop groups are given for all map units in Table 9.

Table 7 Normative yields of marketable product (kg/ha) and estimated nutrient requirements for a growing season (kg/ha). Crops are arranged in the order of N requirement.

Crop group	Crop	Normative yield	Nutrient requirements		
			N	P	K
I	cashewnut	750	20	4	20
	coconut	2 500 [1]	20	4	25
	millet	750	25	6	20
	simsim	500	25	7	30
	cowpea/green gram	500 [3]	25[4]	7	35
II	sunflower	750 [2]	35	5	35
	cassava	15 000	35	8	70
	sweet potato	8 000	40	7	65
III	cotton	600 [2]	55	9	50
	sorghum	2 250	60	8	55
	maize	3 000	75	12	70

[1] nuts per ha, [2] seeds, [3] pulses, [4] N absorbed from soil.

Source: Boxem et al., 1987

Table 8 Limitations with respect to nutrient availability without fertilizer application; maximum yield is S1: >80%, S2: 40-80%, S3: 20-40%, and N: <20% of the normative yields mentioned in Table 7.

Soil Fertility Class	Crop group (see Table 7)		
	I	II	III
C	S1	S1	S1
D	S1	S1	S2
E1	S1	S2	S3
E2	S1	S2	S3
E3	S2	S3	N

Source: Boxem et al., 1987

Table 9 Soil fertility class of Map units and Suitability level for crop groups. See Table 8.

Mapping unit	Fertility class	Suitability Crop group I	II	III
1 PL1	D2	S1	S1	S2
2 PL2	D2	S1	S1	S2
3 PL3	D2	S1	S1	S2
4 PL3p	D3	S1	S1	S2
5 PA1	D3	S1	S1	S2
6 PA2	E2	S1	S2	S3
7 PA3	E2	S1	S2	S3
7 PA3*	E2	S1	S2	S3
8 PA4	E2	S1	S2	S3
9 PA5	E2	S1	S2	S3
10 PA5p	E3	S2	S3	N
11 PA5f	E3	S2	S3	N
12 PA6	E2	S1	S2	S3
12 PA6*	D3	S1	S1	S2
13 PA7	E2	S1	S2	S3
14 PA7p	E3	S2	S3	N
15 PJ1	E2	S1	S2	S3
16 PJ2	D3	S1	S1	S2
17 AA	D1	S1	S1	S2
18 C1	E2	S1	S2	S3
19 C2	D2/E2	S1	S1/S2	S2/S3

Fertilizer requirements can be calculated, if nutrient uptake requirements of the crops concerned are known. An example is given below:

If one wants to raise the maize yield level from 1300 kg/ha to 2250 kg/ha (i.e. raise soil nutrient uptake from class D3 to C2, see Table 5), the available N, P and K in the soil has to be increased from 35, 6 and 50 kg/ha to 55, 9 and 80 kg/ha, respectively.

Assuming a respective fertilizer recovery rate of 50%, 10% and 50% (as experienced in the Kilifi area, but lower rates were common also), it means that (55-35)x100:50kgN, (9-6)x100:10kgP and (80-50)x100:50kgK, i.e. 40 kg N; 30 kg P; and 60 kg K per ha has to be applied.

Recovery rates are dependent on soil conditions and have to be established by trials in the GASP areas; also the relation of nutrient uptake and yield levels of maize and other crops has to be assessed in the most widespread soil types in the schemes.

Recommendations for fertilizer applications for maintenance of soil fertility and higher yields have been given in A.H.T.(1985). These appear in the same order of magnitude as the above calculated. It can be advised here to follow AHT's recommendations untill field trial results justify modifications. The reportedly adequate levels of Potassium, however, may turn out to be limiting once N P fertilizer has been applied.

AHT's data, applicable to the present survey area, are summarized in Table 10. However, these data only refer to amounts recommended, in case one decides to use chemical fertilizers. The figures do not necessarily imply that fertilizer application is advisable in the context of planning sustainable forms of landuse. See Section 5.5.

Table 10 Recommended fertilizer application in kg/ha for Maize and Cotton, after A.H.T., 1985. Data extrapolated over similar soil types. See also Section 5.5

Mapping Unit	Maize			Cotton		
	N	P	K	N	P	K
1 PL1	30	25	-	25	12	-
2 PL2	30	25	-	25	12	-
3 PL3	10	12	-	12	-	
4 PL3p						
5 PA1	40	35	-	35	20	-
6 PA2	35	35	-	35	15	-
7 PA3	30	30	-	30	15	
8 PA4	30	30	-	30	15	-
9 PA5	30	30	-	30	15	-
10 PA5p	25	25	-	35	12	-
11 PA5f						
12 PA6	30	30	-	30	15	-
13 PA7						
14 PA7p						
15 PJ1						
16 PJ2						
17 AA						
18 C1	30	30	-	30	15	-
19 C230	30/10	30/12	-	30/12	15/-	-

5.3.3 Erosion hazard

Signs of runoff and "sealing" of the soil surface, leading to a reduced infiltration capacity, are present in the Pleistocene beach ridges in the Katsaka Kairu area (Mapping unit 7: PA3).

This is related to the relatively sloping character of the land and attributable to the fine-sandiness or siltiness of the soil texture, in combination with past agricultural activities.

Factors determining erosion are the erosivity of rain (rainfall intensity), susceptibility of the soil surface to detachment of soil particles, slope degree, and protective cover of the vegetation.

Data on **rainfall erosivity** have not been consulted; it is assumed that there is no differentiation among this factor in the survey area.

Soil erodibility depends on infiltration capacity, which is a function of topsoil structure, organic matter content, and texture. The mapping units that have medium

sand or loamy medium sand topsoils, with, or practically without organic matter, have a sufficient infiltration capacity: rainwater runoff has not been observed, even on somewhat sloping positions (such as in map unit 8: PA4).
Soils with a distinctly higher clay content in the topsoil, such as map units 1 and 2: PL1 and PL2, do show slight signs of runoff. However, as slope degrees are negligible, and of short length in these units, the erosion features are not regarded as potentially leading to serious soil degradation under the future farming practices.
The loamy fine sands as occur in the pleistocene beach ridges of the Katsaka Kairu area, however, are sensitive to rainsplash detachment. Some sheet erosion is in progress there.
The factor **slope degree and -length** is an insignificant one in the present survey area. Slopes are all less than 1%; except in clear beach-ridge-like landforms, where land locally slopes up to 3%, such as in map units 7 and 8: PA3 and PA4.
Vegetation cover has not been taken into consideration.

Table 11 Erosion hazard: Ratings of Map Units

Mapping Unit	Slope[1]	Erodibility[2]	Final rating[3]
1 PL1	1/2**	2	S1/S1-2**
2 PL2	1/2**	2	S1/S1-2**
3 PL3	1	2	S1
4 PL3p	1	2	S1
5 PA1	1/2**	1	S1
6 PA2	1	1	S1
7 PA3	2	1	S1
7 PA3*	3	3	S2
8 PA4	2	1	S1
9 PA5	1	1	S1
10 PA5p	1	1	S1
11 PA5f	1	1	S1
12 PA6	1	1	S1
12 PA6*	1	3	S1-2
13 PA7	1	1	S1
14 PA7p	1	1	S1
15 PJ1	1	2	S1
16 PJ2	1	2	S1
17 AA	1	1	S1
18 C1	1	1	S1
19 C2	1	1	S1

1 Subrating Slope: 1 = 0-1%; 2 = 1-3%; 3 = >3%
2 Subrating Erodibility: Surface Texture: 1 = coarse sandy surface; 2 = clayey surface; 3 = fine sandy, silty surface
3 Final rating: Sum of subratings: 2 and 3 = S1, low hazard; 4 and 5 = S1-2, low - moderate hazard; 6 = S2, moderate hazard
* Katsaka Kairu area
** locally steeper parts: "escarpments"

Table 11 gives ratings for slope and erodibility for each mapping unit, and a final rating for erosion hazard. It will be obvious that soil erosion is not a limiting factor for future agricultural practices. However, contour plowing on locally occurring "steeper" land, especially in the Katsaka Kairu Area (map unit 7: PA3*) and in places of units 1, 2 and 5: PL1, PL2 and PA1 (along the "escarpments"), must be considered necessary.

5.3.4 Drainage conditions, oxygen availability

Plant roots need oxygen. Soils that are not well aerated through for instance poor drainage conditions pose limitations to crop growth. The land characteristic "drainage condition" is highly variable in space and time in the planned setlement schemes. In many areas either the groundwater, or a stagnant layer of rainwater features for longer or shorter periods in the root zone. Intensity and amount of rain is responsible, in cooperation with an impervious clay layer at some depth, and the relative topographic position of the area. The vast permeable layer of sand in the "sand-over-clay" soils allows for considerable lateral movements of soil water, such as is obviously the case in the northern parts of LKSS-II.

The presence of shallow groundwater is considered an obstruction to root development, especially for tree crops, banana's, pawpaw. Likewise, the risk of a rising watertable during the cropping season is high in a number of map units, and can obviously be harmfull to a number of annual crops (maize, simsim).

Ratings are given in Table 12.

Table 12 Oxygen Availability: Ratings of Map Units

Mapping Unit	Tree crops, maize, sesame	(Other) annual crops
1 PL1	S1-2	S1
2 PL2	S1-2	S1
3 PL3	S3-N	S2-3
4 PL3p	N	S3-N
5 PA1	S1-2	S1
6 PA2	S1	S1
7 PA3	S1	S1
8 PA4	S1	S1
9 PA5	S2-3	S1-2
10 PA5p	S3-N	S2-3
11 PA5f	N	S3-N
12 PA6	S2-3	S2
13 PA7	S3-N	S3
14 PA7p	N	S3-N
15 PJ1	N	S3-N
16 PJ2	N	S3-N
17 AA	N	N
18 C1	S2/S3	S1/S2
19 C2	S2/N	S2/S3

5.3.5 Ease of cultivation

Workability of the topsoil, or ease of cultivation, is a particularly important landquality for low level technology farming, as cultivation is mainly done by use of handtools.

Factors involved are: topsoil consistence (important for use of handtools), presence of stones and rock outcrops (important for use of tractor, animal traction); and steepness of the land. The latter characteristic is nowhere in the schemes of such condition that it has any impact on ease of cultivation, except perhaps where contour plowing is advisable in view of soil erosion hazard.
Table 13 gives ratings for consistence and rockiness of map units in view of cultivation by handtools, animal traction, and use of tractor. Heavy clay soils are considered unsuitable for cultivation by hand; soils with rock outcrops are unsuitable for mechanized agriculture.

Table 13 Ease of Cultivation: Ratings of Map Units

Mapping Units	Surface consistence[1]	Rockiness[2]	Drainage conditions[3]	Suitability (hand tools)	Suitability (mech, agr.)
1 PL1	2	1	1	S2	S1
2 PL2	2	3	1	S2	N
3 PL3	3	1	2	S3	S2
4 PL3p	3	1	3	N	S3
5 PA1	1-2	1	1	S1	S1
6 PA2	1	1	1	S1	S1
7 PA3	1	1	1	S1	S1
8 PA4	1	1	1	S1	S1
9 PA5	1	1	1	S1	S1
10 PA5p	1	1	2	S1	S1
11 PA5f	1	1	3	S1	S3
12 PA6	1	1	1	S1	S1
13 PA7	1	1	1	S1	S1
14 PA7p	1	1	3	S1	S3
15 PJ1	3	1	2	S3	S2
16 PJ2	3	1	3	N	S3
17 AA	2-3	1	3	N/S2	S3
18 C1	1	1	1	S1	S1
19 C2	1/3	1	2	S1/S2	S1/S2

[1] 1 = loose, very friable; 3 = very sticky, very hard
[2] 1 = non-rocky; 3 = rocky
[3] 1 = well, mod. well drained; 3 = poorly, very poorly drained.

5.3.6 Soil toxicity: salinity and sodicity

Soil salinity may hamper root development and may cause moisture stress. Electrical conductivity (EC) is directly related to concentration of salts. High EC values were found in the subsoils in lagoonal deposits (Units PJ) and at many sites very high values in the topsoils of the floodplain soils (Unit AA). Sodicity may be

detrimental to soil structure and porosity. The high Exchangeable Sodium Percentage figures (ESP) that were found, coincide with high EC figures in subsoils. Sodicity is not further taken in consideration in the present ratings. Establishing ratings for the mapping units, subsoil salinity is regarded a limitation for treecrops more than for annuals. Topsoil salinity renders land that is in a low position, like unit AA, unsuitable for agriculture.
Ratings are given in Table 14.

Table 14 Soil toxicity (Salinity, Sodicity), Ratings of Map Units

Mapping unit	Annuals (rooting 0-60 cm)	Tree crops (rooting 0-120 cm)
1 PL1	S1	S1
2 PL2	S1	S1
3 PL3	S1	S1
4 PL3p	S1	S1/S3
5 PA1	S1	S1
6 PA2	S1	S1
7 PA3	S1	S1
8 PA4	S1	S1
9 PA5	S1	S1
10 PA5p	S1	S1
11 PA5f	S1	S1
12 PA6	S1	S1
13 PA7	S1	S1
14 PA7p	S1	S2
15 PJ1	S3	N
16 PJ2	N	N
17 AA	N	N
18 C1	S1	S1
19 C2	S1	S1/S3

5.4 Suitability Classification

The preceding paragraphs deal with the performance of land mapping units in respect of individual land qualities: For each land quality an indication is given to what extent there is a limitation to the success of low technology farming in each map unit. These **ratings** appear assembled in Table 15.

To arrive at final ratings for each crop, given in Table 16, the following steps were taken:

1 Combine moisture availability ratings of Table 15 with data of Tables 3a, b, and 1 to arrive at moisture availability ratings for individual crops in each map unit;
2 Refer to Table 6 to arrive at soil fertility ratings for individual crops in each map unit;
3 Of all ratings, moisture availability, fertility and the others of Table 15 combined, the lowest determines the final suitability class.

The symbols of suitability classes in Tables 15 and 16 have the following (tentative) connotation:

S1 Suitable. Likely more than 60% of normative yield
S2 Moderately suitable. Between 40 and 60% of normative yield
S3 Marginally suitable. Likely less than 40% of normative yield
N Not suitable. Likely less than 20% of normative yield.

Suffixes indicate the character of the limitation:

m Limitations due to moisture stress
f Limitations due to low soil fertility
e Limitations due to erosion hazard
d Limitations due to oxygen stress in the root zone
s Limitations due to soil salinity
w Limitations as to ease of cultivation, "workability".

For example, for maize, the unit PA4 in the LKSS-II area indicates S3f, i.e. this unit is marginally suitable for maize, primarily due to lack of soil nutrients. Unit PA5p is marginally suitable to unsuitable for citrus, due to moisture stress and drainage conditions: S3md-N, etc.
Table 17 forms the final result of the suitability assessment of the present GASP soils study area. It is the basis for recommendations on land use and physical planning.

