RECONNAISSANCE SOIL SURVEY OF PART OF THE MAKUENI AREA AND DETAILED SOIL SURVEY OF THE KAMPI YA MAWE AGRICULTURAL EXPERIMENTAL SUBSTATION KENYA

by

F.N. Muchena

Kenya

1975

MSc - COURSE ON SOIL SCIENCE AND WATER MANAGEMENT

AGRICULTURAL UNIVERSITY
WAGENINGEN - THE NETHERLANDS

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1. INTRODUCTION.

This report describes the results of a soil survey carried out in Kenya as part of a training on the job, in accordance with the requirements of the MSc-course in Soil Science and Water Management organized by the Agricultural University of Wageningen, The Netherlands. This practical exercise was carried out between 2nd September and 15th November 1974, during which period the author was in Kenya.
Prior to soil mapping, a preliminary study was made of the geology, geomorphology, hydrology, climate, population and road pattern of the survey area. An analysis of the aerial photographs (scale 1:25,000) was done and a photointerpretation map was made. At the same time, the base map (scale 1:100,000) for the reconnaissance soil survey was prepared.
Two types of soil surveys were carried out, namely, a detailed soil survey (scale 1:2,500) of Kampi ya Mawe Agricultural Experimental Substation and a reconnaissance soil mapping (scale 1:100,000) of a part of Makueni area.
All the survey work, data collection and initial compilation of the soil maps and land suitability classification maps were done in Kenya. The report was prepared in Wageningen after the fieldwork.
Chapters 3 through 7 of this report give information about the reconnaissance survey, chapter 8 is devoted to the detailed survey.

2. OBJECTIVES.

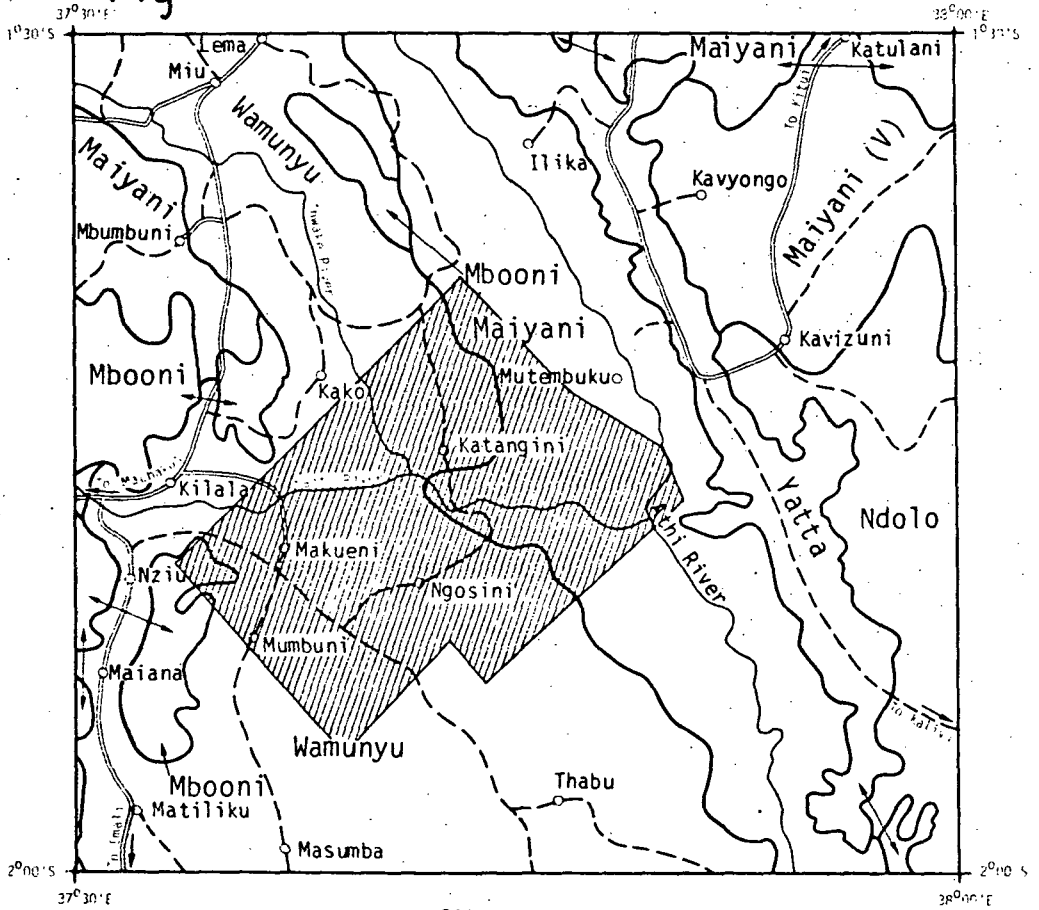
The main objective of this fieldwork was actual training on the job in detailed and reconnaissance soil surveys. This exercise included aerial photointerpretation, the study of the geological and geomorphological formation of the survey area, detailed and reconnaissance soil mapping, making soil profile drawings, and the morphological description and classification of the soil profiles. It also included the preparation of derived maps such as land suitability maps and the compilation of a soil survey report.

3. THE ENVIRONMENT.

3.1. Location, communications and population.

The surveyed area, which covers 61,000 hectares is situated in the Eastern part of Kenya, in Eastern Province and covers part of the Makueni Division, Machakos district. It runs in a S.W.-N.E. direction and is bounded in between latitude $1^{\circ}35'$ and $1^{\circ}55'$ S and longitudes $37^{\circ}32'$ and $37^{\circ}53'$ E (see fig. 1a & b).
The chief means of communication is by road. The survey area is served by two all-weather roads, one from Machakos town via Kilala, Wote and going further north to Kitui via Kalawa, and the other going via Nziu to join the Nairobi-Mombasa main road at Emali. However, there are numerous tracks in the area which are easily accessible by car (particularly a landrover) during the dry season.
The population distribution pattern of the locations within and around the survey area (Kenya population Census, 1969) is shown in table 1.

Fig 1a: LOCATION MAP OF MAKUENI SURVEY AREA



SCALE 1:500,000

KEY

- Road
- Motorable Track
- River
- Village
- Land System Boundary
- Survey area

Drawing No 74025

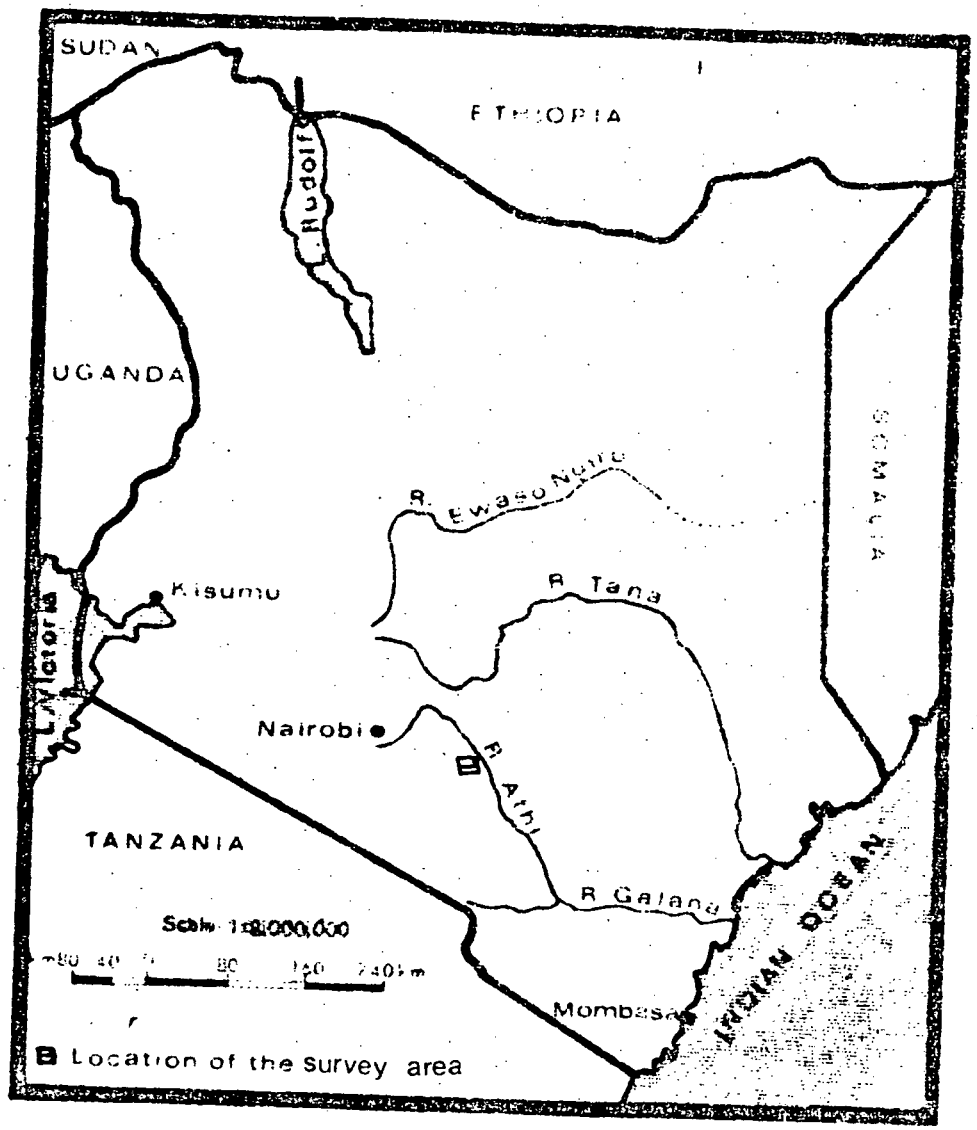

SUDAN
ETHIOPIA
Rudolf
UGANDA
SOMALIA
R. Ewaso Ngiro
Kisumu
L. Victoria
R. Tana
Nairobi
R. Athi
TANZANIA
R. Galana
Scale 1:8,000,000
Mombasa
INDIAN OCEAN
Location of the survey area

Fig 1b

Table 1.

Population distribution of Makueni area.