5.5 Recommended Land Use

Recommendations for future land use are based on a selection of the land, that is "best" suited (i.e. least limitations), matched with the most desirable, productive or just feasible use.
Most productive/desirable is obviously rainfed farming, standard size family plot, with annual crops like maize and cotton and a wide choice of additional crops. Communal grazing is feasible on land, that is rated agriculturally unsuitable. In between these two extremes, that are rather easily identifiable, but restricted in extent, there are other options.

In Table 17 some relevant forms of landuse, categorized according to choice of crops/produce, and some desirable or required management aspects are set out against the map units with their final suitability levels of table 16. The highest attainable categories have been indicated, in some cases along with feasible alternatives. An important criterium is, that in cases of marginal suitability levels (Table 16) a less demanding use of the land is preferred. The resulting most desirable form of land use is indicated for each map unit, resulting in the following 6 land use types:

1 Rainfed farming; standard plot size; wide choice of crops; manuring recommended, chemical fertilizer use feasible.

2 Rainfed farming; standard plot size; choice of crops limited to low nutrient and moisture demanding crops (maize, cotton, sorghum not recommended, unless adequate manuring is a standard part of the system; coconut, citrus, not recommended); application of manure prerequisite for sustained crop production. Application of chemical fertilizer less feasible.

3 Rainfed farming; enlarged plot size; choice of crops limited to those tolerant to drought, low soil fertility and/or poor drainage conditions; application of manure prerequisite, application of chemical fertilizer not recommended.

4 (Agro-)Forestry; enlarged plot size; emphasis on adapted tree crops (Mango, cashew) and adapted timber/fuelwood, with small livestock.

5 (Agro-)Forestry; communal land, no demarcation of plots; adapted timber/fuelwood and/or (small) livestock.

6 Extensive grazing; communal land, no demarcation of plots; Wildlife protection.

Distribution of these recommended land use types is shown in figures 5[a] and 5[b].

2 Rainfed farming; standard plot size; choice of crops limited to low nutrient and moisture demanding crops (maize, cotton, sorghum not recommended, unless adequate manuring is a standard part of the system; coconut, citrus, not recommended); application of manure prerequisite for sustained crop production. Application of chemical fertilizer less feasible.

3 Rainfed farming; enlarged plot size; choice of crops limited to those tolerant to drought, low soil fertility and/or poor drainage conditions; application of manures prerequisite, application of chemical fertilizer not recommended.

4 (Agro-)Forestry; enlarged plot size; emphasis on adapted tree crops (Mango, cashew) and adapted timber/fuelwood, with small livestock.

5 (Agro-)Forestry; communal land, no demarcation of plots; adapted timber/fuelwood and/or (small) livestock.

6 Extensive grazing; communal land, no demarcation of plots; Wildlife protection.

Distribution of these recommended land use types is shown in figures 5 and 6.

Table 15 Final Ratings of Land Qualities per Map Unit

Soil Mapping Unit	Location, AESZ [1]	Moisture Availability (Tables 3a & b)		Soil Fertility per Crop Group (Table 9)			Erosion Hazard (Table 11)	Oxygen Availability (Table 12)		Soil Salinity (Table 14)		Ease of cultivation (Table 13)	
		Ann.	Tree crops	I	II	III		Ann.	Tree crops	Ann.	Tree crops	Hand-tools	Mecha-nized
1 PL1	WSS: W.-Kip.	S1-2	S1	S1	S1	S2	S1/S1-2	S1	S1-2	S1	S1	S2	S1
1 PL1	LKSS-II	S2-3	S1	S1	S1	S2	S1	S1	S1-2	S1	S1	S2	S1
2 PL2	WSS: W.-Kip.	S2/S3-N	S1/S3	S1	S1	S2	S1/S1-2	S1	S1-2	S1	S1	S2	N
3 PL3	WSS: W.-Kip.	S2-3	S1-2	S1	S1	S2	S1	S2-3	S3-N	S1	S1	S3	S2
3 PL3	LKSS-II	S3	S2-3	S1	S1	S2	S1	S2-3	S3-N	S1	S1	S3	S2
4 PL3p	WSS: W.-Kip.	S2	S2	S1	S1	S2	S1	S3-N	N	S1	S1/3	N	S3
4 PL3p	LKSS-II	S3	S3	S1	S1	S2	S1	S3-N	N	S1	S1	N	S3
5 PA1	WSS: W.-Kip.	S1-2	S1	S1	S1	S2	S1	S1	S1-2	S1	S1	S1	S1
6 PA2	WSS: W.-Kip.	S2	S1	S1	S2	S3	S1	S1	S1	S1	S1	S1	S1
6 PA2	LKSS-II	S3	S2	S1	S2	S3	S1	S1	S1	S1	S1	S1	S1
7 PA3	WSS: W.-Kip.	S2	S1-2	S1	S2	S3	S1	S1	S1	S1	S1	S1	S1
7 PA3	WSS: Kats.K.	S3'-N	S3	S1	S2	S3	S2	S1	S1	S1	S1	S1	S1
8 PA4	WSS: W.-Kip.	S3	S2	S1	S2	S3	S1	S1	S1	S1	S1	S1	S1
8 PA4	LKSS-II	S3'	S3	S1	S2	S3	S1	S1	S1	S1	S1	S1	S1
9 PA5	WSS: W.-Kip.	S3	S2	S1	S2	S3	S1	S1-2	S2-3	S1	S1	S1	S1
9 PA5	LKSS-II	S3'	S3	S1	S2	S3	S1	S1-2	S2-3	S1	S1	S1	S1
9 PA5	WSS: Kats.K.	S3'-N	S3-N	S1	S2	S3	S1	S1-2	S2-3	S1	S1	S1	S1
10 PA5p	WSS: W.-Kip.	S2	S2	S2	S3	N	S1	S2-3	S3-N	S1	S1	S1	S1
10 PA5p	LKSS-II	S3	S3	S2	S3	N	S1	S2-3	S3-N	S1	S1	S1	S1
11 PA5f	LKSS-II	S3	S3	S2	S3	N	S1	S3-N	N	S1	S1	S1	S3
12 PA6	WSS: W.-Kip.	S2	S2	S1	S2	S3	S1	S2	S2-3	S1	S1	S1	S1
12 PA6	LKSS-II	S3	S2-3	S1	S2	S3	S1	S2	S2-3	S1	S1	S1	S1
12 PA6	WSS: Kats.K.	S3'-N	S3	S1	S1	S2	S1-2	S2	S2-3	S1	S1	S1	S1
13 PA7	WSS: W.-Kip.	S2	S2	S1	S2	S3	S1	S3	S3-N	S1	S1	S1	S1
13 PA7	LKSS-II	S3'	S2-3	S1	S2	S3	S1	S3	S3-N	S1	S1	S1	S1
13 PA7	WSS: Kats.K.	S3'-N	S3-N	S1	S2	S3	S1	S3	S3-N	S1	S1	S1	S1
14 PA7f	WSS: W.-Kip.	S2	S2-3	S2	S3	N	S1	S3-N	N	S1	S2	S1	S3
14 PA7f	LKSS-II	S3	S3	S2	S3	N	S1	S3-N	N	S1	S2	S1	S3
15 PJ1	WSS: Kats.K.	S3'-N	N	S1	S2	S3	S1	S3-N	N	S3	N	S3	S2
16 PJ2	WSS: W.-Kip.	S2	S2	S1	S1	S2	S1	S3-N	N	N	N	N	S3
16 PJ2	WSS: Kats.K.	S3'-N	N	S1	S1	S2	S1	S3-N	N	N	N	N	S3
17 AA	WSS: W.-Kip.	-	-	S1	S1	S2	S1	N	N	N	N	N/S2	S3
17 AA	WSS: Kats.K.	-	-	S1	S1	S2	S1	N	N	N	N	N/S2	S3
18 C1	WSS: W.-Kip.	S2	S2/S1-2	S1	S2	S3	S1	S1/2	S2/3	S1	S1	S1	S1
19 C2	WSS: W.-Kip.	S3	S1-2/S2	S1	S2	S3	S1	S2/3	S2/N	S1	S1/3	S1/3	S1/2

[1]) WSS: Witu Settlement Scheme; W.-Kip.: Witu-Kipini area; Kats.K.: Katsaka Kairu area; LKSS-II: Lake Kenyatta Extension area

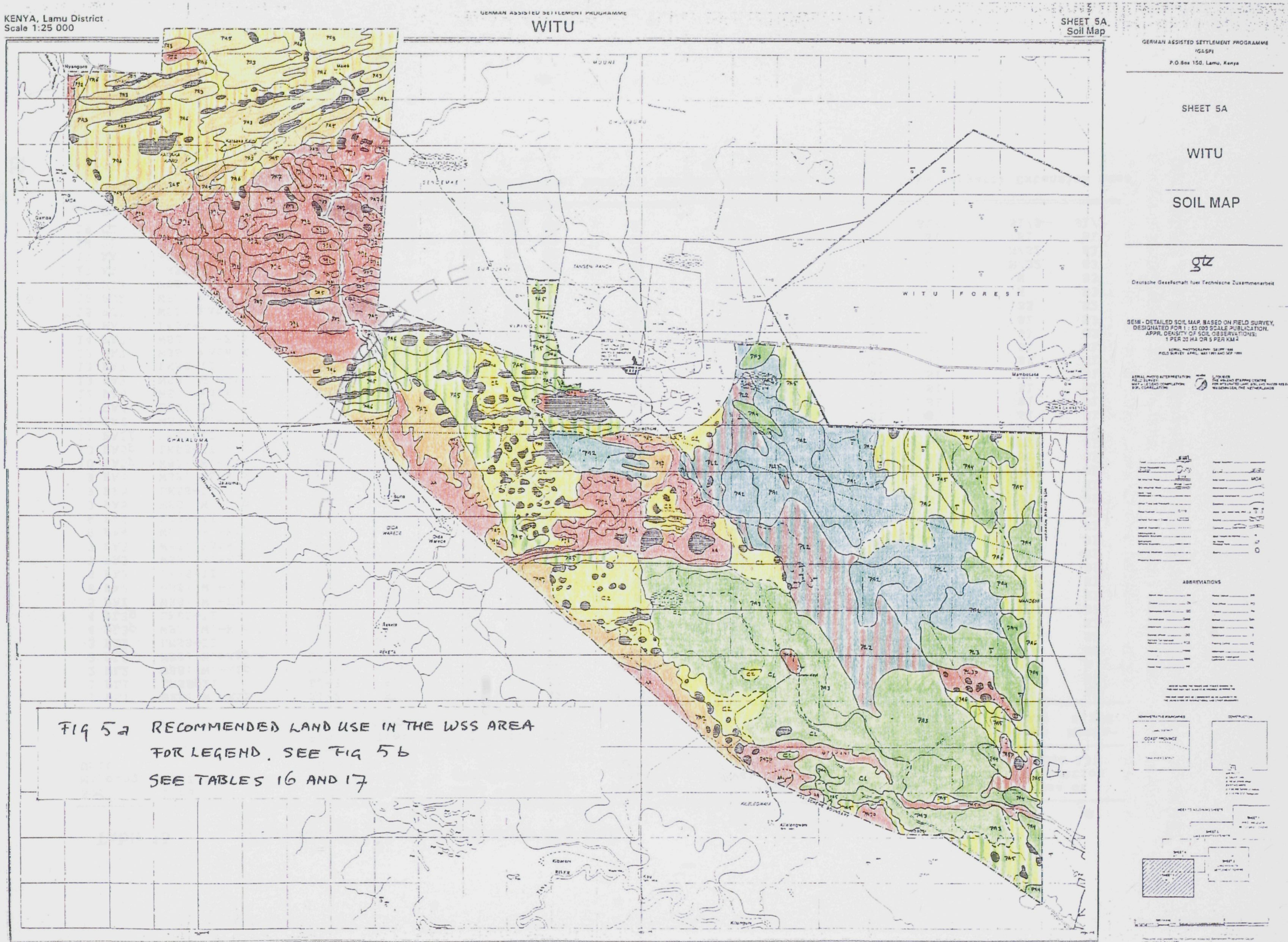


FIG 5a RECOMMENDED LAND USE IN THE WSS AREA
FOR LEGEND. SEE FIG 5b
SEE TABLES 16 AND 17

Table 16 Final land suitability ratings per land unit, for individual crops

Soil Mapping Unit	Location, AESZ [1]	Coconut	Banana	Citrus	Pawpaw	Bixa	Cassava	Cashew	Mango	Simsim	Cotton	Tomatoe	Green Gram	Chinese Cabbage	Maize	Cowpea	Doli-chos Bean	Onion	Sweet Potatoe	Millet	Sunflo-wer	Sorghum
1 PL1	WSS: W.-Kip.	S2m	S2m	S2m	S1	S1	S1	S1	S1	S2mw	S2fw	S1-2w	S1-2w	S1-2w	S2fw	S1-2w	S1-2w	S1-2w	S1-2w	S1-2w	S1-2w	S2fw
1 PL1	LKSS-II	S2m	S2m	S2m	S1	S1	S1	S1	S1	S2mw	S2mf	S2mw	S2mw	S1-2w	S2fm	S1-2w	S1-2w	S1-2w	S1-2w	S1-2w	S1-2w	S2fw
2 PL2	WSS: W.-Kip.	S2m/N	S2m/N	S2m/N	S1/N	S1/N	S1/N	S1/N	S1/N	S2/N	S2/N	S2/N	S2/N	S1-2/N	S2/N	S1-2/N	S1-2/N	S1-2/N	S1-2/N	S1-2/N	S1-2/N	S2/N
3 PL3	WSS: W.-Kip.	S3d	S3d	S3d	S3d	S3d	S3d	S3d	S3d	S3dw	S3w	S3wd	S3wd	S3wd	S3dw	S3wd	S3wd	S3wd	S3wd	S3wd	S3wd	S3w
3 PL3	LKSS-II	S3dm	S3dm	S3dm	S3d	S3d	S3d	S3d	S3d	S3dw	S3mw	S3wd	S3wd	S3mw	S3dw	S3wd	S3wd	S3wd	S3wd	S3wd	S3wd	S3w
4 PL3p	WSS: W.-Kip.	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
4 PL3p	LKSS-II	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
5 PA1	WSS: W.-Kip.	S2m	S2m	S2m	S1	S1	S1	S1	S1	S2m	S2mf	S2m	S1	S1	S2f	S1	S1	S1	S1	S1	S1	S2f
6 PA2	WSS: W.-Kip.	S2m	S2mf	S2m	S2f	S1	S2f	S1	S1	S2m	S3f	S2mf	S2m	S2f	S3f	S1	S1	S2f	S2f	S1	S2f	S3f
6 PA2	LKSS-II	S3m	S3m	S3m	S2mf	S2m	S2f	S1	S1	S2m	S3mf	S2mf	S2m	S2f	S3f	S2m	S2m	S2mf	S2mf	S1*	S2*f	S3*f
7 PA3	WSS: W.-Kip.	S2m	S2mf	S2m	S2mf	S2m	S2f	S1	S1	S2m	S3f	S2mf	S2m	S2f	S3f	S1-2m	S1-2m	S2f	S2f	S1*	S2*f	S3*f
7 PA3	WSS: Kats.K.	N	N	N	S3m	S3m	S2mf	S2m	S1	S3m-N	S3m-N	S3m-N	S3me	N	S3*m	S2me	S2me	S2*m	S3m-N	S2*m	S2*m	S3*f
8 PA4	WSS: W.-Kip.	S3m	S3m	S3m	S2mf	S2m	S2f	S1	S1	S2m	S3m	S2mf	S2m	S2f	S3f	S2m	S2m	S2mf	S2mf	S1*	S2*f	S3*f
8 PA4	LKSS-II	S3m-N	S3m-N	S3m-N	S3m	S3m	S2fm	S2m	S1	S3m	S3m-N	S2-3m	S2m	N	S3*f	S2m	S2m	S2mf	S2mf	S2*m	S2*m	S3*f
9 PA5	WSS: W.-Kip.	S3m	S3m	S3m	S2fd	S2md	S2d	S2-3d	S2d	S2md	S3mf	S2mf	S2m	S2f	S3f	S2m	S2m	S2mf	S2mf	S1*	S2*f	S3*f
9 PA5	LKSS-II	S3m-N	S3m-N	S3m-N	S3m	S3m	S2md	S2-3d	S2d	S3md	S3m-N	S2-3m	S2m	N	S3*f	S2m	S2m	S2fm	S2fm	S2*m	S2*m	S3*f
9 PA5	WSS: Kats.K.	N	N	N	S3m-N	N?	S2*m	S3md	S2-3m	S3m-N	S3m-N	S3m	S2m	N	S3*f	S2m	S2m	S2*m	S2-3f	S2*m	S2*m	S3*f
10 PA5p	WSS: W.-Kip.	S3md	S3md	S3m-N	S3fd	S3d	S3fd	S3d-N	S3d	S3d-N	N	S3fd	S3d	S3f	N	S2-3d	S2-3d	S3f	S3f	S2-3d	S3f	N
10 PA5p	LKSS-II	S3m-N	S3m-N	S3m-N	S3md	S3md	S3md	S3d-N	S3d	S3d-N	N	S3fd	S3d	S3fm	N	S2-3d	S2-3d	S3f	S3f	S2-3d	S3f	N
11 PA5f	LKSS-II	N	N	N	N	N	S3d-N	N	N	N	N	S3f-N	S3d-N	N	N	S3d	S3d	S3df	S3df	S3d	S3df	N
12 PA6	WSS: W.-Kip.	S2dm	S2df	S2dm	S2df	S2d	S2df	S2-3d	S2d	S2-3d	S3f	S2df	S2md	S2md	S3fd	S2d	S2d	S2f	S2f	S2d	S2fd	S3f
12 PA6	LKSS-II	S3m-N	S3m-N	S3m-N	S2md	S2md	S2df	S2-3d	S2d	S2-3d	S3mf	S2mf	S2md	S3md	S3fd	S2md	S2md	S2mf	S2mf	S2d	S3fd	S3f
12 PA6	WSS: Kats.K.	N	N	N	S3md	S3m	S2m	S2-3d	S2d	S2-3m	S3m-N	S3m	S2md	N	S3*m	S2md	S2md	S2*m	S3m	S2*m	S2*m	S2*m
13 PA7	WSS: W.-Kip.	S3d-N	S3d-N	S3d-N	S3d-N	S3d	S3d	S3d-N	S3d-N	S3d-N	S3fd	S3d	S3d	S3d	S3d-N	S3d	S3d	S3d	S3d	S3d	S3d	S3fd
13 PA7	LKSS-II	S3m-N	S3m-N	S3m-N	S3d-N	S3m-N	S3d	S3d-N	S3d-N	S3d-N	S3fd	S3d	S3d	S3md	S3d-N	S3d	S3d	S3d	S3d	S3d	S3d	S3fd
13 PA7	WSS: Kats.K.	N	N	N	N	N	S3d	S3d-N	S3d-N	N	N	S3m-N	S3d	N	S3*-N	S3d	S3d	S3*d	S3dm	S3*d	S3*d	S3*f
14 PA7f	WSS: W.-Kip.	N	N	N	N	N	N	N	N	N	N	S3d-N	S3d-N	S3d	N	S3d-N	S3d-N	S3f-N	S3d-N	S3d-N	S3d-N	N
14 PA7f	LKSS-II	N	N	N	N	N	N	N	N	N	N	S3d-N	S3d-N	S3dm	N	S3d-N	S3d-N	S3fd	S3fd	S3d-N	S3d-N	N
15 PJ1	WSS: Kats.K.	N	N	N	N	N	N	N	N	N	N	S3d-N	S3d-N	S3d-N	N	S3d-N	S3d-N	S3d-N	S3d-N	S3d-N	S3d-N	S3fw
16 PJ2	WSS: W.-Kip.	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
16 PJ2	WSS: Kats.K.	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
17 AA	WSS: W.-Kip.	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
17 AA	WSS: Kats.K.	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
18 C1	WSS: W.-Kip.	S2d/3m	S2d/3m	S2d/3m	S2fd	S2md	S2d/2f	S2-3d	S2d	S2-3d	S3f	S2f/2d	S2m/2d	S2m/2d	S3f/3d	S1 /2d	S1 /2d	S2f	S2f	S1 /2d	S2f/2d	S3f
19 C2	WSS: W.-Kip.	S2m/3d	S2f/3d	S2m/3d	S2f/3d	S2d/3d	S2f/3d	S3d	S2d/3d	S3d/3w	S3f/3w	S2f/3w	S2m/3d	S2m/3w	S3f/3d	S2d/3w	S2d/3w	S2f/3w	S2f/3w	S2d/3w	S2f/3w	S3f/3w

* in case of early maturing, cq drought resistant cultivars

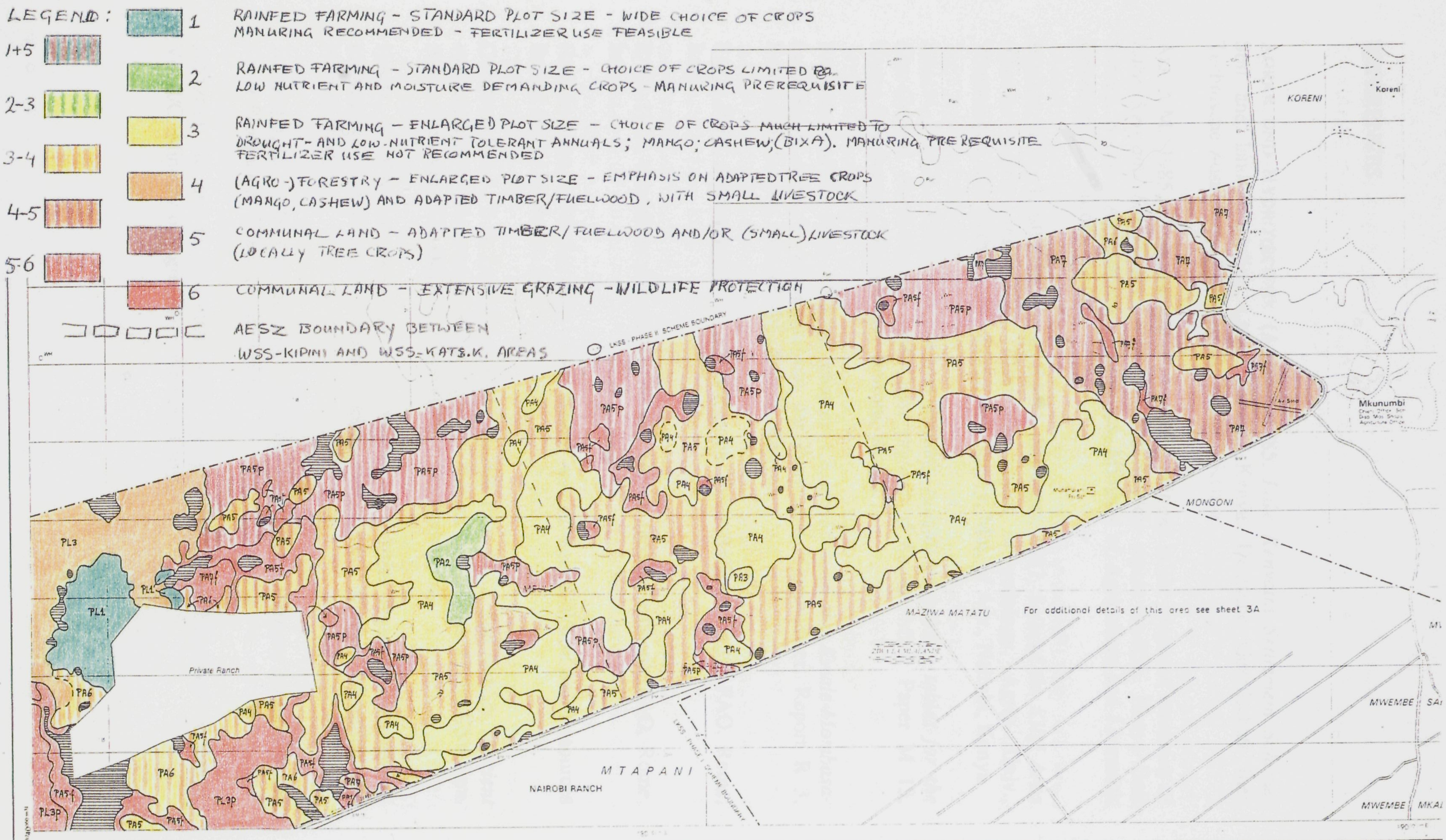
[1]) WSS: Witu Settlement Scheme; W.-Kip.: Witu-Kipini area; Kats.K.: Katsaka Kairu area; LKSS-II: Lake Kenyatta Extension area

Table 17 Recommended Land Use: For description of recommended land use types, see text; see figs. 5a and 5b
+ - recommended;
o - second choice alternative

Soil Mapping Unit	Location, AESZ [1]	Rainfed farming							Fuel-wood, Timber, with small livestock	Communal Grazing		Wildlife Protec-tion	Management Aspects			Physical Planning Aspects			Recommended Land Use Type: See Text; See Fig. 5a & 5b
		Annuals				Tree crops													
		All	All, except Maize, Cotton, Sorghum	All, except Cotton, Vegeta-bles	All, except Maize, Simsim	All	All, except Citrus Coconut Banana	Only Mango, Cashew Bixa		Cattle Gra-zing	Sheep & Goats		Ferti-lizer Appli-cation Feasi-ble	Manu-ring Pre-requi-site	Erosion Control Desira-ble	Stand-ard Plot Size	Enlar-ged Plot Size	Commu-nal Land: No Plot Demar-cation	
1 PL1	WSS: W.-Kip.	+				+							+			+			1
1 PL1	LKSS-II	+				+							+			+			1
2 PL2	WSS: W.-Kip.	o				o			+		o		o				+		1 or 5
3 PL3	WSS: W.-Kip.								+		o	+					+	o	4
3 PL3	LKSS-II								+		+	+					+	o	4
4 PL3p	WSS: W.-Kip.									+		+						+	6
4 PL3p	LKSS-II									+		+						+	6
5 PA1	WSS: W.-Kip.	+				+							+			+			1
6 PA2	WSS: W.-Kip.	o	+			+							o	+		+			1
6 PA2	LKSS-II	o	+				+						o	+		+			2
7 PA3	WSS: W.-Kip.		+			+								+		+			2
7 PA3	WSS: Kats.K.			o				+	+					o	+	o	+		4
8 PA4	WSS: W.-Kip.	o	+			o	+							+		+	o		2
8 PA4	LKSS-II		+				o	+	o					+			+		3
9 PA5	WSS: W.-Kip.	o	+			o	+							+		+	o		2-3
9 PA5	LKSS-II		+	o			o	+	+					+			+		3-4
9 PA5	WSS: Kats.K.		+	+				o	+		+			+			+		4
10 PA5p	WSS: W.-Kip.								o		+	+						+	5-6
10 PA5p	LKSS-II								o		+	+						+	5-6
11 PA5f	LKSS-II										+	+						+	6
12 PA6	WSS: W.-Kip.	o	+		o	+							o	+		+			2-3
12 PA6	LKSS-II		+		o		o	+	+					+			+		3-4
12 PA6	WSS: Kats.K.		o	o	o		o	+	+		+			+	o		+		3-4
13 PA7	WSS: W.-Kip.		o	o	o			o	+	+	+			o			o	+	4
13 PA7	LKSS-II		o	o	o			o	+	+	+						o	+	4-5
13 PA7	WSS: Kats.K.		o	o	o			o	+	+	+						o	+	5
14 PA7f	WSS: W.-Kip.									+								+	6
14 PA7f	LKSS-II									+	+	+						+	6
15 PJ1	WSS: Kats.K.									o	+	+						+	6
16 PJ2	WSS: W.-Kip.									+		+						+	6
16 PJ2	WSS: Kats.K.									+		+						+	6
17 AA	WSS: W.-Kip.									+		+						+	6
17 AA	WSS: Kats.K.									+		+						+	6
18 C1	WSS: W.-Kip.	o	+											+		+			2
19 C2	WSS: W.-Kip.		o		+	o			+					+			+	+	3

[1]) WSS: Witu Settlement Scheme; W.-Kip.: Witu-Kipini area; Kats.K.: Katsaka Kairu area; LKSS-II: Lake Kenyatta Extension area

FIG 5b RECOMMENDED LAND USE IN THE LKSS-II AREA SEE TABLES 16 AND 17



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ANNEX 1 DESCRIPTION OF SOIL MAPPING UNITS

MAPPING UNIT 1: PL1

SURFACE AREA:
WSS, Lamu District: 13 ha; 0.5%
WSS, Tana River District: 278 ha; 3.5%
LKSS II: 136 ha; 2.1%

LANDFORM, GEOLOGY:
Almost flat coastal plain, cq. marine terrace. Soils developed on deeply weathered coral rock.

VEGETATION:
Tall grassland of predominantly *Hyparrhenia cymbaria*, with clusters of dense bush, and with abundant Doum palms (*Hyphaene coriacea*) and scattered old Mango trees.

SOILS:
Well drained, very deep, yellowish red to dark red, friable, sandy clay to clay; locally with a lighter textured topsoil.
The topsoil is well developed, with a fair amount of organic matter (1-1.5% in the top 20 cm). It is a sandy clay loam with friable consistence when moist, and has a moderate, fine to medium subangular blocky structure. The transition to the subsoil is gradual. Due to the relative high clay content, infiltration rate is lower in comparison to other units. Some local runoff under heavy rainfall occurs.
The subsoil is well aerated to more than 1.20 m depth: there are no signs of a temporary high groundwatertable. It has a good waterholding capacity, and there is no hindrance to root development. Structure is weak angular blocky to porous massive, moderately coherent. Consistence is firm when moist.
Laboratory analysis data: pH-H_2O: 6.5-7.0; pH-KCl: 5-6; low Base Saturation; CEC: 10-20 meq/100g

INCLUSIONS:
A Occurrence of soils with lighter textured topsoils. These form transitions to soils of unit 5:PA1.

GENERAL INTERPRETATION OF DATA:
A Apart from a low nutrient status, these soils do not pose any limitations to rainfed agriculture. They are well aerated; rooting depth is not limited, and due to the relative high clay content and good soil structure, water holding capacity is favourable (around 100mm up to 1m depth). Also the response to fertilizer application is much better in comparison to the more sandy soils of the survey areas, due to the much higher cation exchange capacity: also losses through leaching are much less on these clayey soils.