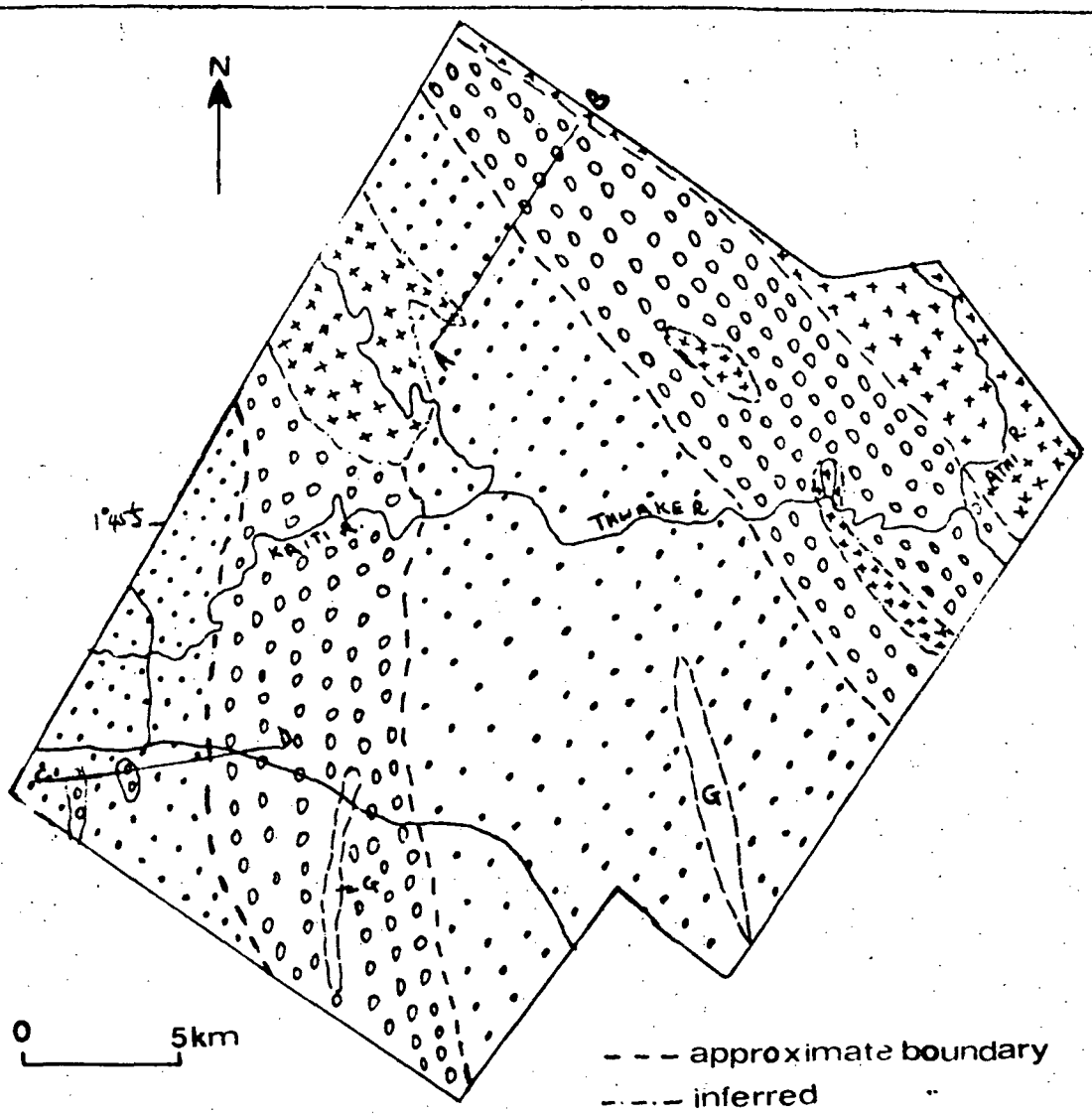
Location	Area in sq. km	Density/sq. km	Total population
Mutembuku	42	43	1,811
Kalawa	109	30	3,223
Katangini	64	53	3,386
Kako	32	97	3,130
Wote	70	74	5,155
Muvau	91	44	4,033
Kikumini	125	41	5,144
Mumbuni	74	37	2,737

3.2. Geology, geomorphology and hydrology.

3.2.1. Geology.

The area was geologically surveyed between March and September 1950 and a map plus report was published in 1953 (Dodson, 1953).
It is mainly occupied by Precambrian rocks of the Basement System. The predominant rock of the Basement System is a microcline rich biotite gneiss of which the mineral composition remains constant over a wide area. Other Basement System rocks occurring in the area are granitoid gneisses, banded gneisses, amphibolites and granites.
The undifferentiated banded gneisses and biotite gneisses which are the major geological formations in the central part of the survey area give rise to soils of varying textures and colours (cf. soil mapping unit symbol BU..).
The granitoid gneisses occur as two major outcrops stretching N - S through the area (see fig. 2). They have suffered granitization and are more resistant to erosion than the other gneisses of the Basement System. Consequently they form the bulk of hills in the area. The soils derived from the granitoid gneisses are dominantly coarse textured (cf. soil mapping unit symbol BQ1).
The amplibolites and other Basement System rocks rich in ferromagnesian minerals (hornblende, biotite, diopside and plagioclase feldspars) occur mainly in the north eastern part of the survey area. The soils derived from these rocks are mainly red or dark red clays (cf. soil mapping unit symbol BF..).
Granites occur at Mathemba and Kampi ya Mawe areas as narrow rock outcrops The soils derived from these rocks are coarse textured and are included in the mapping Unit BQ1.
Subrecent alluvial deposits occur as small stretches along the rivers. These give rise to alluvial soils (cf. soil mapping unit symbol AR).
Table 2 shows the geological formations and the soil mapping units whereas figure 3 shows the relationship between geological formations and the soils.

Fig·2 **GEOLOGY** (simplified) adapted from: Geological map of the area S.E. of Machakos, report No 25 1953



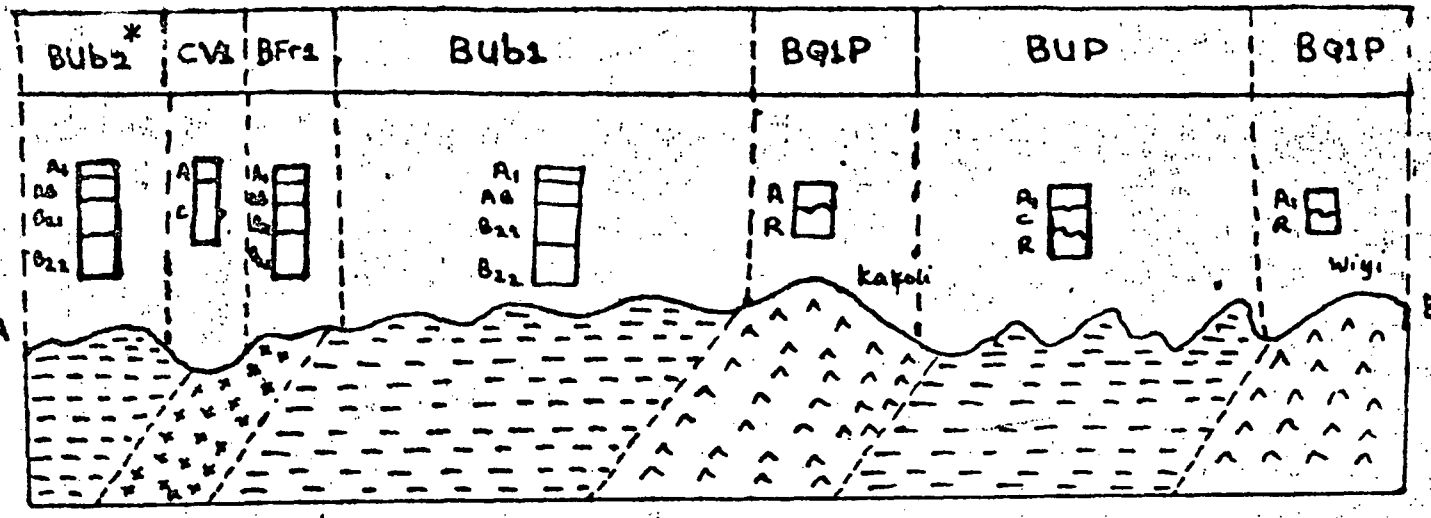
KEY

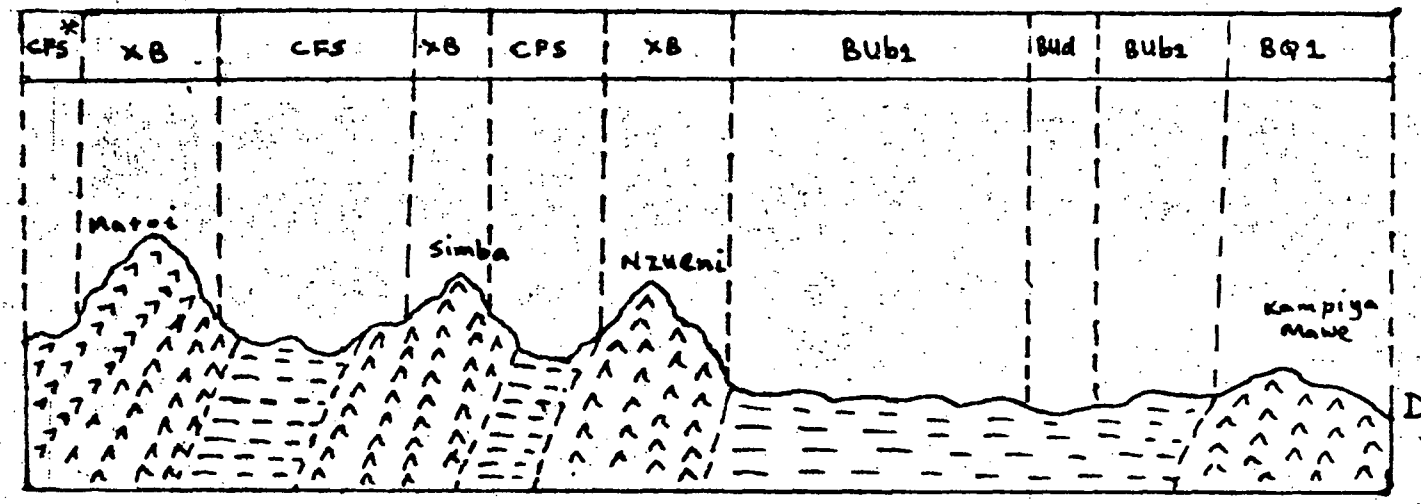
undifferentiated banded gneisses

granitoid gneisses

rocks rich in ferromagnesian minerals

G granite





(not to scale)

KEY

- predominantly granitoid gneisses

- predominantly undifferentiated banded gneisses

- gneisses rich in ferromagnesian minerals.

* Mapping units - for explanation see the reconnaissance soil map legend.

Fig. 3 Cross sections showing relationship between geology, geomorphology and the soil mapping units

Table 2.

Geological formations and the soil mapping units.

Geological formation	Rock type	Soil mapping unit
Basement complex	a) Undifferentiated Basement System (biotite gneisses + banded gneisses)	BU
	b) granitoid gneisses + granites	BQ1
	c) Basement System rocks rich in ferromagnesian minerals + amphibolites	BF
Younger sediments	Subrecent alluvial deposits	AR

3.2.2. Geomorphology.

The area can be divided into four physiographic units: 1) hills, 2) footslopes, 3) uplands (dissected peneplains) and 4) river terraces.
The hills (mapping unit xB) are prominent features of the area. Most of the hills consist of granitoid gneisses which are resistant to erosion. The footslopes (mapping unit CFS) are the gently and moderately sloping areas at the foot of the hills. The uplands (mapping unit B) which form the bulk of the area, is a dissected peneplain consisting mainly of more easily erodable rocks such as banded gneisses, biotite gneisses and amphibolites. The river terraces (mapping unit AR) consist of recent alluvial sediments.
Three erosion surfaces are evident in the area. The most extensive one is the dissected peneplain which forms the uplands. It is the most youthful surface and occurs at an altitude between 900 metres and 1,000 metres. The monotony of this youngest planation surface is broken only by the inselberg remnants of an older plain now represented by the tops of low lying small hills, such as Makueni, Katumbua, Mandui and Mubau. The third and oldest erosion surface is represented by the fairly high and large hills such as Matoi and Nzaui (see fig. 4).
Rock types have to a great extent influenced the topography. Where there are more resistant gneisses, for example north of Kaiti river the surface is more irregular. The most noticeable feature of topography in the area is nevertheless the abrupt change which occurs east of a line connecting roughly Nthangu, Malibani and Matoi hill ranges. This abrupt change in topography may be attributed partly to the abundance of granitoid gneisses which form the hill ranges west of the topographic break and partly to the far away distance of the main drainage channel (Athi river). Because of this distance from the principal river, the hill ranges in the west are unaffected by the formation of the most youthful erosion surface.

3.2.3. Hydrology.

The topography is dissected by a mature drainage system of which the Athi is the principal river and the only one that has a perennial flow. The Kaiti-Thwake rivers and their tributaries are intermittent (see fig. 5). They seldom flow for more than a few months in the year. However, subsurface water is found in the dry river beds buried by sand. Water is drawn by the

Fig·4 Erosion surfaces in the survey area.

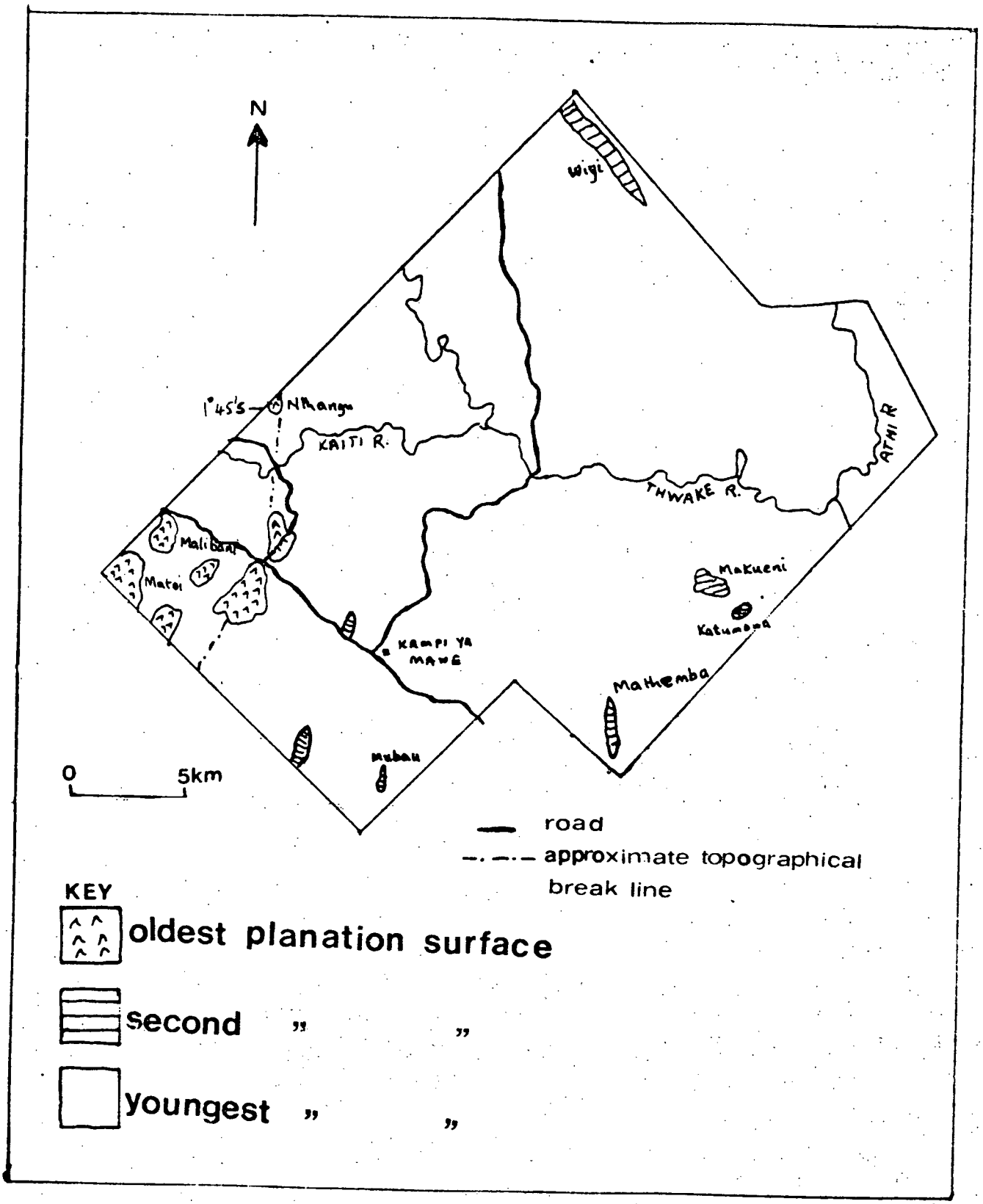


Fig. 5. Dry riverbed - river Kaiti.

inhabitants by simply excavating the sand to a depth of approximately 1 metre. A few large dams where all season water for both livestock and human use may be drawn exist in the area (see Appendix C).
Also boreholes exist in the area but the water is reportedly salty.
Generally the whole area has good external and internal soil drainage. The hilly areas, due to steep slopes, have a rapid external drainage which creates a high erosion hazard (mapping unit xB).

3.3. Climate and ecological zone.

In addition to climate being one of the soil forming factors, the prevailing climatic conditions of an area determine its agricultural potential. The climatic variables which are of greatest importance are temperature and the amount of precipitation and evaporation. Unfortunately the only two recording stations within the survey area give a limited amount of climatic data. Consequently, the climatic data summarised in this report include an interpolation of the data of surrounding areas which are within the same climatic zone.
The area has a subhumid tropical climate according to Thornthwaite (1948). Rainfall is not equally distributed throughout the year. There are pronounced wet and dry seasons in the area; the dry season January - February is followed by a rainy season mid March - April - end of May (long rains), followed by a dry season June - July - August - September - mid October, which is followed by a wet season November - end December (short rains)(see fig. 6). Generally evaporation exceeds precipitation for the greater part of the year, in the survey area (see fig. 7 and 8a + 8b).
The average annual rainfall at Kampi ya Mawe and Makueni Athi Camp, over 15 years, (Thwake river, 3 km upstream from its junction with the Athi river) are 725 and 684 mm respectively (E.A.M.D., 1973). Comparing this with that of surrounding stations which have records for many years, the adjusted average annual rainfall of these stations, using Kitui as reference station, is 675 and 647 mm respectively. Averaging the differences Kampi ya Mawe would have 700 mm and Makueni Athi Camp 665 mm.
The average mean annual temperature, taking Makindu as the reference station, is 22.5°C with a mean monthly minimum of 14°C in July and August and a mean monthly maximum of 31°C in March (see table 3).

Table 3. Climatic data of Makueni and the surrounding areas.

JAN.	FEBR.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Average monthly rainfall at Kampi ya Mawe for 19 years (in mm).											
39	37	81	132	47	13	3	5	5	60	196	95
Average mean maximum temperatures in °C at Makindu from 1958-72.											
29	30	31	29	28	27	26	26	28	30	28	27
Average mean minimum temperatures in °C at Makindu from 1958-72.											
18	18	19	19	17	15	14	14	15	17	18	18
Average mean minimum and mean maximum temperature in °C at Makindu from 1958-72.											
23.5	24	25	24	22.5	21	20	20	21.5	23.5	23	22.5
Potential evapotranspiration at Makindu in 1971 (in mm).											
232	253	281	212	147	155	141	136	212	261	223	167
Precipitation at Makindu in 1971 (in mm).											
25	5	15	244	31	2	0.6	0.4	0.9	2	174	93

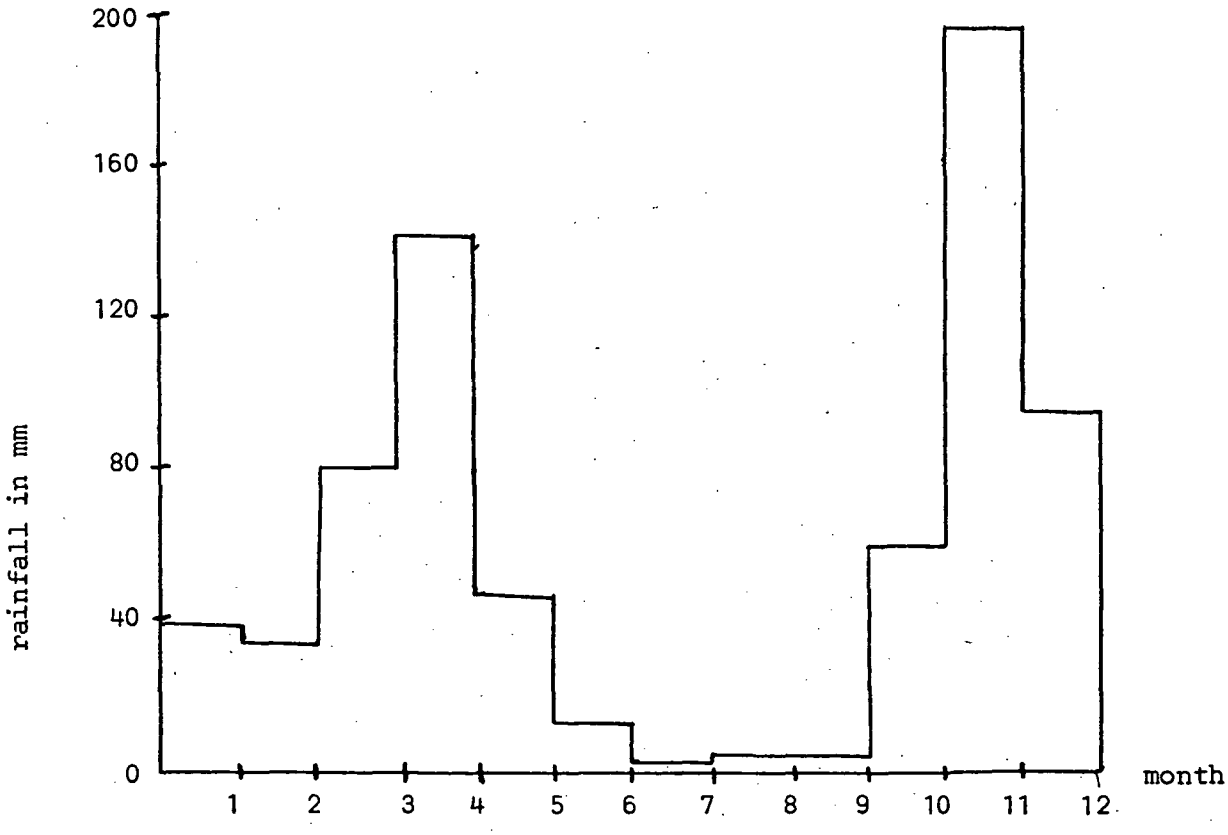


Fig. 6. Average monthly rainfall at Kampi ya Mawe for 19 years.