B: Topsoil organic matter tends to disappear upon prolonged intensive use. This topsoil degradation may take longer than the sandy soils of most other mapping units. However, in this case it will lead to a hard, compacted surface layer, with low infiltration capacity. Due to the almost flat topography (short, very gentle slopes) eventual erosion will be modest and can be checked by simple measures.

CORRELATION WITH A.H.T.(1985):
The soils of this unit are regarded as identical to unit PL1 and PL2 in LKSS-I.
A representative profile is given in Annex 2: No 1.

MAPPING UNIT 2: PL2

SURFACE AREA:
WSS, Lamu District: 117 ha; 4.3%
WSS, Tana River District: 728 ha; 9.2%
LKSS II: 0 ha; 0%

LANDFORM, GEOLOGY:
Almost flat coastal plain, cq Pleistocene marine terrace; very gently undulating mesotopography; locally irregular in relation with rock outcrops. Soils developed over coral rock.

VEGETATION:
Almost exclusively grassland of *Hyparrhenia cymbaria* and *Heteropogon contortus* (over 50% cover), occasionally wooded with Doum palms.

SOILS: Complex of:
a soils of unit 1:PL1, but in many places moderately deep to shallow over coral rock
b outcrops of coral rock

The very deep soils (rock at more than 120 cm depth) do not differ from those as described under mapping unit 1:PL1. The shallow, moderately deep and deep soils (rock within 40, 80 and 120 cm, respectively) tend to have higher clay contents in the topsoils and upper subsoils as compared to the previous unit. Also the topsoils tend to be more shallow (5-10 cm). The soil - bedrock boundary is abrupt and very irregular.

Laboratory analysis data: Cation Exchange Capacity amounts to 10-15 meq/100g soil; pH-H_2O: 6.5; pH-KCl: 5-5.5; Base Saturation is moderately low.

GENERAL INTERPRETATION OF DATA:
A Areas with frequent rock outcrops and/or very shallow soils have a restricted rooting space and hence a limited water holding capacity.
B Mechanical cultivation, and even animal traction will be impossible in much of the area (ca. 40% of the unit).
C The area of this unit needs to be reviewed in more detail, prior to the demarcation/allocation of plots.

Apart from the presence of rock outcrops and frequent shallowness of the soils, these soils are to be rated as among the best of the scheme. See PL1.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are identical to those of units PL1-r and PL1-vr in LKSS-I.

A representative profile is given in Annex 2: profile No. 2.

MAPPING UNIT 3: PL3

SURFACE AREA:
WSS, Lamu District: 0 ha; 0%
WSS, Tana River District: 214 ha; 2.7%
LKSS II: 256 ha; 3.9%

LANDFORM, GEOLOGY:
Almost flat coastal plain, with very gently undulating mesotopography, with seasonal and permanent ponds. Soils are developed over coral rock, under less well drained conditions, and/or clayey lagoonal deposits.

VEGETATION:
Wooded grassland of Doum palms over *Andropogon sp.*, *Heteropogon contortus* and *Digitaria diagonalis*. Clusters of bush thicket are present.

SOILS:
Imperfectly to poorly drained, very deep, yellowish brown to light olive brown, mottled, very firm clay; in places with a thin sandy loam topsoil.
The topsoil is mostly a 10-15cm deep, black to very dark greyish brown, friable to firm sandy clay to sandy clay loam (20-40% clay), with a fair amount of organic matter (1-2%). However, in ca. 30% of the observations topsoils are very thin or hardly perceptible. Locally topsoils are more sandy.
The upper subsoil is a dark greyish brown to yellowish brown clay, that shows cracks in the dry season. The structure is moderate to strong angular blocky; consistence is very hard when dry; very firm when moist, and very sticky and very plastic when wet. The clay is non-calcareous and non-saline.
The deeper subsoil is a yellowish brown to light olive brown, distinctly mottled clay of weak structure. Consistence when moist is firm; very sticky and plastic when wet. In places some calcareous nodules are found at greater depth. Concretions of Manganese oxide are mostly present.

INCLUSIONS:
A Transitional forms with the well drained clays of unit 1: PL1
B Poorly drained and waterlogged local depressions.

GENERAL INTERPRETATION OF DATA:

A The workability of these clay soils poses problems: sticky and plastic when wet, and (very) hard when dry. This disadvantage may be waved, if mechanical or animal traction can be practiced.

B Drainage conditions limit the choice of crops: Maize, Simsim, and most tree crops will suffer from lack of oxygen in the rooting zone.

C The development of the rootsystem of crops is hampered by the the high soil density and the poor drainage conditions.

D Water content at wilting point is high: A certain amount of rain is needed to raise the moisture content to such a level that soil moisture becomes available to plant roots. Infiltration rates, once the surface soils are moist, are very low: occasional rainshowers may shortly pond the surface, and much of this water be lost by evaporation.

E Soils have a relative high natural fertility (high C.E.C.; moderate base saturation); Chemical fertilizers will not be rapidly leached as is the case with the sandy soils.

F These areas have a high potential for grazing.

CORRELATION WITH A.H.T.(1985):
The soils of this unit are identical to units PL3 and PL4 in LKSS-I.

MAPPING UNIT 4: PL3p

SURFACE AREA:
WSS, Lamu District: 0 ha; 0%
WSS, Tana River District: 72 ha; 0%
LKSS II: 158 ha; 2.4%

LANDFORM, GEOLOGY:
Almost flat coastal plain, with very gently undulating mesotopography, with seasonal and permanent ponds. Soils are developed over clayey lagoonal deposits and/or coral rock, under poor drainage conditions.

VEGETATION:
Mostly grassland of *Digitaria diagonalis, Dactyloctaenium aegyptiacum* and *Hyparrhenia*, with scattered small trees, mostly *Acacia* species (*A. seyal; A. senegal; A. mellifera* ?)

SOILS:
The soils of this unit are similar to those of unit 3: PL3, but of much poorer drainage conditions. Also they show signs of salinity, locally in the deeper subsoil.

GENERAL INTERPRETATION OF DATA:
Drainage conditions render this soil unit unsuitable for arable land. Also all other adverse soil conditions as mentioned under unit 3: PL3 prevail here as well

SUITABILITY RATING:
Regarded as unsuitable for rainfed agriculture; locally possibilities for recession agriculture.
The area is also problematic for infrastructure development, such as permanent housing, road maintenance.

MAPPING UNIT 5: PA1

SURFACE AREA:
WSS, Lamu District: 317 ha; 11.5%
WSS, Tana River District: 356 ha; 4.5%
LKSS II: 0 ha; 0%

LANDFORM, GEOLOGY:
Almost flat coastal plain, cq marine terrace, with very gently undulating mesorelief (slopes less than 2%). Soils developed in older aeolian deposits (over deeply weathered coral rock).

VEGETATION:
Wooded grassland of *Hyparrhenia cymbaria* and *Panicum maximum* (30-50% cover) under Doum palms (10-20% cover). Clusters of bush or forest remnants are present.

SOILS:
Well drained, 30-50 cm, dark brown to dark reddish brown, friable, sandy loam to sandy clay loam over very deep, yellowish red, friable to firm, sandy clay.
The topsoil consists of friable, black sandy loam to sandy clay loam, with weak, medium subangular blocky structure. It is well developed, but rather shallow on most places (ca.15 cm). Rain infiltrates rapidly: soil water will be readily available to crops after the first rains. Transition to the subsoil is gradual.
The upper subsoil is a dark brown, friable sandy clay loam to sandy loam up to 50 cm depth, with a moderately coherent, porous massive structure. It has a low nutrient reserve and moderate soil moisture retention.
The deeper subsoil consists of yellowish red to dark red, firm to friable sandy clay, with a moderately coherent porous massive structure. The upper part of the deeper subsoil shows signs of clay illuviation.
Laboratory analysis data: Topsoil contains 0.5-1% Organic Carbon; Available Phosphorus (Mehlig): 12 ppm; Cation Exchange Capacity: 8-10 meq/100g; Base Saturation: 50-75%, increasing with depth.

INCLUSIONS:
A The sandy clay loam upper subsoil merges laterally and rather haphazardly into the more sandy textured upper subsoil of mapping unit 6: PA2. Due to this, the boundary between these two units is poorly identified.

GENERAL INTERPRETATION OF DATA:
Apart from the rather low nutrient status, no serious restrictions to arable farming are foreseen on these soils.
They are well aerated to greater depth; the soils have ample rooting space, also for tree crops; The friable topsoil allows favourable infiltration rates and easy "workability".

CORRELATION WITH A.H.T.(1985):
soils of this mapping unit are comparable to those of units PA2 and PA1 in LKSS-I.

MAPPING UNIT 6: PA2

SURFACE AREA:
- WSS, Lamu District: 417 ha; 15.2%
- WSS, Tana River District: 453 ha; 5.7%
- LKSS II: 55 ha; 0.8%

LANDFORM, GEOLOGY:
Very gently undulating coastal plain, cq Pleistocene marine terrace, with very gently undulating mesotopography. Soils are developed in deeply weathered coral rock, overlain by sandy aeolian/lagoonal deposits.

VEGETATION:
Wooded grassland of Doum palms (5-10% cover) over *Hyparrhenia cymbaria* and *Panicum maximum* (30-50% cover). Patches of wooded bush thicket or small remnants of secondary forest cover ca. 20-40% of the land.

SOILS:
Well drained, 50-70 cm deep, dark brown to dark reddish brown, very friable loamy sand; over very deep, yellowish red to yellowish brown friable to firm sandy clay.
The topsoil is a loamy sand, with either a deep (0-25 cm), but weakly developed brown A horizon, or a shallow (0 - 10cm) and well developed very dark brown to black one. This degree of development appears to be related to bush or to grassland vegetation, respectively. Topsoils are very friable when moist, and have a very weak subangular blocky structure.
The upper subsoil is a dark brown to dark reddish brown sand to sandy loam, of very friable consistence when moist. Structure is weakly coherent porous massive. There is a gradual or clear transition to the heavier textured deeper subsoil. In places some few faint bleached mottling occurs.
From a depth of about 50-70 cm onwards the soil consists of yellowish brown or yellowish red to dark red sandy clay or sandy clay loam, containing some clay cutans (signs of clay illuviation). Structure is moderately coherent porous massive; the consistence is friable to firm when moist; hard when dry.
Laboratory analysis data: Organic Carbon in topsoil amounts to 0.5-1.0%; figures for available Phosphorus in the topsoil range between 10 and 35 ppm; the pH-H_2O

is around 6.0; pH-KCl 5.0. Cation Exchange Capacity ranges from 5-10 meq/100g, depending on clay content and Organic matter; Base Saturation is mostly below 50%.

INCLUSIONS:

A The soils of this unit merge gradually into those of unit PA1, where the topsoils contain less sand. Boundaries between units PA1 and PA2 are gradual transitions and can be located only at a more detailed scale of mapping.

GENERAL INTERPRETATION OF DATA:

A Waterholding capacity of the upper subsoil is, due to its sandy character, low.

B Cation exchange capacity and base saturation are (very) low in the topsoil and upper subsoil, i.e. fertility depends largely on organic matter content, which tends to diminish rather rapidly under intensive cultivation.

C The rather strong difference in texture of upper and lower subsoil may act as a hindrance to root development, although the transition is not an abrupt one.

D The friable light textured topsoils have a rapid infiltration rate. First rains will supply moisture that is immediately available for the crops.

E Soils are light and easily workable with handtools, in both dry and wet conditions.

CORRELATION WITH A.H.T.(1985):

Soils of this unit are comparable to unit PA3 in LKSS-I.

A representative profile is given in Annex 2: profile no. 3

MAPPING UNIT 7: PA3

SURFACE AREA:

WSS, Lamu District: 812 ha; 12%

WSS, Tana River District: 1275 ha; 16.2%

LKSS II: 8 ha; 0.1%

LANDFORM, GEOLOGY:

Gently undulating plain: remnants of Pleistocene beach ridges and low dunes. In the Katsaka Kairu area a marked pattern of parallel ridges. Soils are developed in (fine-sandy) Pleistocene aeolian deposits.

VEGETATION:

Much of this unit is under wooded bush of broadleaf deciduous species. The aspect of this dense woody vegetation, as it appears on the aerial photographs, is very similar to that of the Witu forest.

Bushed grassland outside these forest remnants shows, especially in the Katsaka Kairu area, a remarkably lush and dense cover of the tall grass *Panicum maximum*.

SOILS:

Well drained, to somewhat excessively drained, very deep, dark red to dark reddish brown or yellowish brown, very friable loamy (fine) sand with a deeper subsoil of

(fine) sandy loam.
Soils are (fine) sandy at the top, with a gradual, very slight increase in clay content with depth. Topsoils are only locally well developed. Throughout the profile, the consistence is very friable to friable, when moist, but, when dry, hard in the deeper subsoil; structure is porous massive, with increasing coherence with depth. Root distribution is well developed throughout the profile. Water holding capacity is very low. (This seems better in the Katsaka Kairu area, compared to other sandy soils, due to the there prevailing fine-sandyness of the coarse fraction). Fertility levels are low, and depend much on the organic matter of the topsoils.
Laboratory analysis data: Topsoil Organic Carbon is around 0.5 %; Figures for available Phosphorus range between 10 and 25 ppm, (av. 15 ppm). Cation Exchange Capacity increases with depth (and clay content) from 2-8 meq/100g; Base Saturation is generally less than 50 %; pH-H_2O: 6.5-7.0; pH-KCl: around 5.5.

GENERAL INTERPRETATION OF DATA:

A The water holding capacity of the first 100cm is low, so that annual crops may suffer drought stress.
B Low fertility level, partly depending on the topsoil organic matter. The latter tend to disappear rather rapidly in these sandy topsoils when under annual crops.
C Due to a somewhat marked topography of these soils in the Katsaka Kairu area, some sheet erosion takes place there: as a consequence topsoils are being, or have been, truncated in that area.
D The soils have good drainage conditions and are well aerated to very deep in the profile.
E The soils are easy to work.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are comparable to unit PA4 in LKSS-I

A description of two representative profiles is given in Annex 2: profiles No. 4 and 5.

MAPPING UNIT 8: PA4

SURFACE AREA:
WSS, Lamu District: 36 ha; 1.3%
WSS,Tana River District: 227 ha; 2.9%
LKSS II: 1514 ha; 22.9%

LANDFORM; GEOLOGY:
Almost flat to very gently undulating coastal plain, with gently undulating mesotopography. Soils developed in Kilindini sands: sandy beach ridges; sandy beach deposits.

VEGETATION:
Closed or almost closed bush, with a canopy of Doum palms and/or broadleaf trees; Forest patches; clusters of bush among grassland glades.

SOILS:
Somewhat excessively to moderately well drained, very deep, yellowish brown to pale brown, very friable sand to loamy sand.
Topsoils are weakly developed, and relatively deep (up to 25 cm). Deep, well developed, humus-rich topsoils are found only locally in grassland glades among dense bush. Soils have a high infiltration rate, have a very friable consistence, and a very weak subangular blocky structure.
The subsoils are homogeneously porous massive, well aerated, and show a slight and gradual increase of clay content from sand in the upper subsoil to loamy sand in the deeper subsoil.

INCLUSIONS:
A Intergrades with soils of mapping unit PA2; where subsoil colours tend to be strong brown to yellowish red.
B Intergrades with soils of mapping unit PA5; where soils show some bleached mottling at greater depth (over 80cm).

GENERAL INTERPRETATION OF DATA:
A The sandy texture offers but little moisture reserve: soils dry out soon after the rains. This is somewhat compensated by a fair humus content.
B Soils have a very poor nutrient status (very low C.E.C. and low Base saturation). Application of fertilizers has to be done very carefully to avoid losses through leaching.
C Sustained levels of production will require considerable fallow periods and/or the application of organic mulch.
D Soils absorb rainfall rapidly: runoff losses are minimal; soil moisture is immediately after the first rains available to the crops.
E The soils are easily workable with hand tools.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are somewhat comparable with soils of Unit PA4 (but are less loamy, and never reddish or yellowish red) and with soils of unit PA7 (but are well drained, and without a mottled heavier textured deeper subsoil) in LKSS-I.

MAPPING UNIT 9: PA5

SURFACE AREA:
WSS,Lamu District: 1167 ha; 17.2%
WSS,Tana River District: 448 ha; 5.7%
LKSS II: 2067 ha; 31.3%

LANDFORM, GEOLOGY:
Almost flat coastal plain with very gently undulatng mesotopography. Kilindini beach- and lagoonal deposits: "sand-over-clay" deposits.

VEGETATION:
Clusters of bush, consisting of broadleaf deciduous shrubs and Doum palms,

among grassland glades. Dominant grass species are *Hyparrhenia cymbaria, Digitaria diagonalis* and *Dactyloctenium aegyptiacum*.(Going from better drained parts towards temporarily poorly drained parts, respectively.)

SOILS:
Moderately well to imperfectly drained, dark brown over pale brown, mottled, loose to very friable sand to loamy sand, in places over a strongly mottled, very firm sandy loam to sandy clay deeper subsoil.
The top soil is strongly developed, but thin (ca.10cm), when under grass vegetation; weakly developed (i.e. hardly darker in appearance compared to the underlying horizon), but deeper (ca. 25 cm), when under closed bush canopy. The surface soils are weakly structured, subangular blocky to porous massive; very friable, non-"sealing", and of high infiltration capacity.
The upper subsoil (ca. 25-60 cm) is pale brown to greyish brown, with faint to distinct mottles of bleached soil. The degree (contrast) of mottling is related to temporary (ground)water saturation: Mottling and pale colours increase with depth. This section of the profile has a very friable to loose consistence, when moist; and a weakly coherent, porous massive structure.
The deeper subsoil consists of a (pale greyish brown), faintly to prominently mottled, sandy clay to sandy loam, which is extremely hard under dry conditions, but firm to friable when moist. It contains concretions of iron and manganese oxides and silcrete nodules (hard lumps that do not soften when moistened).
Laboratory analysis data: Organic Carbon in the topsoil ranges from 0.4-0.8%; Available Phosphorus (P-Mehlig) is in general very low: 8 ppm; locally up to 20-30 ppm; pH-H_2O is around 6.0; pH-KCl around 4.5; Cation Exchange Capacity does not ecxeed 2-4 meq/100g in the sandy horizons; up to 10 meq/100g in clayey deeper subsoils; Base Saturation is around or below 50%.

INCLUSIONS:
A In ca. 50% of the observations, the sandy clay to sandy loam deeper subsoil may be absent, or occurs at a depth beyond 1.20 m. (LKSS II; Eastern parts of unit in WSS). However, drainage conditions and profile morphology are similar.
B Intergrades with the better drained soils of unit PA4: Bleached mottling is faint and only present below 1.00 m depth.
C Intergrades with the poorer drained soils of unit PA5p: strongly bleached mottling starts at shallow depth; there is groundwater between 50 and 100 cm during most of the growing season.

GENERAL INTERPRETATION OF DATA:
A Soils have a very poor nutrient status (Extremely low CEC; low base saturation). Also the organic matter content of the topsoil is not high, and tends to disappear after only few cropping seasons.
B The deep sandyness offers a low water holding capacity. This is not compensated by an adequate humus content, as the A-horizon is either thin or weakly developed. Also the clay layer in the deeper subsoil does not offer moisture reserve, as it does not belong to the rooting space for annuals.

C Bleached mottling is caused by a seasonally high water table, or temporary water-saturated condition. Deeper rooting crops, that have no resistance to oxygen stress may fail in "above average" rainy seasons.

D The loose, friable sandy soil will absorb all rainwater readily. Runoff losses are negligible. Soil moisture is immediately available to crops at the onset of the rains.

E The soil is easily workable with handtools.

CORRELATION WITH A.H.T.(1985):

Soils of this unit are comparable to unit PA7 and unit PA10 in LKSS-I. However, a heavier textured deeper subsoil as described in A.H.T.(1985) is absent in the present survey area in about 50% of the observations.

In Annex 2, two representative profiles are given: profiles No's 6 and 7.

MAPPING UNIT 10: PA5p

SURFACE AREA:

WSS, Lamu District: 0 ha; 0%
WSS, Tana River District: 108 ha; 1.4%
LKSS II: 900 ha; 13.6%

The soils of this unit differ from those of the previous unit only in drainage conditions. These are imperfect to poor. The profile morphology differs somewhat in colour: a generally pale brown matrix from ca. 40 cm, with rusty coloured mottles.

LIMITATIONS TO RAINFED AGRICULTURE/SUITABILITY:

The limitations as mentioned under the previous unit description are valid here as well. However, waterlogged conditions are a more prominent feature here, so that deeper rooting annuals and tree crops are not suited to these soils.

CORRELATION WITH A.H.T.(1985):

Soils of this unit are comparable to unit PA10 in the LKSS-I area. In part of the observations the heavier textured deeper subsoil starts at a depth of more than 1.20 m, or is absent.

Profile No. 8, Annex 2, is a representative example.

MAPPING UNIT 11: PA5f

SURFACE AREA:

WSS, Lamu District: 0 ha; 0%
WSS, Tana River District: 14 ha; 0.2%
LKSS II: 337 ha; 5.1%

LANDFORM, GEOLOGY:
Almost flat coastal plain, with very gently undulating mesotopography; soils developed in Kilindini sands ("sand-over-clay" deposits).

VEGETATION:
mostly grassland, with some scattered Doum palms. Dominant grass species are *Digitaria diagonalis* and *Dactyloctaenium aegyptiacum*, with many *Juncus* and *Cyperus* species. Basal grass cover is 15-20%.

SOILS:
Poorly drained, temporary waterlogged, very deep, loose to very friable, pale brown, faintly mottled sand, in places with a heavier textured deeper subsoil from ca. 80 cm
The topsoil is locally strongly developed, but always less than 10cm deep.
The upper subsoil consists of structureless, almost loose, very pale sand, with some vague rusty mottling.
The deeper subsoil is somewhat darker, with more distinct mottling, and may or may not show an increase in clay content.
All E.C.measurements show extremely low figures; between 30 and 70 micro Mho, suggesting a very low nutrient status.

GENERAL INTERPRETATION OF DATA:
A Drainage conditions are very poor: Soils are waterlogged for several weeks during and after the rains.
B Partly in connection with the poor drainage conditions and the almost pure sandy texture, chemical fertility is extremely low (See also profile No 8 in Annex 2). The wet conditions and the very low cation exchange capacity will cause losses of fertilizer by leaching.
C Water holding capacity is also very low: in drier than "average" rainy seasons, the soils are very droughty.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are comparable to unit PA11 in the LKSS-I area, except for the abruptness of the textural change.

MAPPING UNIT 12 :PA6

SURFACE AREA:
WSS, Lamu District: 1278 ha; 18.9%
WSS, Tana River District: 341 ha; 4.3%
LKSS II: 180 ha; 2.7%

LANDFORM, GEOLOGY:
Almost flat coastal plain with gently undulating mesorelief; subcircular depressions that form seasonal swamps or permanent ponds may occupy up to 40% of the surface. Soils are developed in lagoonal sediments; shallow layer of sand over clayey deposits.

VEGETATION:
Wooded grassland with clusters of bush thicket and grassland glades. Dominant grasses are *Hyparrhenia cymbaria, Digitaria diagonalis* and *Brachiaria sp.*

SOILS:
Moderately well to poorly drained, 40-60 cm of dark brown to pale brown, mottled, very friable loamy sand, over very deep, yellowish brown to olive grey, strongly mottled, very firm clay to sandy clay.
{N.B. Soils of this type in the Katsaka Kairu area show a marked fine-sandyness of the sand fraction in top- and upper subsoils. Also, the organic matter content of the topsoils is higher than the equivalent soils elsewhere in the scheme. This seems associated with the adjoining fine-sandy older beach ridges, that are subject to light forms of sheet erosion.}
The topsoil is a thin but strongly developed A horizon: 5-15 cm of dark brown to black loamy sand, of very friable to loose consistence. Structure is medium, weak subangular blocky.
The upper subsoil is a pale brown to greyish brown, almost loose loamy sand to sand, often with bleached and dark brown mottling. The lower part of this profile section may be water saturated for several weeks after the rains, caused by the slow permeability of the underlying horizon.
The deeper subsoil is a yellowish brown to olive grey prominently mottled clay or sandy clay, which is very firm to firm when moist and extremely hard when dry. Structure is coarse angular blocky or prismatic. This part of the profile contains concretions of manganese and iron oxides, in amounts that decrease with depth.
Laboratory analysis data: Organic Carbon content of the surface horizon are low (0.6-0.8%); Available Phosphorus (P-Mehlig) is in general very low: 6-8 ppm; soils are of (slight) acid reaction (pH 5.5-6.5); CEC attains 3-5 meq/100g in the sandy upper subsoils, and rises with depth and clay content to about 10 meq/100g soil. Base Saturation is under 50%.

INCLUSIONS:
A Transitions with soil mapping unit PA5, where the sand-clay boundary is deeper.
B Transitions with soil mapping unit PA7, where the sandy top- and upper subsoil are more shallow, and sand-clay transitions more abrupt.

GENERAL INTERPRETATION OF DATA:
A Due to the textural change at shallow to moderate depth, there is a restriction for root development for annual crops.
B The sandy texture of this rather shallow arable layer has a low water holding capacity.
C The soil shows in many places a 'perched watertable' due to the slowly permeable subsoil. Poor drainage conditions or even waterlogging are a frequent hazard in the wet season.
D The leached sandy top- and upper subsoil have a poor nutrient reserve. This may be somewhat alleviated by the more clayey subsoil.

(N.B. In the Katsaka Kairu area, soils of this unit combine a fine-sandyness with a relatively high organic matter content in the topsoils. Both water holding capacity and nutrient reserve are more favourable).

Soils are easily 'workable' with handtools.
Soil moisture is practically immediately available to crops after the first rains.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are somewhat comparable to unit PA6 in LKSS-I. However, the description of the "somewhat restricted" drainage in AHT's PA6 does not apply in the present survey area. Hence the discrepancy in suitability rating for tree crops.

A representative profile is given in Annex 2: Profile No. 9.

MAPPING UNIT 13 : PA7

SURFACE AREA:
WSS, Lamu District: 451 ha; 6.7%
WSS, Tana River District: 492 ha; 6.2%
LKSS II: 615 ha; 9.3%

LANDFORM, GEOLOGY:
Almost flat to very gently undulating coastal plain. Transitional area of Kilindini sand-over-clay deposits (PA-units) towards more recent lagoonal clay deposits at a lower position in the landscape (PJ-units).

VEGETATION:
Wooded and bushed grassland to dense bushland. Sparse grasscover. Frequent woody species are *Terminalia spinosa, Ormocarpum kirkii*, and *Acacia* species (*mellifera; senegal*?) together with many others.

SOILS:
Imperfectly to poorly drained, shallow to moderately deep very friable, compact sand, abruptly over firm (extremely hard when dry) grey to olive brown, mottled, sandy clay loam to sandy clay.
The topsoil is weakly developed and thin.
The upper subsoil is a pale brown sand, in many places with a distinctly bleached layer on top of an abrupt transition to the heavier textured deeper subsoil.
The deeper subsoil is a brightly mottled sandy clay loam to sandy clay with coarse prismatic to columnar structure. "White tonguing" is common: along the columns white sandy "infills" can be observed. The bleached sands in the upper subsoil and along the structure peds in the B horizon point to an unstable character of the clay minerals and impeded drainage with anaerobic conditions in part of the profile for some time in the year.
Laboratory analysis data: Topsoil Organic Carbon content is low (0.5-1.0%); Available Phosphorus (P-Mehlig) does not exceed 6-8 ppm; upper subsoils are moderately acid; deeper subsoils slightly acid to neutral; CEC is 5-10 meq/100g in the upper subsoil, and rise with increasing clay content to 15-20 meq/100g in the deeper subsoil; Base Saturation is less than 50%in the surface horizons; 50-60% in the deeper subsoil.

INCLUSIONS:
Transitions to mapping unit 12: PA6
Transitions to mapping unit 15: PJ1

GENERAL INTERPRETATION OF DATA:

A Rooting space is shallow: The abrupt textural change is a serious hindrance to root development
B Drainage conditions are imperfect to poor
C Water holding capacity of the top and upper subsoil is low.
D Low chemical fertility.
E Rapid infiltration of rain;
F Soils are easy to work by handtools.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are comparable to unit PA11 in the LKSS-I area, as far as the abrupt textural change is concerned. Drainage conditions are better, and the transition of coarse to fine texture is more shallow compared to PA11 in LKSS-I

A representative profile is given in Annex 2: Profile No. 10.

MAPPING UNIT 14 : PA7p

SURFACE AREA:
WSS, Lamu District: 0 ha; 0%
WSS, Tana River District: 167 ha; 2.1%
LKSS II: 48 ha; 0.7%

These soils are similar those of unit 13: PA7, but poorly to very poorly drained, while the abrupt textural change occurs at a somewhat shallower depth (between 30 and 50 cm).

LIMITATIONS TO RAINFED AGRICULTURE:
The same limitations as mentioned under 13: PA7 apply; however the drainage conditions are more adverse.

SUITABILITY RATING:
The soils of this unit are regarded unsuitable for arable farming.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are comparable to unit PA11 in LKSS-I; however, the abrupt textural change is present at a more shallow depth in the Witu scheme.