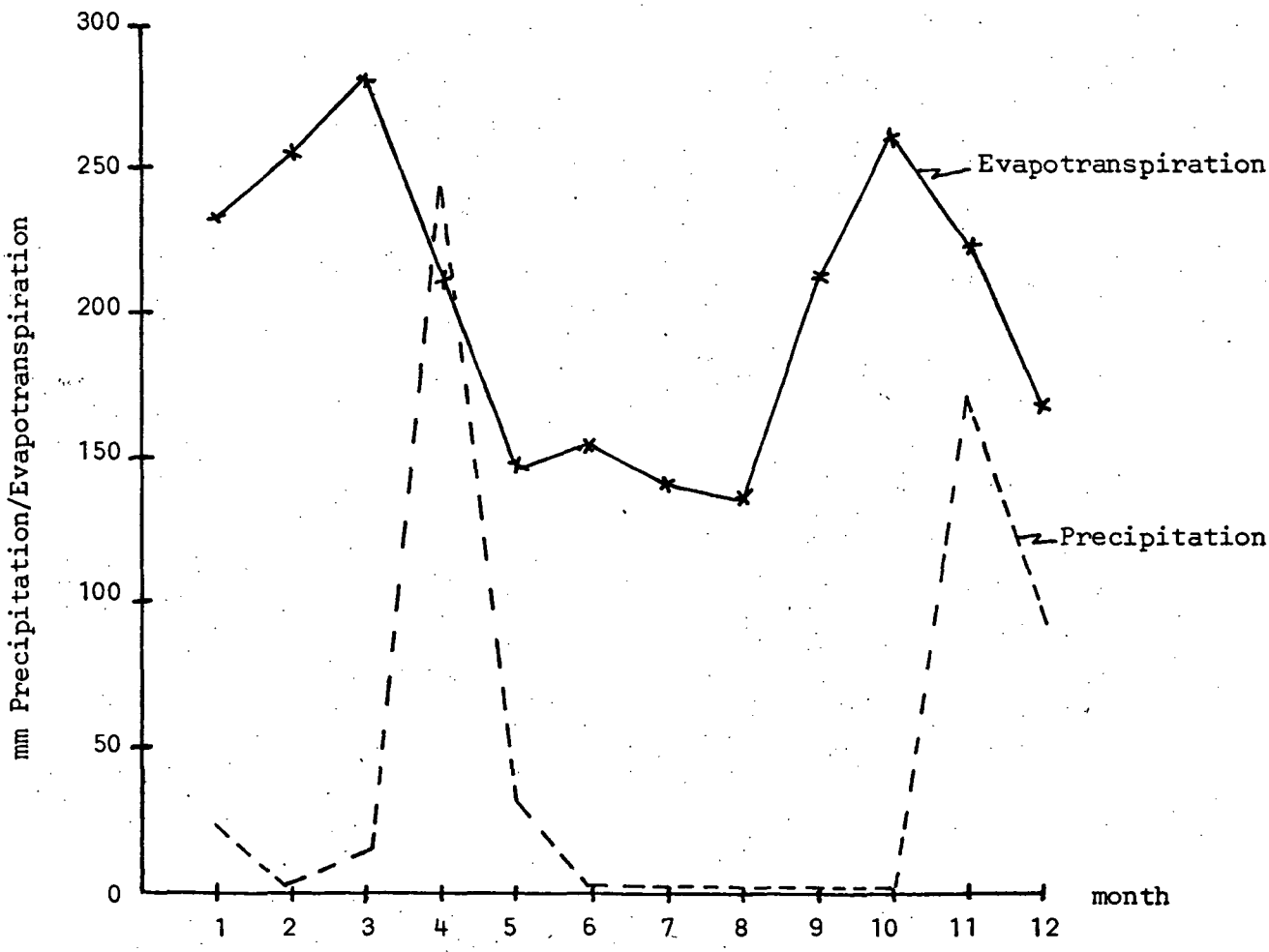


Fig. 7. Precipitation, Evapotranspiration at Makindu 1971

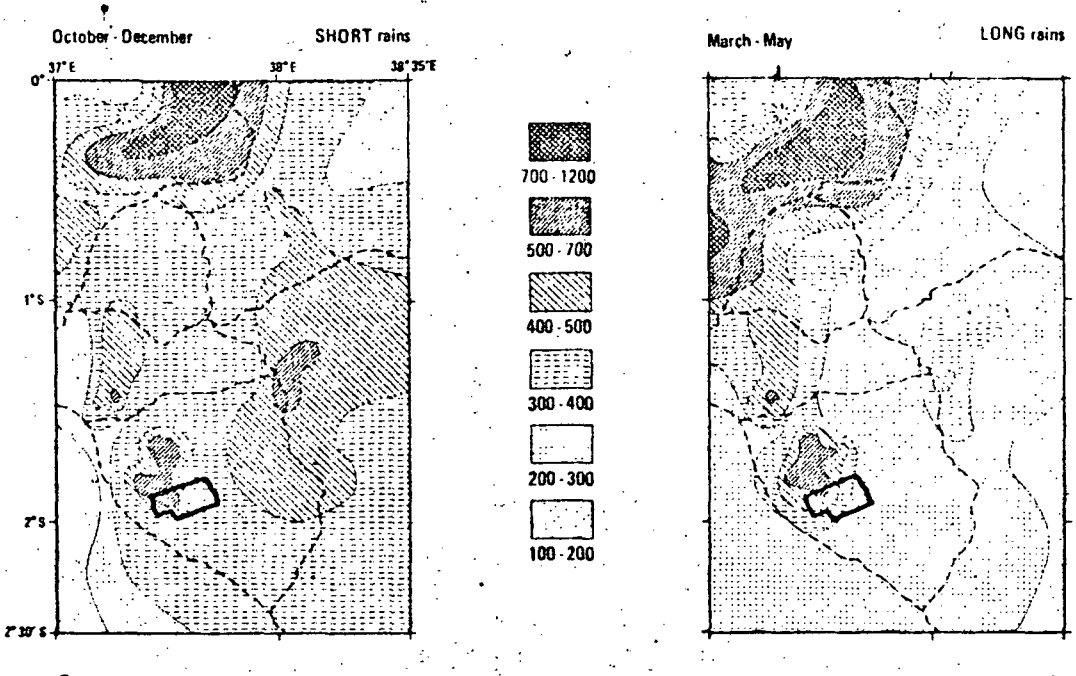


Fig 8a - Average rainy-season rainfall (in mm)

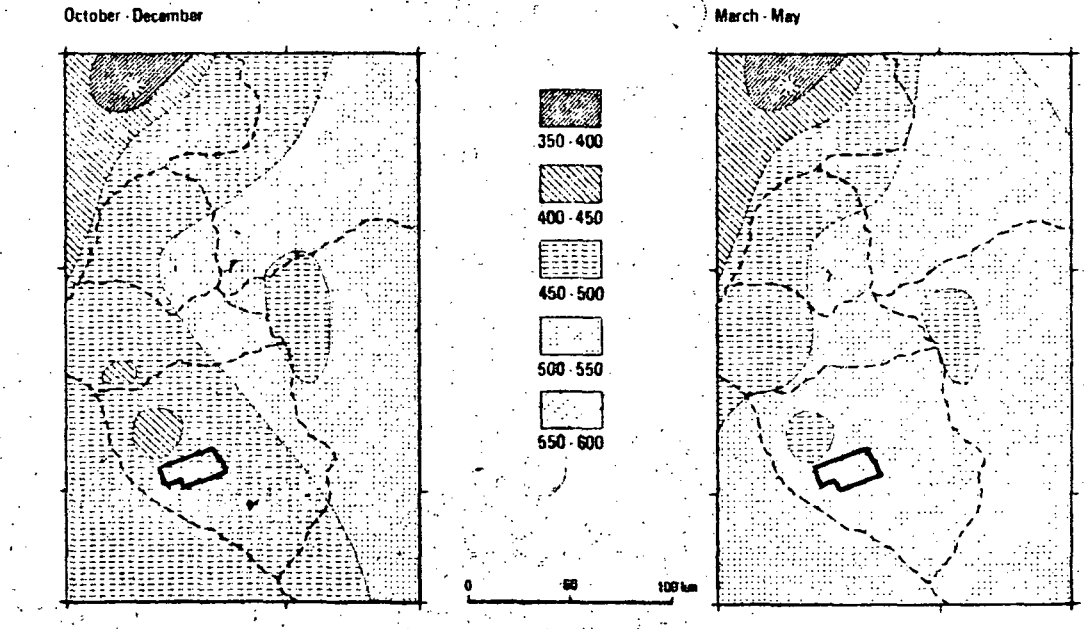


Fig 8b - Average rainy-season potential evaporation (in mm)

The map on page 29 of the Kenya Atlas (Survey of Kenya, 1970) shows most of the survey area in ecological zone V except for the western edge which is mapped as zone IV. In this text, the ecological zones are referred to as defined in the Atlas of Kenya (page 28).

Ecological zone IV: Land of marginal agricultural potential, carrying as natural vegetation dry forms of woodland and "savanna" or derived semi-evergreen or deciduous bushland (moisture index, $^{r}/Eo$, 33 to 48%).

Ecological zone V: Land only very locally suited to agriculture, the woody vegetation being dominated by Commiphora, Acacia and allied genera, mostly of shrubby habit. Perenial grasses such as Cenchrus Ciliaris and Chloris roxburghiana can dominate (moisture index, $^{r}/Eo$, 18 to 33%).

Woodheads' (1970) map gives an annual index of available water between 30 and 40% for the whole survey area except its north western part (Makueni Boma) which is in class 40 to 50%. The same author (p. 651) indicates that an index between 30 and 45% is the boundary criterion for ecological zone IV. With an estimated potential evaporation (Woodhead, 1968) of 2000 and 2050 mm per annum, the ratio $^{r}/Eo$ (where r is rainfall and Eo potential evapotranspiration) is 35% for Kampi ya Mawe and 32% for Makueni Athi Camp, which puts both stations in ecological zone IV.

3.4. Vegetation.

The natural vegetation of the survey area consists mainly of dry forms of woodland and "savanna" (Atlas of Kenya). No clear differences are observed in the vegetation of different kinds of Basement soils (red, brown, sandy) except for the Vertisols (mapping unit BUd) which have a physiognomy and botanical composition different from all the other mapping units.

Combretum apiculatum is the most abudant small tree. Acacia drepanolobium was found only on Vertisols (mapping unit BUd). On some sheet eroded areas the broad-leaved species of Combretum, which are dominating the aspect elsewhere, are absent. The Acacia and Commiphora are predominant with two other unidentified shrubs, while the grass cover is very poor to virtually absent. Due to overgrazing and dry status of the herbaceous layer it was impossible to obtain an idea on the botanical composition of this layer. The list of woody species and grasses identified in the area is given in Appendix A.

From the species mentioned in the Atlas of Kenya as indicators of ecological zones (see 3.3.), the following are present in the area.

Species	Zone
Combretum molle	III
Acacia hockii	III and IV
Albizia amara	IV
Acacia seyal	IV
" drepanolobium	IV
Croton dichogamus	IV
Acacia mellifera	V
Commiphora africana	V
Chloris roxburghiana	V

Combretum molle is only common in the western part of the survey area. Acacia mellifera and Commiphora africana are dominant in the eastern part

of the survey area. From the vegetation cover, it can be concluded that the greater part of the survey area belongs to ecological zone IV grading to zone V in the eastern section.

3.5. Present land use.

The greater portion of the survey area is under Makueni settlement scheme. The common agricultural practice is rainfed arable mixed farming. The farm holdings range from 25 acres (± 10 hectares) to 200 acres (± 83 hectares).
The main crops grown in the area are: maize (Katumani variety), pigeon peas, beans, cassava, bulrush millet, and sorghum. Cotton has recently been introduced as a cash crop. Cotton is planted during the short rains (October-December) and it flowers and matures after the long rains (March-May). Cotton yields are generally low. Other crops grown (locally) are citrus, mangoes and castor.
Livestock keeping is commonly practised by most of the farmers. Livestock, particularly goats in the drier areas, cattle in the parts with higher rainfall, form an important source of income.
Ox-ploughing is commonly practised, but occasionally also tractors are used. Bench terracing and contour ploughing is a common practice as a measure of erosion control (see fig. 9).