MAPPING UNIT 15: PJ1

SURFACE AREA:
WSS, Lamu District: 688 ha; 10.2%
WSS, Tana River District: 0 ha; 0%
LKSS II: 0 ha; 0%

LANDFORM, GEOLOGY:
Almost flat coastal plain, with gently undulating meso- or microtopography (gilgai formation). Soils developed over very deep lagoonal clay deposits

VEGETATION:
mostly dense shrubland or thicket of semi-sclerophillous tall scrub species. Also frequent *Acacia* species (*senegal; mellifera; seyal, var. fistula* ?), *Ormocarpum kirkii* and *Terminalia spinosa.*

SOILS:
Imperfectly drained, very deep, yellowish brown to olive brown, mottled, very firm cracking clay, with a silty clay topsoil, and a saline (deeper) subsoil.
The topsoil is a shallow, compacted silty clay to silty loam, with a faintly developed A-horizon. The surface shows distinct undulations, as a consequence of swell-shrink properties of the subsoil clay. Small pools of standing water form during the rains, due to very slow infiltration rates.
The upper subsoil is a yellowish brown, mottled, extremely firm clay, in most places slightly saline. It forms locally wide cracks in the dry season.
The deeper subsoil is an olive brown, calcareous, saline and sodic, very firm, heavy clay.
The topsoil is slightly acid, and of low base saturation; the subsoil is alkaline, has a high exchangeable Sodium percentage (ESP) and high base saturation. Cation Exchange Capacity ranges from 15 meq/100g at shallow depth to 25 meq/100g in the deeper subsoil.

INCLUSIONS:
A Transitions to unit 13: PA7
B Transitions to unit 16: PJ2

GENERAL INTERPRETATION OF DATA:
A In the peak of the wet season these soils are ponded in many places.
B Soil-water relations are unfavourable: the heavy clays suffer a water loss when dry, at the onset of the rains, due to open cracks in the subsoil; Water retention at wilting point is high; In addition, there is a slight to moderate salinity.
C Actual rooting depth is restricted, due to low porosity (high bulk density), salinity and swell-shrink mechanisms.
D In spite of the silty character of the top soil, workability by hand tools is heavy.
E The soils have some mineral reserves

CORRELATION WITH A.H.T.(1985):
Soils of this unit are not found in LKSS-I.

MAPPING UNIT 16: PJ2

SURFACE AREA:
WSS, Lamu District: 698 ha; 10.3%
WSS, Tana River District: 247 ha; 3.1%
LKSS II: 0 ha; 0%

LANDFORM, GEOLOGY: Flat coastal plain, with gilgai microrelief (regular undulation of the surface with height difference of ca. 75 cm over ca. 2 m, as a consequence of the swell-shrink capacity of the dominant clay mineral). Soils developed over lagoonal clay deposits.
In many places the term bottomland applies: soils are mostly ponded during the rainy season for some period.

VEGETATION: Grassland of *Andropogon sp.*, *Asparagus sp.* and *Cyperaceae*, partly wooded with *Acacia seyal (zanzibarica?)*.

SOILS: Very poorly drained, very deep, black to pale olive brown, mottled, saline-sodic, cracking clay.
The top- and upper subsoil consists of a very dark gray to black clay, which is sticky and plastic when wet, very hard when dry. The surface shows cracks in the dry season. In wet condition infiltration rates are negligible: This, in combination with the flat surface and depressional position, causes ponding in the wet season.
The deeper subsoil is olive grey or light olive brown, very firm clay, mostly with lime concretions; and saline in various degrees (between 3 and 8 mMho in 1 : 2.5 susp.). The pH measures well above 7.5, locally up to 8.5. Sodicity.
Laboratory analysis data: Topsoil contains 1.0-1.5% Organic Carbon; also available Phosphorus is relatively high P-Mehlig: 20 - 40 ppm); Content of clay is 45 - 50% from the surface throughout the profile; soil reaction is slightly acid to slightly alkaline; CEC is 25-30 meq/100g; Base Saturation is around 75%; subsoil shows high exchangeable Sodium percentage (ESP 15-20%).

GENERAL INTERPRETATION OF DATA:
A: Soils are ponded or very poorly drained. This limits the choice of crops virtually to paddy rice.
B: The soils are extremely heavy to work, even for mechanical implements.
C: The soils have some mineral reserve.

SOIL CORRELATION WITH A.H.T.(1985):
This type of soil is not found in the LKSS-I.

A representative profile is given in Annex 2, profile no. 11.

MAPPING UNIT 17: AA1

SURFACE AREA:
WSS, Lamu District: 497 ha; 6.3%
WSS, Tana River District: 70 ha; 1.0%
LKSS II: 0 ha; 0%

LANDFORM, GEOLOGY: Almost flat coastal plain, lowest level, merging with the Tana river delta. The area is seasonally flooded, also in response to off-site, up-country rains. Soils are developed over stratified lagoonal and riverine clay and loam deposits, locally with peat layers.

VEGETATION: short and tall grassland, of varying density. A very common grass species is *Sporobolus spicatus*, associated with high soil salinity.

SOILS: Seasonally ponded, very deep, black to pale olive brown, locally brightly mottled, stratified clays and loams, strongly saline in the topsoil.
The salinity is strongest in the fringe along the "slopes" towards dry, non-flooded land.
The bright yellow and red mottles in the profile suggest potentially acid sulphate soils.

GENERAL INTERPRETATION OF DATA:
A High soil salinity in the surface soils in many places.
B Adverse drainage conditions, and very high risk of flooding.
C This land is regarded unsuitable for arable farming.

As grazing land it seems highly suitable: a high biomass production (High mineral content), resistance to degradation through overutilization, and relatively tsetse free (?). Inaccessible in large part of the rainy season.

CORRELATION WITH A.H.T.(1985):
Soils of this unit are not found in LKSS-I.

MAPPING UNIT 18 :C1

SURFACE AREA:
WSS, Lamu District: 0 ha; 0%
WSS, Tana River District: 888 ha; 11.3%
LKSS II: 0 ha; 0%

This land consists of a complex of soils of units 9: PA5, 10: PA5p and 12: PA6

MAPPING UNIT 19: C2

SURFACE AREA:
WSS, Lamu District: 156 ha; 2.3%
WSS, Tana River District: 781 ha; 9.9%
LKSS II: 0 ha; 0%

This land consists of a complex of soils of units 12: PA6, 3: PL3 and 4: PL3p

MAPPING UNIT 20

SURFACE AREA:
WSS, Lamu District: 475 ha; 7.0%
WSS, Tana River District: 295 ha; 3.7%
LKSS II: 326 ha; 4.9%
Total: 1096 ha; 5.2%

Numerous depressions, mostly between one and five ha large, are seasonally waterlogged to various extents. It is not possible at the present scale of mapping to differentiate according to the average timespan these seasonal ponds are under standing water during and after each rainy season. Also, it has been observed that soil conditions may vary widely: from peat or firm clay, to very deep, almost pure sand.
In some cases recessional agriculture (rice, a.o.) is practiced along the margins, at a very minor scale.

ANNEX 2 DESCRIPTION AND ANALYTICAL DATA OF REPRESENTATIVE PROFILES

PROFILE No. **1**, Field No. **251** Soil Mapping Unit **PL1**

Location: Kipini road, near Witu Secondary School. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1983): CL3 m i vs. **Geology, Soil Parent Material**: Coral limestone rock. **Landform, Relief**: Marine terrace. Almost flat. **Drainage Conditions**: Well drained. **Vegetation, Land Use**: Wooded tall grassland of old mango trees over Hyparrhenia. **Erosion**: slight runoff.

A1 0 - 15cm very dark reddish brown (2.5YR 2/1, moist); clay loam; slightly sticky and plastic when wet; friable when moist; strong, fine subangular blocky structure; many fine pores; clear and wavy boundary to: [Sample No. 251 A]

A3 15 - 40cm dark reddish brown (2.5YR 2/3, moist); fine sandy clay loam; sticky and plastic when wet; friable when moist; weak, moderate subangular blocky structure; many fine pores; clear and wavy boundary to: [Sample No. 251 B]

B1 40 - 60cm dark red (2.5YR 3/7, moist); clay loam; sticky and plastic when wet; friable when moist; weak fine angular blocky to porous massive, moderately coherent structure; many fine pores; gradual smooth boundary to: [Sample No. 251 C]

B2 60 - 90/120cm red (2.5YR 4/7, dry, 2.5YR 3/7, moist); medium sandy clay loam; slightly sticky and plastic when wet; friable when moist; hard when dry; porous massive, moderately to strongly coherent structure; many fine pores; abrupt and broken boundary to: [Sample No. 251 D]

R 90/120cm$^+$ Rock of coral limestone.

Horizon	top soil	A1	A3	B1	B2
Depth (cm)	0-20, mix	0-15	15-40	40-60	60-90/120
Field Ref.	251 M	251 A	251 B	251 C	251 D
Sand %		68	60	56	60
Silt %		8	6	2	8
Clay %		24	34	42	32
Texture class		SCL	SCL	SC	SCL
pF 2.0 (%w/w)			18.3	22.2	
pF 4.2 (%w/w)			11.5	14.3	
Bulk Density			1.40	1.30	
AWC %			9.5	10.3	
$pH-H_2O$ (1:2.5)	6.8	7.1	6.7	7.2	6.4
pH-KCl (1:2.5)		6.3	5.8	5.5	4.8
Ec mS/cm (1:2.5)		0.24	0.1	0.07	0.05
Organic C %		1.48	0.73	0.27	0.36
Total N %					
C/N					
P-Mehlig ppm	8				
CEC NH_4OAc me/100g		11.0	17.5	13.1	12.4
Exch. Ca me/100g		10.7	1.5	2.5	1.3
Exch. Mg me/100g		4.2	3.9	1.6	2.3
Exch. K me/100g		0.94	0.70	0.62	1.02
Exch. Na me/100g		0.90	0.65	0.48	0.85
Base Sat. %		> 100	< 50	< 50	< 50
Exch. Sodium %					

PROFILE No. **2**, Field No. **U 512** Soil Mapping Unit **PL2**

Location: WSS, Witu-Kipini area, SW of Witu Forest. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1983): CL3 m i vs. **Geology, Soil Parent Material**: Coral limestone rock. **Landform, Relief**:Pleistocene Marine terrace. Almost flat. Irregular mesotopography due to frequent rock outcrops. **Drainage Conditions**: Well drained. **Vegetation, Land Use**: Grassland of *Hyparrhenia cymbaria* and *Heteropogon contortus*. **Erosion**: slight runoff.

Al 0 - 5cm black (7.5YR 2/0, moist only); sandy clay loam; moderate to strong, medium, subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; many very fine pores; many, fine roots ; clear and wavy boundary to: (Sample No: 512A)

Bl 5 - 2Ocm dark reddish brown (5YR 5/3.5, moist only); (sandy) clay loam; weak to moderate, medium, angular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; few, weak clay skins; many, very fine pores; many fine roots; gradual and wavy boundary to: (Sample No: 512B)

B2 20 - 35cm dark reddish brown (6YR 3/3 moist only); clay loam to clay; moderate, medium, angular blocky structure; friable when moist, slightly sticky and plastic when wet; abundant moderate clay skins; many very fine pores; common fine roots; gradual and wavy boundary to: (Sample No: 512C)

B3 35 - 75cm yellowish red (4YR 4/3 moist only); clay; weak, coarse, angular blocky structure; friable when moist, slightly sticky and plastic when wet; few weak clay skins; many very fine pores; common fine and few coarse roots; abrupt and irregular boundary to: (Sample No: 512D)

R 75+cm Coral rock, with petrocalcic capping.

Horizon	A1	B1	B2	B3
Depth (cm)	0- 5	5-20	20-35	35-75
Field Ref.	512 A	512 B	512 C	512 D
Sand %	76	58	60	56
Silt %	6	10	6	4
Clay %	18	32	34	40
Texture class	SL	SCL	SCL	SC
pF 2.0 (%w/w)				
pF 4.2 (%w/w)				
Bulk Density				
AWC %				
pH-H_2O (1:2.5)	6.4	6.4	6.8	6.5
pH-KCl (1:2.5)	5.1	5.1	5.5	5.6
Ec mS/cm (1:2.5)	0.06	0.05	0.04	0.08
Organic C %	1.88	0.96	0.48	0.45
Total N %				
C/N				
P-Mehlig ppm				
CEC NH_4OAc me/100g	19.15	13.15	10.55	10.25
Exch. Ca me/100g	10.90	6.10	5.40	6.30
Exch. Mg me/100g	2.93	1.95	1.30	0.94
Exch. K me/100g	1.02	1.07	0.76	0.23
Exch. Na me/100g	0.20	0.25	trace	0.10
Base Sat. %	79%	71%	71%	75%
Exch. Sodium %				

PROFILE No. **3**, Field No. **264** Soil Mapping Unit **PA2**

Location: WSS, Witu-Kipini area, SW of Witu Forest, along cutline. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1983): CL3 m i vs. **Geology, Soil Parent Material**: Coral limestone rock, covered with sandy deposits. **Landform, Relief**:Pleistocene Marine terrace. Almost flat. **Drainage Conditions**: Well drained. **Vegetation, Land Use**: Wooded grassland of *Hyphaene coriacea* over *Hyparrhenia cymbaria*. **Erosion**:Nil.

A 0 - 15cm very dark gray (7.5YR 3/1, dry) and black (7.5YR 2/0, moist); loamy medium sand; very weak sub angular blocky structure; non sticky, slightly plastic when wet, very friable when moist, soft when dry; abundant pores; abundant fine roots; gradual and wavy boundary to: [Sample No. 264A]

AB1 15 - 30cm dark brown (7.5YR 3/2, dry) and very dark gray (7.5YR 3/1, moist); medium sandy loam; porous massive, weakly coherent structure; non sticky, slightly plastic when wet, hard when dry; abundant pores; abundant fine and medium roots; diffuse and smooth boundary to:

AB2 30 - 50 cm brown (7.5YR 4/3, dry) and dark brown (7.5YR 3/2, moist); medium sandy loam; porous massive, moderately coherent structure; non sticky, slightly plastic when wet, slightly hard when dry; abundant pores; many fine and medium roots; gradual and wavy boundary to: [Sample No. 264B]

Bt2 50 - 70cm strong brown (6YR 5/6, dry and moist); medium sandy clay; porous massive to weak, coarse angular blocky structure; sticky and plastic when wet, very hard when dry; clay cutans; abundant pores; common medium and fine roots; diffuse and smooth boundary to: [Sample No. 264C]

B3 70 - 120cm yellowish red (5YR 5/6, dry and moist); medium sandy clay loam; porous massive strongly coherent structure; sticky and plastic when wet, hard when dry; abundant pores; few medium and fine roots; abrupt and irregular boundary to: [Sample No. 264D] coral rock at 110-140^{+}.

Horizon	top soil	A	AB	Bt2	B3
Depth (cm)	0-20, mix	0-15	15-50	50-70	70-120
Field Ref.	264 M	264 A	264 B	264 C	264 D
Sand %		86	84	62	72
Silt %		4	2	2	2
Clay %		10	14	36	26
Texture class		LS	LS	SCL	SCL
pF 2.0 (%w/w)			10.2		15.3
pF 4.2 (%w/w)					
Bulk Density			1.43		13.1
AWC %					
pH-H_2O (1:2.5)	6.4	5.9	6.2	6.0	6.6
pH-KCl (1:2.5)		5.0	4.9	4.9	5.2
Ec mS/cm (1:2.5)		0.05	0.07	0.13	0.05
Organic C %	0.73	0.65	0.36	0.42	trace
Total N %					
C/N					
P-Mehlig ppm	36				
CEC NH_4OAc me/100g		4.9	6.0	12.7	7.8
Exch. Ca me/100g		1.9	0.7	2.3	1.1
Exch. Mg me/100g		1.3	0.8	1.4	0.8
Exch. K me/100g		0.64	0.31	0.48	0.10
Exch. Na me/100g		0.28	0.22	0.65	0.40
Base Sat. %		85%	35%	38%	30%
Exch. Sodium %					

PROFILE No. **4**, Field No. **267** Soil Mapping Unit **PA3**

Location: Along Witu-Kipini Road, near Kibaoni. **Agro-Ecological Subzone** (Jaetzold & Schmidt 1985): CL3 m i (vs). **Geology, Soil Parent Material**: Pleistocene beach ridge deposits, deep loamy sands. **Landform, relief**: marine terrace, very gently undulating due to beach ridge remnants. **Drainage Conditions**: well drained. **Vegetation, Land Use**: Cashew, Mango; bush fallow. **Erosion**: no signs of runoff.

A 0 - 20cm very dark grayish brown (7.5YR 3/2, moist); medium sand to loamy sand; very weak medium subangular blocky structure; non sticky, non plastic when wet, very friable when moist; very porous; abundant fine and medium roots; gradual and wavy boundary to: [Sample No. 267A]

E1 20 - 33cm dark brown (7YR 4/4, moist); medium sand to loamy medium sand; very weak subangular blocky to porous massive structure; non sticky non plastic when wet, very friable when moist; very porous; many fine and medium roots; gradual and wavy boundary to: [Sample No. 267B]

E2 33 - 80 cm dark reddish brown (6YR 3/4, moist); loamy medium sand; very weak sub angular blocky to porous massive structure; non sticky non plastic when wet, very friable when moist; very porous; many fine and medium roots; clear and wavy boundary to: [Sample No. 267C]

Bt2 80 - 120^{+}cm reddish brown (5YR 4/5, dry and 5YR 4/4, moist); medium sandy clay loam; very weak angular blocky to porous massive, strongly coherent, structure; sticky and plastic when wet, very hard when dry; cutans; abundant pores; common fine and medium roots. [Sample No. 267D]

Horizon	top soil	A	E1	E2	Bt2
Depth (cm)	0-20, mix	0-20	20-33	33-80	80-120
Field Ref.	267 M	267 A	267 B	267 C	267 D
Sand %		90	88	86	76
Silt %		4	2	2	2
Clay %		6	10	12	22
Texture class		S	(L)S	LS	SCL
pF 2.0 (%w/w)				6.7	13.0
pF 4.2 (%w/w)				3.4	
Bulk Density				1.44	1.45
AWC %				4.8	
$pH-H_2O$ (1:2.5)	6.9	6.6	6.8	6.9	6.5
pH-KCl (1:2.5)		5.6	5.6	5.6	5.2
Ec mS/cm (1:2.5)		0.08	0.05	0.05	0.06
Organic C %		0.42	0.23	0.22	0.34
Total N %					
C/N					
P-Mehlig ppm	25				
CEC NH_4OAc me/100g		2.0	3.9	6.3	8.0
Exch. Ca me/100g		0.5	0.3	0.5	
Exch. Mg me/100g		0.5	0.2	0.9	2.2
Exch. K me/100g		0.34	0.22	0.28	0.40
Exch. Na me/100g		0.19	0.27	0.24	0.46
Base Sat. %		75 %	< 50	< 50	
Exch. Sodium %					

PROFILE No. **5**, Field No. **259** Soil Mapping Unit **PA3***

Location: WSS, Katsaka Kairu area; Along Witu-Garsen Main road, at junction with road to Moa. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1985): CL4 s/vs i (vs). **Geology, Soil Parent Material**:Pleistocene, fine-sandy beach ridge deposits. **Landform, Relief**:Very gently undulating due to SW-NE stretching Pleistocene beach ridges. **Vegetation, Land Use**: Cooperative ranching; Bushed grassland, with *Ormocarpum Kirkii*, a.o. **Drainage Conditions**: Well drained. **Erosion**: slight to moderate signs of runoff.

A 0 - 15cm reddish brown (5YR 4/4, dry) to dark reddish brown (5YR 3/3, moist); loamy fine sand; weak sub angular blocky structure; non sticky non plastic when wet, loose when moist, soft to slightly hard when dry; many fine roots; many to abundant micro pores; gradual and wavy boundary to: [Sample No. 259A]

B1 15 - 40cm yellowish red (5YR 4/6, dry) to reddish brown (5YR 4/4, moist); loamy fine sand; weak sub angular blocky to porous massive structure; non sticky non plastic when wet, very friable when moist, hard when dry; many fine and common coarse roots; many to abundant micro pores; diffuse and smooth boundary to: [Sample No. 259B]

B21 40 - 80cm yellowish red (4YR 4/8, dry and 4YR 4/7, moist); loamy fine sand; porous massive, moderately coherent structure; non sticky non plastic when wet, very friable when moist, hard when dry; cutans in pores?; common fine roots; many to abundant micro pores; diffuse and smooth boundary to: [Sample No. 259C]

B22 80 - 120+cm yellowish red (4YR 4/8, dry and 4YR 4/7, moist); fine sandy clay loam; porous massive, strongly coherent structure; slightly sticky slightly plastic when wet, friable when moist, hard when dry; cutans in pores?; few fine roots; many to abundant micro pores. [Sample No. 259D]

Horizon	top soil	A	B1	B21	B22
Depth (cm)	0-20, mix	0-15	15-40	40-80	80-120
Field Ref.	259 M	259 A	259 B	259 C	259 D
Sand %		86	80	74	80
Silt %		4	8	4	4
Clay %		10	12	24	16
Texture class		(L)S	LS	SL	SL
pF 2.0 (%w/w)			11.4	12.2	
pF 4.2 (%w/w)			5.1	5.0	
Bulk Density			1.44	1.39	
AWC %			9.1	10.0	
pH-H_2O (1:2.5)	6.4	6.8	5.8	4.8	4.8
pH-KCl (1:2.5)		5.7	5.0	4.2	4.2
Ec mS/cm (1:2.5)		0.07	0.05	0.04	0.03
Organic C %	0.69	0.54	0.36	0.26	0.28
Total N %					
C/N					
P-Mehlig ppm	12				
CEC NH_4OAc me/100g		5.3	7.1	10.2	8.0
Exch. Ca me/100g		1.3	0.5	0.7	0.5
Exch. Mg me/100g		1.4	0.7	2.3	2.0
Exch. K me/100g		0.42	0.10	0.10	0.10
Exch. Na me/100g		0.36	0.22	0.42	0.42
Base Sat. %		75 %	< 50	< 50	< 50
Exch. Sodium %					

PROFILE No. **6**, Field No. **257** Soil Mapping Unit **PA5**

Location: WSS, Witu-Kipini area; Along Witu-Garsen Main road, 500m from junction on road to Buito/Dida Warede. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1985): CL3 m i (vs). **Geology, Soil Parent Material**: Lagoonal sand-over-clay deposits. **Landform, Relief**: Very gently undulating coastal plain. **Vegetation, Land Use**: Bush fallow: Mango, Cashew, Banana **Drainage Conditions**: Internally well drained, but impervious layer at 100⁺cm. **Erosion**: no signs of runoff.

A 0 - 15cm very dark gray (10YR 3.5/1. dry and 10YR 2.5/1, moist); loamy medium to fine sand; porous massive to weak fine subangular blocky structure; non sticky, non plastic when wet, slightly hard when dry; abundant fine, medium and coarse roots; many medium and fine pores; gradual and smooth boundary to: [Sample No. 257A]

A1 15 - 40cm brown (10YR 4.5/3, dry) to very dark gray (10YR 2.5/1, moist); medium to fine sand; porous massive to weak medium sub angular blocky structure; non sticky non plastic when wet, slightly hard when dry; abundant fine faint mottles (bleached); few fine and coarse roots; many medium pores; diffuse and smooth boundary to: [Sample No. 257B]

E2g 40 - 75cm brown (10YR 5/3, dry) to dark brown (10YR 3/3, moist); loamy medium sand; porous massive to very coarse prismatic structute; non sticky non plastic when wet, hard when dry; abundant medium distinct mottles (bleached+ dark brown); few fine and medium roots; few fine manganese concretions; many fine pores; clear to abrupt boundary to: [Sample No. 257C]

Bgt 75 - 100⁺cm brown (10YR 5/3, dry, 10YR 4/3, moist); medium sandy loam; moderate coarse angular blocky structure; non sticky slightly plastic when wet, very hard when dry; abundant medium distinct mottles; few medium roots; many fine manganese concretions; many medium pores. [Sample No. 257D]

Horizon	top soil	A	E1	E2	Bgt
Depth (cm)	0-20, mix	0-15	15-40	40-75	75-100+
Field Ref.	257 M	257 A	257 B	257 C	257 D
Sand %		86	88	86	78
Silt %		4	4	4	2
Clay %		10	8	10	20
Texture class		LS	(L)S	SL	S(C)L
pF 2.0 (%w/w)				7.2	
pF 4.2 (%w/w)				3.3	
Bulk Density				1.34	
AWC %				5.2	
$pH-H_2O$ (1:2.5)	6.6	5.8	5.8	6.7	5.6
pH-KCl (1:2.5)		4.8	4.6	4.4	4.1
Ec mS/cm (1:2.5)		0.05	0.06	0.04	0.04
Organic C %		0.78	0.50	0.13	0.20
Total N %					
C/N					
P-Mehlig ppm	8				
CEC NH_4OAc me/100g		4.8	3.2	5.7	9.8
Exch. Ca me/100g		1.5	0.3	0.5	0.5
Exch. Mg me/100g		1.0	0.4	1.9	2.1
Exch. K me/100g		0.31	0.10	0.10	0.10
Exch. Na me/100g		0.25	0.27	0.40	0.45
Base Sat. %		65 %	< 50	52 %	< 50
Exch. Sodium %					

PROFILE No. **7**, Field No. **268** Soil Mapping Unit **PA5** (component of Unit C1)

Location: WSS, Witu-Kipini area; Along Witu-Kipini road, near junction with road to Kilelengwani. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1985): CL3 m i (vs). **Geology, Soil Parent Material**: Lagoonal sand-over-clay deposits. **Landform, Relief**: Very gently undulating coastal plain. **Vegetation, Land Use**: Dense Woodland - Wooded bushed grassland **Drainage Conditions**: Internally well drained, but slowly permeable layer at 80^{+}cm. **Erosion**: no signs of runoff.

A 0 - 5cm dark grayish brown (10YR 4/2, dry) and very dark grayish brown (10YR 3/2, moist); medium sand; very weak sub angular blocky structure; non sticky non plastic when wet, very friable when moist, soft when dry; many pores; many fine and coarse roots; clear and wavy boundary to:

E1 5 - 30cm dark brown (10YR 3/3, moist); abundant medium very faint, bleached mottles; medium sand; porous massive to very weak sub angular blocky structure; non sticky non plastic when wet, very friable when moist, slightly hard when dry; many pores; many fine and coarse roots; diffuse and smooth boundary to: [Sample No. 268A]

E2 30 - 80cm light yellowish brown (10YR 6/4, dry) and dark brown (10YR 4/3, moist); abundant medium distinct dark brown mottles; loamy medium sand; porous massive to very weak sub angular blocky structure; non sticky non plastic when wet, very friable when moist, hard when dry; many pores; manganese concretions; common coarse roots; clear and irregular boundary to: [Sample No. 268B]

Bg 80 - 150^{+}cm light brownish gray (10YR 6/2, dry) and grayish brown (10YR 5/2, moist); abundant medium distinct orange mottles; medium sandy clay loam; strong, very coarse angular blocky structure; very sticky and plastic when wet, extra hard when dry; bleached sand on ped faces; many pores within peds; few coarse roots. [Sample No. 268C]

Horizon	top soil	A	E1	E2	Bg
Depth (cm)	0-20, mix	0- 5	5-30	30-80	80-150+
Field Ref.	268 M		268 A	268 B	268 C
Sand %			90	92	74
Silt %			2	2	2
Clay %			8	6	24
Texture class			S	S	SCL
pF 2.0 (%w/w)			7.7	7.7	
pF 4.2 (%w/w)					
Bulk Density			1.50	1.48	
AWC %					
pH-H_2O (1:2.5)	6.8		6.3	6.2	5.8
pH-KCl (1:2.5)			5.3	4.5	4.5
Ec mS/cm (1:2.5)			0.06	0.05	0.5
Organic C %			0.43	0.31	0.45
Total N %					
C/N					
P-Mehlig ppm	32				
CEC NH_4OAc me/100g			3.7	2.9	11.8
Exch. Ca me/100g			0.3	0.1	1.1
Exch. Mg me/100g			0.5	0.3	2.0
Exch. K me/100g			0.26	0.12	0.56
Exch. Na me/100g			0.25	0.22	0.49
Base Sat. %			< 50	52 %	< 50
Exch. Sodium %					

PROFILE No. 8, Field No. **U 510** Soil Mapping Unit **PA5p**

Location: WSS, Witu-Kipini area; NE-corner. **Agro-Ecological Subzone** (Jaetzold & Schmidt'85): CL3 m i (vs). **Geology, Soil Parent Material**: Lagoonal sand-over-clay deposits. **Landform, Relief**: Almost flat coastal plain with gently undulating mesorelief. **Vegetation, Land Use**: Wooded bushed grassland. **Drainage Conditions**: Internally well drained, but high groundwater table at some part of the year. **Erosion**: no signs of runoff.