4. THE SURVEY METHODS.

4.1. Office methods.

Before starting the actual fieldwork, the available aerial photographs, topographic and geological maps together with all the existing reports and other literature about the area were collected and studied.
The reconnaissance soil survey area covers parts of topographical map sheets 163/1, 163/2, 163/3 and 163/4 published in 1970 by the Survey of Kenya at scale 1:50,000. They were used as base maps.
The aerial photographs (scale approximately 1:25,000) were provided by the Survey of Kenya. Prior to fieldwork all photographs were studied stereoscopically and a preliminary photointerpretation map with legend was prepared. The value of the photointerpretation was different in the various physiographic units. In some places photointerpretation was less useful than expected.
Consequently, some of the photointerpretation boundaries had to be thoroughly checked in the field and redrawn. The reliability of the photointerpretation was affected by the nature of the bedrock material, the vegetation, unpronounced relief differences and year to year changes in land use. However, photointerpretation worked very well where there were pronounced relief differences.
During the fieldwork all observations and boundaries seen in the field were plotted directly on aerial photographs and on the topographic field maps. After finalizing the fieldwork, all the data were transferred to a "final field map" at scale 1:50,000. Transfer of the details from the aerial photographs to the topographical base map was done mainly by hand. After completing the "final field map", boundaries and symbols were transferred to a translucent 1:50,000 topographical map, which was handed over to the draughtsman for reduction to 1:100,000.

Fig. 9. Bench terracing - a common practice in the area as a measure of erosion control.

4.2. Field methods.

The field work took six weeks. The field operations were executed from Kampi ya Mawe field headquarters. The survey party consisted of eight people; two drivers, four labourers, one technical assistant and one soil surveyor (the author). Two landrovers were used.
The actual field work started with a detailed soil survey of Kampi ya Mawe Agricultural Experimental Substation (see chapter 8 and appendix C). This was followed by reconnaissance soil mapping of part of the Makueni area. For the reconnaissance soil survey, the field work, which took five weeks, started with a few reconnaissance trips through the area in order to check the photointerpretation units and to get familiar with the kinds of soil as related to their geological and geomorphological condition, vegetation, land use pattern, drainage etc. This was done by making augerings and examining road cuts.
Routine soil augerings were taken by Edelman auger type to a depth of 120 cm, preferably at selected spots in relation to the photointerpretation map. These sites were immediately pinpointed on aerial photographs and on the topographical maps (see auger hole map, appendix G). Land and soil properties were filled in on standard soil profile description forms, following the standards applied by the Kenya Soil Survey. From all representative soils, sites were selected for profile pits to be dug. The pits were 150-200 cm deep. The pits were described in detail followed Kenya Soil Survey standards which are based on the Soil Survey Manual (U.S.D.A., 1951) and the F.A.O. Guidelines for soil description. Each horizon was sampled for mechanical and chemical analysis in the laboratory.
A total of 11 profile pits were fully described and sampled. An additional 226 augerings were made and described (see appendix G).

4.3. Laboratory methods.

For all the soil samples received:

Preparation: Breaking up of the aggregates by careful pounding with pestle and mortar. Sieving through 2 mm sieve.

Texture (hydrometer method): No chemical treatments to remove cementing agents. Shaking overnight with sodiumhexametaphosphate/ sodium carbonate in an end to end shaker at 40 r.p.m. Measurement of silt + clay (0-50µ) and clay (0-2µ) with a hydrometer, ASTM 152 H, after 40 seconds and 2 hours respectively. Sand fraction (50-2000µ) obtained by difference (Day, 1956).

pH and electrical conductivity: determined in a 1:1 soil water suspension.

pH - KCl: pH measurement in a 1:1 soil-N KCl suspension.

C%: Walkley & Black method (Black, 1965), on all horizons.

N%: Semi-micro Kjeldahl method (Black, 1965), on A horizons only.

Cation exchange capacity (C.E.C.): Subsequent leachings of the soil with N sodiumacetate of pH 8.2, 75% ethylalcohol and N ammonium acetate of pH 7.0. Determination of sodium in the last leachate with an EEL flamephotometer. (For some selected samples, the CEC has been determined with N ammonium acetate at pH 7.0 as the saturating solution. After a washing step with 96% ethylalcohol and leaching with acidified calcium chloride, NH_4^+ 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 with an EEL flamephotometer, with lanthanumchloride addition for the last element.

Colorimetric Mg determination with thiazol yellow reagent (Mehlich et al., 1962).

Exchange acidity (Hp): Titrimetric determination of the acidity in a leachate of 0.6 N bariumchloride not buffered at any pH (Mehlich et al., 1962).

"Mass Analysis" for available nutrients: (A horizons only). Extraction of the soil by shaking for 1 hour at a 1:5 ratio with 0.1 N HCl/0.025 N H_2SO_4. Determination of Ca, K and Na with an EEL flamephotometer after an anion resin treatment for Ca. For Mg the same procedure as under exchangeable cations. For P Vanadomolybdophosphoric yellow method. For Mn colorimetric, using phosphoric acid - potassium-periodate for colour development (Mehlich et al., 1962).

Clay Mineralogy: The soils were treated with hydrogen peroxide for the removal of organic matter, dispersed with sodium hexametaphosphate (calgon) and subsequently separated into sand (50-2000μ), silt (2-50μ) and clay (<2μ). Iron oxides were removed following the method of Mehra and Jackson (1959). Portions of clays were saturated with Mg and K respectively by suspending the clays repeatedly in N solutions of $MgCl_2$ and KCl. The clay samples were prepared for diffractometry by spreading small quantities of saturated clays evenly with unidirectional strokes on to petrographic microscope slides (Theisen and Howard, 1962). After air and oven drying, each sample was examined with a Philips direct X-ray diffractometer, using Copper K & radiation. The clay minerals were identified by comparing the diffraction patterns of standard clays with those of the unknowns. In the quantitative estimation the method of Theisen and Bellis (1964) was followed except that peak area ratios were considered instead of peak height ratios.
The soil analysis were carried out in the routine laboratory of the National Agricultural Laboratories, Kenya.

5. THE SOILS.

5.1. Previous work.

Little work on soils has been carried out in the area previous to the present survey. Nyandat (1971) carried out an investigation of arable land in parts of Makueni, Nzawi, and Mbitini Locations of Machakos District. He divided the soils into two broad groups; those with sandy loam texture or coarser and those with texture finer than sandy loam. He estimated that 33,000 hectares of arable land existed in Makueni location.

5.2. General properties of the soils.

The soils may broadly be divided into two groups; those with sandy loam texture or coarser and those with texture finer than sandy loam. The texture of the soil appears to be strongly related to the nature of the parent material. In general it can be stated that soils developed on quartz rich Basement System rocks such as granitoid gneisses are coarse textured and those developed on undifferentiated Basement System rocks such as banded gneisses (see fig. 10) and amphibolites are fine textured. However, it should be noted that some banded gneisses are quartz rich and as a result may give rise to some coarse textured soils. Soils developed on alluvial deposits are in general coarse textured.

Fig. 10. Undifferentiated banded gneisses of the Basement System rocks.

The texture of the soil has profound influence on the moisture holding capacity, the nutrient content and permeability. The coarse textured soils have low moisture holding capacity, low natural fertility and very rapid permeability.* The fine textured soils have a moderate water holding capacity, and a moderate to rapid permeability. The soils, apart from the Vertisols (unit BUd) are moderately well drained to well drained.
The structural development of most of the soils is weak. In some cases there is very little horizon differentiation with often diffuse or gradual transitions between horizons. The A1 horizons exhibit weak to moderate subangular blocky structure. With an exception of unit BFr2a, the B horizons do not show strongly developed clay skins. Most of them have a weak structural development; they are porous massive (weakly coherent) with or without a tendency to break into subangular or prismatic blocks (see appendix B).
The soils have good physical conditions. They are porous and are characterized by moderate to high biological activity - mainly termites and ants. Most of the soils outside the hilly areas are deeply weathered and contain no or very little weatherable primary minerals.
The natural fertility of these soils is medium to very low (see analytical data in appendix B). They are characterized by low C.E.C. values. The major nutrients, nitrogen and phosphorus are deficient. The Vertisols (unit BUd) show a moderate potassium deficiency and the subsoils have sodic characteristics with an exchangeable sodium percentage (E.S.P.) greater than 15 and a pH greater than 8.5.
The organic matter content of all soils is low. This may have to be increased by manuring so that the water holding capacity, C.E.C., and water availability of the topsoils may be increased. From the point of view of the low natural fertility, use of fertilizers is necessary. However, it should be stressed that proper management practices are necessary to avoid loss of fertilizers by leaching and erosion. Leaching can be alleviated by addition of manure (increase of organic matter content).

5.3. Description of mapping units.

5.3.1. Systematics and nomenclature.

The highest category on the soil map (appendix B) are the physiographic land types, based on geomorphology: hills, footslopes, uplands (dissected peneplains), river terraces and valleys. These types of land are subdivided according to the kind of parent material on which the soils are developed e.g. soils developed on Basement System rocks, this is further subdivided according to the lithology of the rock e.g. soils developed on quartz rich Basement System rocks; predominantly granitoid gneisses.
At the lowest level the soil mapping units are subdivided on important profile characteristics such as drainage, depth, colour, consistency, texture, stoniness etc.
Each mapping unit is identified on the map by a mapping symbol, for which a code system is used. The symbols appearing in the code system are explained below.

I PHYSIOGRAPHIC LAND TYPE

x	= Hills
FS	= Footslopes
No symbol	= Uplands
V	= Valley
AR	= Subrecent river terraces

* The ratings such as low, moderate, high etc. are qualitative and are not based on those being developed for land classification.

II KIND OF PARENT MATERIAL

B = Basement System
BQ = Basement System rocks - quartz rich
BU = " " " - undifferentiated
BF = " " " - rich in ferromagnesian minerals

III IMPORTANT PROFILE CHARACTERISTICS

colour:

r = red
b = brown
d = black

Consistence: c = compactness

depth over rock

p = depth between 50-80 cm
P = depth < 50 cm

depth over petroplinthite (murram)/rock

m = depth between 50-80 cm

clay illuviation:

a = argillic horizon

IV C = complex

V The numerical numbers 1 and 2, refer to different soil types; for instance to differentiate between the two BFr soil types the codes BFr1 and BFr2 are used.

Different depth classes in the same soil unit are indicated by overprints (dot screens) taking into account whether the underlying rock consists of hard rock or of petroplinthite.
The various depth classes used are:

very shallow	0-25 cm
shallow	25-50 cm
moderately deep	50-80 cm
deep	more than 80 cm

The topography (slope class %) of each mapping unit is indicated in the mapping symbol below the fraction line

A slope %	0-2%
B " "	2-5%
C " "	5-8%
D " "	8-16%
E " "	16-30%

The length of the slopes (slope length classes) of each mapping unit is indicated in the mapping symbol below the fraction line after the slope class %.

a length of slope	< 100 m
b " " "	100-300 m
c " " "	> 300 m.

5.3.2. Soils of the hills.

The hills are areas of relatively high relief intensity with slopes in general over 16%.

Mapping unit xB.

These are predominantly very shallow to shallow, rocky soils.

Extent: 2300 ha.

Parent material: mainly granitoid gneisses.

Macro relief: hilly; slopes over 16%.

Profile development: AC or AR.

Range of characteristics.

The texture of the soils varies from loamy sand to sandy clay loam. The depth varies from very shallow (< 25 cm) to shallow (25-50 cm). The rockiness varies from fairly rocky to rocky.

Differentiating criteria.

This mapping unit differs from all the others by having the greatest relief intensity and having predominantly very shallow soils.

Inclusions: There are local inclusions of some moderately deep soils.

Land use: These soils are mainly under natural vegetation cover (trees, shrubs and grasses). In some places goats are grazed and in a few places the soils are cultivated on very steep slopes which makes them highly susceptible to erosion. These soils are unsuitable for agriculture and the land should be protected against erosion by preserving the vegetation cover.