Al 0 - 20cm black (7.5YR 2/l moist only); loamy sand; clear, fine, subangular blocky structure; very friable when moist; many, very fine pores; many, fine roots; clear and smooth boundary to: [Sample No: 510A]

AE 20 - 40cm greyish brown (l0YR 5/2.5 moist only); many small, faint mottles; sand; weakly coherent, porous massive structure; slightly hard when dry, very friable when moist, non sticky, non plastic when wet; many, very fine pores; many fine roots; gradual and smooth boundary to: [Sample No: 510B]

Elg 40 - 70cm light brownish grey (lOYR 6/2 moist only); many, medium faint, reddish yellow (7,5YR 6/3) mottles; loamy sand to sand; structureless; slightly hard when dry, very friable when moist; many, very fine pores; common, coarse and fine roots; gradual and smooth boundary to: [Sample No: 510C]

E2g 70 - l20cm light grey (l0YR 7/2 moist only); common, fine, faint, orange mottles; sand; weakly coherent, porous massive structure; hard when dry, loose when moist, non sticky, non plastic when wet; many, very fine pores; few, fine and coarse roots; gradual and wavy boundary to: [Sample No: 510D]

Bgt l20 - l70cm greyish brown (l0YR 5/2.5 moist only); many, fine, distinct, orange mottles; sandy clay loam; weak, angular blocky structure; friable when moist, slightly sticky and plastic when wet; few weak clay skins; many very fine pores; common coarse and few fine roots: [Sample No: 510E]

Horizon	A1	AE	E1g	E2g	Bgt
Depth (cm)	0-20	20-40	40-70	70-120	120-170
Field Ref.	510 A	510 B	510 C	510 D	510 E
Sand %	90	94	88	90	64
Silt %	4	2	8	6	20
Clay %	6	4	4	4	16
Texture class	S	S	S	S	SL
pF 2.0 (%w/w)	9.5	5.1	5.6	5.3	19.3
pF 4.2 (%w/w)					
Bulk Density	1.56	1.63	1.59	1.56	1.69
AWC %					
pH-H_2O (1:2.5)	5.3	6.6	6.5	6.9	6.8
pH-KCl (1:2.5)	4.2	5.8	5.2	5.5	5.4
Ec mS/cm (1:2.5)	0.1	0.06	0.05	0.03	0.03
Organic C %	0.42	0.06	0.12	0.06	0.18
Total N %					
C/N					
P-Mehlig ppm					
CEC NH_4OAc me/100g	2.65	0.75	1.45	trace	4.95
Exch. Ca me/100g	1.08	trace	trace	trace	0.86
Exch. Mg me/100g	0.60	trace	trace	0.05	1.20
Exch. K me/100g	0.22	0.07	0.02	trace	0.09
Exch. Na me/100g	trace	trace	trace	trace	0.09
Base Sat. %	72%	< 50%	< 50%	-	< 50%
Exch. Sodium %					

PROFILE No. **9**, Field No. **254** Soil Mapping Unit **PA6**

Location: WSS, Witu-Kipini area; Along Witu-Garsen road, 4 km from Witu town. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1985): CL4 s/vs i (vs). **Geology, Soil Parent Material**: Lagoonal sand-over-clay deposits. **Landform, Relief**: Almost flat coastal plain. **Vegetation, Land Use**: Doum Palm - wooded open bush. **Drainage Conditions**: Imperfectly drained, with slowly permeable layer at 60$^+$cm. **Erosion**: no signs of runoff.

A 0 - 5cm very dark grayish brown (10YR 3/2, dry) and black (10YR 2/1, moist); loamy fine sand; very weak fine subangular blocky structure; non sticky non plastic when wet, soft when dry; many fine pores; many medium and fine roots; clear and smooth boundary to: [Sample No. 254A]

AE 5 - 25cm dark brown (10YR 3/3, dry) and very dark grayish brown (9YR 3/2, moist); many fine faint, bleached and dark brown mottles; loamy fine sand; very weak medium subangular blocky to porous massive structure; non sticky non plastic when wet, hard when dry; many fine pores; common medium roots; few fine manganese concretions; gradual and smooth boundary to: [Sample No. 254B]

E 25 - 60cm yellowish brown (10YR 5/4, dry) and dark brown (10YR 4/3, moist); many fine prominent bleached and brown mottles; sandy loam; weak coarse angular blocky structure; non sticky slightly plastic when wet, very hard when dry; weak cutans; many medium and fine pores; very few medium roots; many medium manganese concretions; abrupt and irregular boundary to: [Sample No. 254D]

Bt 60-100+cm grayish brown (10YR 5/2, dry and moist); many fine distinct orange and dark brown mottles; sandy clay; very strong coarse prismatic or columnar structure; very sticky, very plastic when wet, extra firm when moist, extra hard when dry; cutans on ped faces; few medium pores (cracks along prisms); very few medium roots; common medium manganese concretions. [Sample No. 254D]

Horizon	top soil	A	AE	E	Bt2
Depth (cm)	0-20, mix	0- 5	5-25	25-60	60-100+
Field Ref.	254 M	254 A	254 B	254 C	254 D
Sand %		84	80	78	58
Silt %		6	4	4	2
Clay %		10	16	18	40
Texture class		(L)S	SL	SL	SC
pF 2.0 (%w/w)				12.6	
pF 4.2 (%w/w)				6.6	
Bulk Density				1.46	
AWC %				8.8	
pH-H_2O (1:2.5)	6.6	6.7	5.7	6.8	6.6
pH-KCl (1:2.5)		4.6	4.2	4.5	5.3
Ec mS/cm (1:2.5)		0.04	0.05	0.04	0.12
Organic C %		0.53	0.38	0.20	0.31
Total N %					
C/N					
P-Mehlig ppm	25				
CEC NH_4OAc me/100g		4.8	8.3	8.7	21.3
Exch. Ca me/100g		0.5	1.3	-	4.7
Exch. Mg me/100g		0.5	1.0	2.3	3.8
Exch. K me/100g		0.30	0.12	0.10	0.82
Exch. Na me/100g		0.30	0.35	0.45	0.75
Base Sat. %		< 50%	< 50%	-	< 50%
Exch. Sodium %					

PROFILE No. **10**, Field No. **256** Soil Mapping Unit **PA7**

Location: WSS, Witu-Kipini area; Along Witu-Jalaluma road. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1985): CL4 s/vs i (vs). **Geology, Soil Parent Material**: Lagoonal sand-over-clay deposits. **Landform, Relief**: Almost flat coastal plain. **Vegetation, Land Use**: Open bush of *Acacia mellifera, Ormocarpum kirkii*, a.o. **Drainage Conditions**: Imperfectly drained, with slowly permeable layer at 40⁺cm. **Erosion**: no signs of runoff.

A 0- 10cm very dark gray (10YR 3.5/1, dry and 10YR 2.5/1, moist); many fine faint mottles; loamy fine sand; porous massive structure; non sticky non plastic when wet, hard when dry; many fine pores; common medium roots; gradual and smooth boundary to: [Sample No. 256A]

AE 10 - 25cm brown (10YR 5/3, dry) to very dark grayish brown (10YR 3/2, moist); few fine faint mottles; medium to fine sand; porous massive structure; non sticky non plastic when wet, hard when dry; many fine pores; few medium roots; diffuse and wavy boundary to: [Sample No. 256B]

E 25 - 40cm yellowish brown (10YR 5/4, dry) to dark brown (10YR 4/3, moist); many fine prominent mottles; medium to fine sandy clay loam; porous massive to weak coarse prismatic structure; non sticky, slightly plastic when wet, very hard when dry; few fine roots; many manganese concretions; abrupt and irregular boundary to: [Sample No. 256C]

Bt 40 - 90+cm light brownish gray (10YR 5/2, dry and moist); common fine distinct (rusty) mottles; medium to fine sandy clay; strong coarse angular blocky to prismatic or columnar structure; very sticky, very plastic when wet, extra hard when dry; bleached sand on prismatic ped faces; few medium pores; few fine roots; few manganese concretions. [Sample No. 256D]

Horizon	top soil	A	AE	E	Bt
Depth (cm)	0-20, mix	0-10	10-25	25-40	40- 90+
Field Ref.	256 M	256 A	256 B	256 C	256 D
Sand %		84	86	78	62
Silt %		4	4	2	4
Clay %		12	10	20	34
Texture class		LS	SL	S(C)L	SCL
pF 2.0 (%w/w)				8.9	18.5
pF 4.2 (%w/w)				4.2	9.9
Bulk Density				1.43	1.66
AWC %				6.7	14.3
pH-H_2O (1:2.5)	6.4	6.5	5.6	5.4	5.8
pH-KCl (1:2.5)		4.7	4.3	4.0	4.0
Ec mS/cm (1:2.5)		0.15	0.06	0.04	0.18
Organic C %		0.72	0.28	0.25	0.04
Total N %					
C/N					
P-Mehlig ppm	8				
CEC NH_4OAc me/100g		7.0	4.4	9.6	14.5
Exch. Ca me/100g		0.5	0.3	0.3	0.7
Exch. Mg me/100g		1.1	0.9	1.0	2.0
Exch. K me/100g		0.24	0.08	0.06	0.14
Exch. Na me/100g		0.47	0.22	0.27	0.65
Base Sat. %		< 50%	< 50%	< 50%	< 50%
Exch. Sodium %					

PROFILE No. **11**, Field No. **261** Soil Mapping Unit **PJ2**

Location: WSS, Witu-Katsaka Kairu area; Along Witu-Garsen road, near Katsaka Kairu. **Agro-Ecological Subzone** (Jaetzold & Schmidt, 1985): CL4 s/vs i (vs). **Geology, Soil Parent Material**: Lagoonal clay deposits. **Landform, Relief**: Almost flat coastal plain, with gilgai micro-relief. **Vegetation, Land Use**: Grassland of *Andropogon sp.*, *Hyparrhenia sp.* and *Asparagus*, partly wooded with *Acacia seyal*. **Drainage Conditions**: Imperfectly to poorly drained. **Erosion**: no signs of runoff.

A1 0 - 15 cm dark grayish brown (10YR 4/2, moist); many fine distinct mottles; clay; strong angular blocky to prismatic structure; very sticky, very plastic when wet, very firm when moist, very hard when dry; many fine and medium roots; many fine pores; clear and wavy boundary to: [Sample No. 261A]

AC 15 - 50 cm dark gray (10YR 4/1, moist); few coarse faint mottles; clay; strong coarse prismatic to angular blocky structure; very sticky, very plastic when wet, very firm when moist, very hard when dry; pressure faces; common fine roots; gradual and smooth boundary to: [Sample No. 261B]

Cg1 50 - 70cm dark grayish brown (2.5 Y 4/2, moist);common fine distinct mottles; clay; strong coarse prismatic to angular blocky structure; very sticky, very plastic when wet, very firm when moist, very hard when dry; well developed slickensides; few fine manganese concretions; gradual and smooth boundary to: [Sample No. 261C]

Cg2 70 - 120+cm dark gray (2.5Y 4/1, moist); few fine distinct mottles; clay; strong coarse prismatic structure: very sticky, very plastic when wet, very firm when moist, very hard when dry; strong slickensides; no roots. [Sample No. 261D]

Horizon	top soil	A	AC	Cg1	Cg2
Depth (cm)	0-20, mix	0-15	15-50	50-70	70-120+
Field Ref.	261 M	261 A	261 B	261 C	261 D
Sand %		38	36	42	34
Silt %		16	15	14	12
Clay %		46	49	44	54
Texture class		C	C	C	C
pF 2.0 (%w/w)					
pF 4.2 (%w/w)					
Bulk Density					
AWC %					
$pH-H_2O$ (1:2.5)	6.3	6.2	6.5	7.3	7.6
pH-KCl (1:2.5)		4.6	5.3	6.3	6.6
Ec mS/cm (1:2.5)		0.19	0.70	1.70	2.65
Organic C %	1.07	1.45	0.60	0.21	0.77
Total N %					
C/N					
P-Mehlig ppm	48				
CEC NH_4OAc me/100g		27.5	7.8	26.3	28.5
Exch. Ca me/100g		6.1	3.0	6.3	7.2
Exch. Mg me/100g		5.9	1.0	5.7	6.0
Exch. K me/100g		0.68	0.26	0.30	0.31
Exch. Na me/100g		0.48	0.72	4.67	5.30
Base Sat. %		50%	50%	65%	66%
Exch. Sodium %				18%	19%

ANNEX 3: FIELD OBSERVATION FORM

OBS. Nº

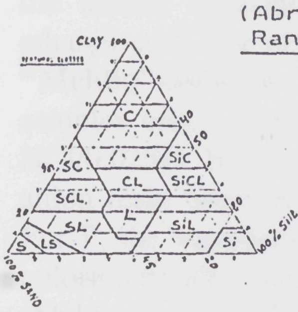
REP OF KENYA MOLS. GTZ/GASP SEMI-DETAILED SOIL SURVEY WITU/LKII

Area/Location: Photo int:
Date: Legend unit I:
Author: Final M. unit:

Physiography:
Mesotopography:
Position Obs: Slope %:
Surface features / Microtop.:
Rock outcrops / Stoniness:
Ponding / Flooding:
Erosion / Deposition:
Local soil name:

OBSERVAT		WATR	COLOUR	MOTTLE	TEXTUR	CONSISTENCE				CONCRET				MI	ANALYSIS		
Num	Depth	GwMs	HuVaCr	AbSzCo	SzClss	Sti	Pla	Mois	Dry	Ab	Sz	K1	K2	Ab	Li	pH	EC
	0 -10																
	10 -25																
	25 -40																
	40 -60																
	60 -70																
	80 -120																
	120 -x																

(Abrupt) textural change
Range: Depth:



pH/EC-Sample

Nº	pH	EC(S)
10-20		
40-60		
80-120		

VEGETATION	%cover	1st dom.sp.	2d dom sp.	remarks
Trees				
Palms				
Shrubs				
Dwarf shrubs				
Tall grass				
Short grass				

ANNEX 4: LABORATORY ANALYSES METHODS

Soil samples were analysed at the National Agricultural Laboratories, which employ the following methods:

a **Standard analysis**

Samples entering the laboratory received the following treatment:
Preparation: Air drying, breaking up of aggregates by careful pounding with pestle and mortar; sieving through 2 mm sieve.
Texture (limited pretreatment): No chemical treatments to remove cementing agents; shaking overnight with soidium hexametaphosphate/ sodium carbonate in an end-over-end shaker at 40 rpm Measurement of silt + clay (0-0.05 mm) and clay (0-0.002 mm) with a hydrometer ASTM after 40 seconds and 2 hours respectively. Silt fraction (0.002-0.05 mm) obtained by difference and sand fraction (0.05-2 mm) is the rest factor (Day, 1956).
pH and EC: Determined in a 1 : 2.5 soil-water suspension; for soils with an EC above 0.8 mmho/cm also a saturation extract is prepared for pH and EC determination.
pH-KCl: measurement in a 1 : 2.5 1N-KCl suspension.
$CaCO_3$%: Determination of volume of CO_2 after the addition of HCl, Scheibler method.
C%: Walkley and Black method (Black, 1965), no recovery factor is used.
Cation Exchange Capacity (CEC): Saturation with Ammonium Acetate of pH 7.0, washing with 95% ethyl alcohol and leaching with acidified Sodium chloride. NH4 is determined by steam distillation and titration.
Exchangeable Cations: Leaching of the soil with N ammonium acetate of pH 7.0. Determination of Na, K and Ca by flame photometer and determination of Mg with the atomic absorption spectrophotometer. Saline soils are prewashed with 70% ethanol until free of Cl.
"Mehlig"-analysis: (Mass analysis for available nutrients, on composite topsoil samples only): Extraction of soil by shaking for 1 hour at a 1 : 5 ratio with 0.1N HCl/0.025N H_2SO_4.Determination of Ca, K, Na by flame photometer, after an anion resin treatment for Ca. For Mg the same procedure as for exchangeable Mg. For P, the vanadomolybdophosphoric yellow method is followed. Mn is measured colorimetrically using phosphoric acid-Potassium periodate for colour development (Mehlig et al, 1962).

b **Additional analyses**

Bulk density: Determination of the oven dry (105 °C) weight of a soil core of known volume.
pF-curve: Determination of moisture percentages at suctions of 0.001, 0,2 and 0,5 and pressures of 5.0 and 16.0 atmospheres (pF 0, 2.3, 2.7, 3.7 and 4.2

respectively). Undisturbed core samples were used for the three lowest pF-values, which were determined on kaolin boxes (Van der Harst and Stakman, 1965). Disturbed samples were used for the two highest pF-values, which were measured with standard moisture extraction equipment as provided by Soil Moisture Co., Sta. Barbara, California, USA (Stakman & Van der Harst, 1962).

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