5.3.3. Soils of the footslopes.

These soils occur at the foot of the hills mainly in the western part of the area.

Mapping unit CFS.

Footslope complex: This is a heterogeneous complex of well drained, shallow to moderately deep, stony, dark brown to dark reddish brown, loose to friable sandy loam to clay soils.

Extent: 1600 ha.

Parent material: mainly Basement System rocks and colluvial deposits.

Macro relief: gently undulating to rolling; slopes in general from 2 to 16%.

Profile development: AR or ABC.

Range of characteristics.

The soils of this complex are of varying colours and texture. The dominant colours of the topsoil vary from very dark greyish brown ($10YR^3/2$) to reddish brown ($5YR^4/4$). The dominant colours of the subsoil vary from dark brown ($7.5YR^3/2$) to dark reddish brown ($5YR^3/4$). The texture of both the topsoil and the subsoil varies from loamy sand to clay.

Differentiating criteria.

This complex differs from the valley complex (unit CV1) and the undifferentiated Basement Complex (unit CBU) by occurring mainly at the foot of the hills.

Inclusions.

Soils of unit BQ1, BUb and BUr are included in this complex. Along the drainage lines occur pockets of soils developed on alluvial/colluvial deposits.

Land use: Parts of the soils are cultivated. The main crops grown are maize, beans and pigeon peas. The uncultivated land is mainly used for grazing sheep, goats and cattle.

Additional remarks: For the greater part of the area, the grass cover is very poor due to overgrazing. This combined with cultivation on very steep slopes, makes the soils highly susceptible to erosion.

5.3.4. Soils of the uplands.

The uplands, which in this case, are mainly dissected peneplains with major rivers deeply incised, is the largest physiographic unit. There are 16 mapping units.

Mapping unit BQ1.

These are well drained, deep, dark brown to yellowish red, loose loamy sandy soils.

Extent: 1850 ha.

Parent material: Quartz rich Basement System rocks; predominantly granitoid gneisses.

Macro relief: Undulating to hilly; slopes in general from 5 to 16%.

Profile development: ABC . a colour B which because of the sandy texture does not qualify as oxic (see appendix B, profile No. 163/3-15*).

Range of characteristics.

The texture of the topsoil is coarse loamy sand and the colour varies from very dark greyish brown (10YR 3/2) to dark brown (7.5YR 3/2). The texture of the subsoil varies from loamy sand to sandy loam, but the loamy sand texture is dominant. The colour of the subsoil varies from dark brown (7.5YR 3/2-4/4) to yellowish red (5YR 4/6). The pH decreases with depth, from 5.8 in the topsoil to 4.3 in the subsoil.

Differentiating criteria: The soils of this mapping unit are coarse textured and differ from soils of mapping unit BUb2 by having no textures finer than sandy loam in the subsoil.

Inclusions: This mapping unit has inclusions of moderately deep soils. Locally soils of unit BUb2, which tend to have a sandy clay loam texture in the subsoil are found.

Land use: Where the soils are cultivated, maize, beans, and pigeon peas are grown. Bench terracing and contour ploughing, using ox-ploughs, is commonly practised. Where the land is not cultivated, it is used for grazing purposes. The grass cover is very poor due to overgrazing.

Additional remarks: These soils have a very low water holding capacity and are generally poor in chemical soil fertility. However, they have high infiltration rates, rapid permeability and very good workability.
Huge, overgrown termite mounds are commonly encountered in the area.

Mapping unit BQ1P.

This is a shallow phase of mapping unit BQ1. The soils are similar but very shallow to shallow, stony and fairly rocky.

Extent: 1950 ha.

Parent material: See unit BQ1.

Macro relief: Rolling to hilly; slopes from 8 to over 16%.

Profile development: AR or AC.

Range of characteristics.

The colour of the topsoil varies from dark greyish brown ($10YR^4/2$) to dark brown ($10YR^4/3$). The soil depth varies from 10 to 45 cm. The surface stoniness varies from very stony to stony (see fig. 11).

Differentiating criteria.

This mapping unit differs from unit BUP by having a coarse texture (loamy sand).

Inclusions: In this unit are included locally very shallow soils belonging to unit BUb1.

Land use: Under natural vegetation.

Mapping unit BUr.

These are well drained, deep, dark reddish brown to dark red, friable clay soils.

Extent: 4300 ha.

Parent material: Undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: Undulating; slopes from 5 to 8% (see fig. 12).

Profile development: ABC (see appendix B profile No. 163/4-14*).

Range of characteristics.

The texture of the topsoil varies from sandy clay loam to clay and the colour varies from dark brown ($7.5YR^3/2$) to dark reddish brown ($5YR^3/2-^3/4$). The texture of the subsoil varies from sandy clay to clay and the colour varies from dark reddish brown ($2.5YR^3/4$) to dark red ($2.5YR^3/6$). The pH varies from 6.0 in the topsoil to 6.4 in the subsoil.

Differentiating criteria.

These soils differ from those of mapping unit BFr1 by having different parent materials and by the clay content.

Inclusions.

In this mapping unit, there are inclusions of soils belonging to mapping unit BUb1. In places where there are rock outcrops, the soils have a topsoil texture of loamy sand or sandy loam. Locally, spots of moderately deep (50-80 cm) soils are found.

Land use.

Most of the cultivated area is used mainly for maize, pigeon peas and beans. The uncultivated land is used for grazing.

Fig. 11. Stony and fairly rocky soils of unit BQ1P at Kakoli ridge.

Fig. 12. Undulating landscape of unit BUr, showing signs of sheet erosion.

Additional remarks.

The grass cover on these soils was generally very poor due to overgrazing. In most of the cultivated areas bench terracing and contour ploughing is used as a measure against erosion. Where this is not practised there was evidence of sheet and gully erosion.
There was very little weatherable primary minerals in the profiles. The biological activity in these soils is moderate. The soils are used for brick making.

Mapping unit BUb1.

These are well drained, deep, yellowish red to dark reddish brown, friable clay soils.

Extent: 13950 ha.

Parent material: Undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: Varies from very gently undulating to rolling; slopes from less than 2% to 16%.

Profile development: ABC (see appendix B, profile No. 163/3-13*).

Range of characteristics.

The texture of the topsoil varies from sandy clay loam to clay and the colour varies from very dark greyish brown (10YR 3/2), dark yellowish brown (10YR 3/4), dark brown (7.5YR 3/2) to dark reddish brown (5YR 3/2-3/4). The texture of the subsoil varies from sandy clay loam to clay and colour from yellowish red (5YR 4/6) to dark reddish brown (5YR 3/4-7.5YR 4/4). The pH decreases with depth, from 5.9 in the topsoil to 4.6 in the subsoil. In some profiles, few distinct red mottles (2.5YR 4/6) occur at depths greater than 1 m. These mottles are fossile. Locally gravel occurs in the subsoil. Drainage class varies from well drained to moderately well drained.

Differentiating criteria.

These soils differ from those of mapping unit BUb2 by being heavier textured and having no topsoil of loamy sand to sandy loam.

Inclusions.

This mapping unit has inclusions of soils of mapping units BUb2 and BUr. Locally there are inclusions of coarse textured soils. Moderately deep soils occur along the drainage lines.

Land use: Mainly pigeon peas, maize, beans, cassava and in a few places mangoes. The land is also used for grazing goats, sheep and cattle.

Additional remarks.

These soils are characterized by a moderately high biological activity. Due to this biological activity, the structural development of the topsoil is more strongly expressed than that of the subsoil. Huge, sometimes overgrown termite mounds are found in the area.
The grass cover was poor due to overgrazing. However, it was observed that where the grass was protected against overgrazing, the coverage was good.
At places in cultivated areas the soils are protected against erosion by bench terracing.
Locally, due to overwash, coarse sand is seen on the soil surface.

Mapping unit BUb1m.

This is a moderately deep phase of unit BUb1. The soils are similar but moderately deep over petroplinthite (murram)/rock.

Extent: 1750 ha.

Parent material: See BUb1.

Macro relief: Undulating to rolling; slopes from 5-16%.

Profile development: ABC.

Range of characteristics.

The topsoil texture varies from sandy clay loam to clay and colour from very dark greyish brown (10YR 3/2) to dark brown (7.5YR 3/2). The subsoil texture varies from sandy clay loam to clay and colour from yellowish red (5YR 4/6) to dark reddish brown (5YR 3/4- 4/4). The depth of the soil to petroplinthite (murram)/rock varies from 50 to 80 cm.

Differentiating criteria.

This mapping unit differs from unit BUb2p by having petroplinthite and heavier textured soils.

Inclusions.

Locally, there are inclusions of some deep soils.

Land use: Maize, pigeon peas, cotton. Grazing of goats and cattle.

Mapping unit BUb2.

These are well drained, deep, yellowish red to (dark) reddish brown, friable sandy clay to clay soils with topsoil of loamy sand to sandy loam.

Extent: 4200 ha.

Parent material: Undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: Gently undulating to undulating; slopes from 2 to 8%.

Profile development: ABC (see appendix B, profile No. 163/3-12*).

Range of characteristics.

These soils show a gradual textural increase with depth. The texture of the topsoil varies from loamy sand to sandy loam and colour from very dark greyish brown (10YR 3/2- 3/3) to dark brown (7.5YR 3/2). The subsoil texture varies from sandy clay loam to clay and colour from yellowish red (5YR 4/6), (dark) reddish brown (5YR 3/3- 3/4) to strong brown (7.5YR 4/4). The clay content increases with depth. The pH increases with depth from 5.2 in the topsoil to 5.7 in the subsoil.
Locally quartz gravel and iron and manganese concretions occur in the subsoil at varying depths.

Differentiating criteria.

These soils differ from those of mapping unit BUb1 by having a sandy topsoil and a gradual textural increase with depth. Also they are lighter textured.

Inclusions.

This unit has inclusions of coarse textured soils of unit BQ1. Locally moderately well drained soils with red mottles ($2.5YR^{4}/3$) at a depth of more than 60 cm are found. Fine quartz gravel and iron and manganese concretions occur locally at depths varying from 60 cm to over 100 cm. In places soils of unit BUb1, with a sandy clay loam to clay topsoil occur.

Land use: Maize, pigeon peas, beans. Grazing of goats, sheep and cattle. Cotton grown on these soils was poor.

Additional remarks.

Termite mounds are common in the area. Biological activity is pronounced particularly in the topsoil. These soils have a moderately rapid permeability but a low chemical soil fertility.

Mapping unit BUb2p.

This is a moderately deep phase of unit BUb2. The soils are similar but moderately deep.

Extent: 700 ha.

Parent material: See unit BUb2.

Macro relief: Undulating; slopes from 5 to 7%.

Profile development: ABC.

Range of characteristics.

The soils show a gradual textural increase with depth. The topsoil texture varies from loamy sand to sandy loam and colour from dark brown ($7.5YR^{3}/2$) to reddish brown ($5YR^{4}/3-^{4}/4$). The subsoil texture varies from sandy clay loam to clay and colour from yellowish red ($5YR^{4}/6$) to (dark) reddish brown ($5YR^{3}/3-^{3}/4$). The depth of the soils to the bedrock varies from 50 to 80 cm.

Differentiating criteria.

This mapping unit differs from unit BUb1m by having a sandy topsoil and having no petroplinthite.

Inclusions.

There are inclusions of some shallow soils.

Land use: Maize, pigeon peas, beans.

Mapping unit BUP.

These are well drained, dominantly shallow, dark reddish brown to yellowish red, stony, in places fairly rocky, sandy clay loam to clay soils.

Extent: 4600 ha.

Parent material: Undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: Rolling to hilly; irregular topography; slopes from 16% to 30%.

Profile development: Mainly AC or AR.

Fig. 13. Sheet and gully erosion on the bare overgrazed soils of unit BUP.

Range of characteristics.

The texture of the topsoil varies from sandy loam to sandy clay and colour from dark brown to brown (7.5YR 3/2-4/4). The subsoil texture varies from sandy clay loam to clay and colour from dark reddish brown to yellowish red (5YR 3/4-4/6). The depth is dominantly between 25 cm and 50 cm. At places soils are shallower than 25 cm and at other places they are deeper than 50 cm. Surface stoniness varies from place to place. On some sheet eroded upper slopes, the surface is very stony.

Differentiating criteria.

These soils differ from soils in all the other mapping units by being dominantly shallow.

Inclusions.

Rock outcrops and locally deep soils on the lower slopes.

Land use: Shifting cultivation. Maize, pigeon peas, beans, are the main crops. Grazing of goats, sheep and cattle.

Additional remarks.

Erosion hazard is very high, particularly on the cultivated steep slopes. Overgrazing and bush clearing also renders the soils susceptible to high erosion hazard (see fig. 13). The shallowness of the soils, presence of surface stones and rock outcrops provide severe limitations to the possible use of mechanical equipment.
The irregular topography in the area is perhaps due to local differences in resistance to weathering of the geological formations.

Mapping unit BUd.

These are imperfectly drained, deep, very dark grey to black, very firm, cracking, moderately calcareous clay soils.

Extent: 150 ha.

Parent material: Undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: Nearly level to very gently undulating; slopes less than 2%.

Profile development: ACca (see appendix B profile No. 163/3-9*).

Range of characteristics.

The texture of the topsoil varies from sandy clay to clay. The calcium carbonate content increases with depth, with very slight matrix reaction on the topsoil to a moderately strong matrix reaction in the subsoil (see fig. 14).
The micro relief is irregular due to differences in intensity of the gilgai relief. The width of the surface cracks varies from 5 to 10 cm.

Differentiating criteria.

These soils differ from soils in all the other mapping units by having slickensides, a very dark colour, gilgai micro relief and being calcareous.

Inclusions.

In the transition zones, there are inclusions of soils of unit BUb1.

Land use: At present only a small part of the soils are under maize cultivation. The rest of the soils are under a natural grass cover which is used mainly for grazing.

Additional remarks.

The vegetation cover on these soils is characterized by Acacia drepanolobium which does not occur in the other mapping units. The subsoil of these soils have sodic characteristics.

Mapping unit BFr1.

These are well drained, deep, dark red friable to very friable, clay soils.

Extent: 1500 ha.

Parent material: Basement System rocks rich in ferromagnesian minerals.

Macro relief: Undulating; slopes from 5 to 8%.

Profile development: ABC (see appendix B, profile No. 163/1-18*).

Range of characteristics.

The topsoil texture varies from sandy clay to clay and colour from reddish brown ($5YR^{4}/3$) to dark reddish brown ($5YR^{3}/3$-$^{3}/4$, $2.5YR^{3}/4$). The subsoil texture is mainly clay but the colour varies from dark reddish brown ($2.5YR^{3}/4$) to dark red ($2.5YR^{3}/6$, $10R^{3}/6$). The pH varies from 5.2 in the topsoil to 4.5 in the subsoil.

Differentiating criteria.

The soils differ from those of unit BFr2a by having no argillic horizon. They differ from soils of unit BUr by having parent material rich in ferromagnesian minerals.

Inclusions.

This mapping unit has inclusions of soils of unit BUr and BUb1.

Land use: Maize, pigeon peas and beans are the main crops. Goats, sheep and cattle are kept.

Additional remarks.

These soils are very porous, are deeply rooted and are characterized by high biological activity. Few dark ferromagnesian minerals and flakes of mica occur in the profile. The bare surface seems to have a strong sealing and a moderately rapid surface runoff. Consequently susceptibility to erosion is high.
It is worthwhile to note that in this mapping unit, there were very few or virtually no termite mounds.

Mapping unit BFr1(P).

This is an association of well drained, shallow and stony to deep, dark reddish brown to dark red, friable to very friable, clay soils.

Extent: 1850 ha.

Parent material: Basement System rocks rich in ferromagnesian minerals.

Macro relief: Undulating to rolling; irregular, slopes from 5 to 16%.

Fig. 14. Profile pit 163/3-9* belonging to unit BUd showing calcium carbonate concretions and deep cracks.

Profile development: AR, AC and ABC.

Range of characteristics.

The topsoil texture varies from sandy clay loam to clay and colour is mainly dark reddish brown ($5YR^3/3$-$2.5YR^3/4$). The texture of the subsoil varies from sandy clay to clay. The depth to the bedrock varies from 30 cm to over 120 cm. Surface stoniness varies from spot to spot.

Differentiating criteria.

This mapping unit differs from unit BFr1 by being an association of shallow to deep soils.

Inclusions.

Locally there are inclusions of very shallow, stony soils.

Land use: Maize, pigeon peas and beans. Grazing of cattle, goats and sheep.

Additional remarks.

In some places, owing to cultivation without proper management, the soils have been eroded leaving behind stones on the surface. However, bench terracing and contour ploughing is practised in places as a measure against erosion.

Mapping unit BFr2a.

These are well drained, moderately deep to deep, dark red, friable to firm (compact), clay soils.

Extent: 3250 ha.

Parent material: Basement System rocks rich in ferromagnesian minerals.

Macro relief: Gently undulating to rolling; slopes from 2 to 16%.

Profile development: A B2t C (see appendix B, profile No. 164/4-16*).

Range of characteristics.

The topsoil texture varies from sandy clay to clay and colour from dark reddish brown ($5YR^3/3$-$^3/4$) to reddish brown ($5YR^4/4$). The subsoil texture is mainly clay and the colour is dominantly dark red ($2.5YR^3/6$-$10R^3/6$). The pH varies from 6.3 in the topsoil to 7.0 in the subsoil. The depth varies from 60 cm to over 120 cm.

Differentiating criteria.

The soils of this mapping unit differ from those of units BFr1 and BUr by having a B2t horizon, more weatherable primary minerals and more sticky clay.

Inclusions.

Rock outcrops, and soils of mapping unit BUb mainly on the transition zones.

Land use: Maize, pigeon peas, beans and sorghum are the main crops. Cattle, goats and sheep are also kept.

Additional remarks.

Where the soils are not cultivated, they have a strong sealing (see Figure 15). Locally the A horizon has been eroded away leaving the B horizon exposed on the surface. These soils have abundant dark ferromagnesian minerals and micas.

Fig. 15. Strong surface sealing of soils of unit BFr2a.

Mapping unit BFr2aP.

This is a shallow phase of unit BFr2a. The soils are similar but shallow and stony.

Extent: 1150 ha.

Parent material: See unit BFr2a.

Macro relief: Undulating to rolling; slopes from 5 to 16%.

Profile development: AR or $AB_{2t}C$.

Range of characteristics.

The colour of the soil varies from dark reddish brown ($5YR^3/4$-$2.5YR^3/4$) to dark red ($2.5YR^3/6$). The depth of the soil varies from 30 to 40 cm.

Differentiating criteria.

Soils of this mapping unit differ from soils of unit BUP by having different parent material, colour and texture.

Inclusions: Rock outcrops.

Land use: Grazing, locally cultivated under maize and pigeon peas.

Mapping unit BQ1p - BUb2p.

This is a complex of soils belonging to unit BQ1p and BUb2p. It consists of well drained, moderately deep, dark brown to yellowish red, loose loamy sandy soils (unit BQ1p) and well drained, moderately deep yellowish red to dark reddish brown, friable clay soils (unit BUb2p).

Extent: 2000 ha.

Parent material: Quartz rich Basement System rocks; predominantly granitoid gneisses (unit BQ1p) and undifferentiated Basement System rocks; predominantly banded gneisses (unit BUb2p).

Macro relief: Undulating; slopes from 5 - 8%.

Profile development: Mainly ABC but AC profiles also exist.

Range of characteristics.

BQ1p. The topsoil texture is mainly loamy sand and the colour varies from very dark greyish brown ($10YR^3/2$) to dark brown ($7.5YR^3/2$). The subsoil texture ranges from loamy sand to sandy loam and colour from dark brown ($7.5YR^3/2$-$^4/4$) to yellowish red ($5YR^4/6$).
BUb2p. The topsoil texture varies from sandy loam to sandy clay loam, and colour from very dark greyish brown ($10YR^3/2$) to dark brown ($7.5YR^3/2$). The subsoil texture varies from sandy clay loam to clay and colour from yellowish red ($5YR^4/6$) to strong brown ($7.5YR^4/4$).
For both units, the depth varies from 50 to 80 cm.

Differentiating criteria.

This complex differs from the undifferentiated Basement complex (unit CBU) by being a complex of only two mapping units, moderately deep and not fairly rocky.

Inclusions.

This complex has inclusions of locally deep soils belonging to units BQ1 and BUb2. Locally, there are soils which are moderately well drained. Along the drainage lines, the soils are shallow with some rock outcrops.

Land use: Maize, pigeon peas, beans. Grazing of goats, sheep and cattle.

Additional remarks.

Few, huge, old, overgrown termite mounds occur in the area.

Mapping unit CBU.

Undifferentiated Basement complex: This is a heterogeneous complex of several kinds of soils. It consists of well drained soils of varying depths: ranging from shallow, stony and fairly rocky to deep and non rocky, friable, sandy clay loam to clay soils belonging mainly to units BUr, BUb2 and BUb1.

Extent: 11300 ha.

Parent material: Mainly Undifferentiated Basement System rocks.

Macro relief: Undulating to rolling; slopes from 5 to 16%.

Profile development: ABC, AC and AR.

Range of characteristics.

BUr: The texture of the topsoil varies from sandy clay loam to clay and the colour varies from dark brown (7.5YR 3/2) to dark reddish brown (5YR 3/2-3/4). The subsoil texture varies from sandy clay to clay and colour from dark reddish brown (2.5YR 4/4) to dark red (2.5YR 3/6).

BUb1: The topsoil texture varies from sandy clay loam to clay and colour from very dark greyish brown (10YR 3/2), dark yellowish brown (10YR 3/4) to dark reddish brown (5YR 3/2-3/4). The subsoil texture varies from sandy clay loam to clay and colour from yellowish red (5YR 4/6) to dark reddish brown (5YR 3/4).

BUb2: The topsoil texture varies from loamy sand to sandy loam and colour from very dark greyish brown (10YR 3/2-3/3) to dark brown (7.5YR 3/2). The subsoil texture varies from sandy clay loam to clay and colour from yellowish red (5YR 4/6) to strong brown (7.5YR 4/4).

The depth of the soil within this complex varies from shallow (< 25 cm) to deep (> 80 cm). The surface stoniness varies from non stony to stony. In places it is fairly rocky to rocky.

Differentiating criteria.

This complex differs from unit BQ1p-BUb2p by being a complex of many mapping units with varying depths, stoniness and rockiness.

Inclusions.

In this complex there are inclusions of soils of unit BQ1. The depth of these soils too ranges from shallow and stony to deep and non stony. Along the major drainage lines (Thwake, Kaiti), there are pockets of alluvial soils of varying texture, colour and drainage.

Land use: Maize, pigeon peas, beans and sorghum. Grazing of goats and cattle.

Mapping unit CV1.

Valley complex: This is a heterogeneous complex of moderately well drained, moderately deep to deep, friable to firm clay soils of varying colours, with pockets of soils on alluvial/colluvial deposits.

Extent: 2100 ha.

Parent material: Various rocks of the Basement System complex and alluvial/colluvial deposits.

Macro relief: Gently undulating to undulating; slopes from 2 to 8%.

Profile development: AC or ABC.

Range of characteristics.

The topsoil texture varies mainly from sandy clay to clay and colour from very dark grey ($10YR^{3}/1-^{2.5}/1$) to dark brown ($7.5YR^{3}/2$). The subsoil texture is mainly clay but colour varies from black ($N^{2.5-4}/0$) to very dark grey ($10YR^{3}/1$). The depth of the soil varies from moderately deep to deep.

Differentiating criteria.

This complex differs from all the other units by having moderately well drained soils and occurring along the valleys.

Inclusions.

Along the transition zones are inclusions of soils of units BUr, BUb2, BUb1 and BFr1. Where the valleys have been eroded, there are shallow soils and rock outcrops. In places there are pockets of alluvial soils.

Land use: Where pockets of soils developed on alluvial/colluvial deposits occur, the soils are cultivated under maize, beans and pigeon peas, otherwise the rest of the soils are under natural vegetation.

Additional remarks.

Along the valleys there are places which have been severely eroded. In places the soils are imperfectly drained and have vertic properties.

5.3.5. Soils of the river terraces.

These soils occur mainly on river terraces in the north western part of the area.

Mapping unit AR1.

These are deep, stratified soils of varying texture, colour and drainage.

Extent: 100 ha.

Parent material: Subrecent alluvial deposits.

Macro relief: Flat to very gently undulating; slopes < 2%.

Profile development: AC.

Range of characteristics.

The texture of the soils varies from loamy sand to silty clay and colour from dark grey ($10YR^{3}/1$) to dark brown ($7.5YR^{3}/2-^{4}/4$). The drainage varies from well drained to imperfectly drained.

Differentiating criteria.

This mapping unit differs from all other mapping units by having soils developed mainly on alluvial deposits.

Inclusions: In the transition zones these soils are overlying soils of unit BFr1.

Land use: Maize, pigeon peas.

Additional remarks.

These soils are rich in micas and probably have a high chemical fertility.

5.4. Soil classification.

Soil classification units are different from mapping units. The mapping units are units of land that can be separated geographically/spatially in the field, can be shown on maps, and can be used as units for land evaluation purposes. In this reconnaissance soil survey, such units rarely comprise of one soil only. Either several soils are concerned in about equal percentages of terrain covered by each mapping unit ("soil associations" or "soil complexes") or one main soil with minor percentages - up to 25% - of one or more other soils ("inclusions" in the mapping units). Soil classification units are abstractions devised for purposes of correlation of soil information between different areas and extrapolation of agronomic research.

Many different kinds of soil classification systems exist and as a result the soil classification units are defined in many different ways. However, in this report two systems of classification are used, namely the new U.S.A. classification referred to as Soil Taxonomy (U.S.D.A., 1970) and the classification as used in the F.A.O./UNESCO Soil Map of the World (Dudal, 1970 and F.A.O., 1973). In both the Soil Taxonomy and F.A.O. System the classification is based on measurable and observable characteristics that are felt to reflect known genetic processes and that are important also for agronomic uses of the soil.

In this report, the classification of the soils up to subgroup level, according to the two systems mentioned above is presented in Table 4. The soil classification for all the representative profiles (see appendix B) is presented at the end of each profile description. However, it is worthwhile to note that owing to the presence of very little analytical data and lack of micromorphological data (thin sections) several difficulties in classification of these soils were experienced. Consequently, for several soils more than one classification name has been suggested.

Some of the difficulties experienced are:

(a) In the field, some of the soils did not show evidence of clay skins, however, the analytical data show that the clay differences within the horizons are sufficient for an argillic horizon. Therefore since there are no thin section data to confirm absence or presence of clay skins, they have been considered tetantively to have an argillic horizon. For example, profile nos. 163/3-13* (unit BUb1), 163/3-12* (unit BUb2) and 163/3-15* (unit BQ1).

(b) Though in the field, some of the profiles were observed to be deeply weathered with no or very few weatherable primary minerals, the C.E.C. of these soils is very high (greater than 16 me/100 g clay at pH = 7.0).
Hence they do not qualify as having an oxic B horizon. On the other hand there is no sufficient analytical data such as primary mineral analysis, clay mineralogy, "flocculation" index, natural clay content, SiO_2/Al_2O_3 ratio etc. to ascertain whether the soils have a cambic or oxic B horizons.

In view of these difficulties, it has been decided to omit the soil classification names in the legend of the soil map and instead present the data in table 4 giving the various alternatives. Further it can be stressed that there is a need for a more detailed study of these soils with particular emphasis on the analytical data. From this, there may arise a need to redefine more precisely the basis for the grouping of the tropical soils in the various classification systems.

Table 4. Soil classification - Reconnaissance Soil Survey.

Mapping Unit	Profile No.	Soil classification Units	
		F.A.O. (1970,1973)	U.S.D.A. (1970)
XB		Lithic Regosols + Lithosols	Lithic Ustorthents
CFS			
BQ1	163/3-15*	Luvic Phaeozem (Happlic Phaeozem) Cambic Arenosols	Udic Argiudolls (Udorthentic Happlustolls) Typic Ustorthents
BQ1P		Lithic Regosols	Lithic Ustorthents
BUr	163/4-14*	Eutric Nitosols	Rhodic Paleustalfs
BUb1	163/3-13*	Dystric Nitosols (Ferralic Cambisols)	Oxic Paleustalfs (Ustoxic Dystropepts)
BUb1m		Plinthic Luvisols (Ferralic Cambisols) (Plinthic phase)	Oxic Haplustalfs Ustoxic Dystropepts
BUb2	163/3-12*	Ferric Luvisols (Xanthic Ferralsols)	Oxic Haplustalfs (Tropeptic Haplustox)
BUb2p		Ferric Luvisols (Lithic phase)	Lithic Haplustalfs Typic Haplustalfs
BUP		Regosols Lithosols	Lithic Ustorthents
BUd	163/3-9*	Pellic Vertisols	Typic Pellusterts
BFr1	163/1-18*	Rhodic Ferralsols (Dystric Nitosols)	Tropeptic Haplustox (Rhodic Paleustalfs)
BFr1(P)		Rhodic Ferralsols (Dystric Nitosols-partly Lithic phase)	Tropeptic Haplustox (Lithic) Paleustalfs
BFr2a	163/4-16*	Chromic Luvisols	Udic Rhodustalfs
BFr2aP		Chromic Luvisols (Lithic phase)	Lithic Rhodustalfs
BQ1p-BUb2p		Dystric Regosols (Cambic Arenosols)	Typic Ustorthents
		Ferric Luvisols (Lithic phase)	Lithic Haplustalfs
CBU		Eutric Nitosols	Rhodic Paleustalfs
		Ferralic Cambisols	Ustoxic Dystropepts
		Ferric Luvisols	Oxic Haplustalfs
		Lithosols	Lithic Ustorthents
CV1		Eutric Fluvisols	Vertic Ustifluvents
		Dystric Cambisols	Fluventic Dystropepts
AR1		Eutric Fluvisols	Typic Ustifluvents

6. INTERPRETATION OF SURVEY DATA.

6.1. Methods of land evaluation.

The method of land suitability classification for this study area follows similar lines as the one used for the Kindaruma area by the Kenya Soil Survey (1974). Basic in this approach is that land evaluation is meaningful only in relation to clearly defined land uses and therefore relevant land use possibilities (land utilization types, land use alternatives) should be identified at an early stage in the land evaluation procedure. The land utilization types used in this report are the ones identified by Luning (K.S.S., 1973) for the medium potential areas of Eastern Province, Kenya. Following Ambrose (1972), the medium potential areas are defined as "those areas where the production of annual field crops is limited severely by lack of available moisture but where the use of out of ordinary conservation methods and specially adapted crop varieties would make crop production sufficiently reliable for an increased population to be carried".
Each land utilization type is defined by using some specific factors that need to be accounted for as having a marked influence on the performance of the land and which therefore are an integral part of a relevant definition of a land utilization type. These factors are: produce, capital intensity, labour intensity, farm power, level of technical knowledge, farm size, land tenure, farm incomes and price structure (see Table 5).
The land utilization types used in this study area are the following:
(a) Small holders rainfed arable/mixed farming; traditional technology (see 6.3.);
(b) Extensive range management (see 6.4.).
Two kinds of interpretative classification have been used:
Current suitability classification: an appraisal of the suitability for a specific use in the present condition or with slight modifications.
Potential suitability: an appraisal of the suitability for a specific use when it is known or assumed that major improvements have been effected where necessary.
Two of the orders of land suitability as defined by F.A.O. (1972 and 1973) have been used.
Order 1: Suitable land.
Land on which sustained use for the defined purpose in the defined manner is expected to yield benefits that will justify required current inputs without unacceptable risk to land resources on the site or adjacent areas.
Order 3: Unsuitable land.
Land having characteristics which appear to preclude its sustained use for the defined purpose in the defined manner or which would create production, upkeep and/or conservation problems requiring a level of recurrent inputs unacceptable at the moment.

Note that order 2, which is defined as conditionally suitable land, is not applied in this land evaluation for the land utilization types under consideration in this report.

In order 1 three classes have been distinguished:
class 1.1 Highly suitable.
" 1.2 Moderately suitable.
" 1.3 Marginally suitable.
In the land suitability classification for Extensive range Management, class 1.3 has been subdivided into two subclasses:
subclass 1.3.1 Marginally suitable.
" 1.3.2 Very marginally suitable.

Table 5. Quantifiable factors for each Land Utilization type (adapted from Luning, 1973).

Land Utilization Type	Produce	Capital Intensity shs./ha	Labour Intensity man months/ha	Farm power	Level of Technical Knowledge	Farm size ha/household	Land tenure	Incomes: value added/ha (approximations)	Price structure
Smallholder rainfed, arable farming, traditional technology	Annuals, drought resistant crops, some livestock	Investment: own labour recurrent costs: shs.20-25/ha occasionally oxen	ca. 5	man power, occasionally oxen	low, but constraint lies in research-tested messages (dry farming)	gross:10-20 actually cultivated 1-4 ha	individual plots No major constraint	300-600 shs./ha	favours maize, pigeon peas, works against sorghum
Extensive Range Management	beef	40-60 shs./ha	less than 0.3	-	low, lack of research tested data on feeding	at least ranch of 1600 ha for economics of scale	group ranching: land adjudication causes difficulties	20-40 shs.	beef is under valued

Note. Due to lack of sufficient data on farm incomes, capital intensity and the present trend of inflation, the figures quoted are tentative.

Class 1.1: Highly suitable.
Land having no significant limitations to sustained application of the defined use, or only minor limitations that will not significantly reduce production levels and/or benefits and will not raise recurrent and minor capital inputs for production and/or conservation above a readily acceptable level.

Class 1.2: Moderately suitable.
Land having limitations which in aggregate are moderately severe for sustained application of the defined use that will reduce production levels or benefits and/or increase required recurrent and minor capital inputs for production and/or conservation to the extent that the overall advantage gained from the use, although still attractive, will be appreciably inferior to that expected on class 1.1. land.

Class 1.3: Marginally suitable.
Land having limitations which in aggregate are severe for sustained application of the defined use and will so reduce production levels or benefits and/or so increase required inputs on production and/or conservation, that this expenditure will only be marginally justified.
The major difference between subclasses 1.3.1 and 1.3.2 is that limitations are higher in the latter than in the former.

For the current and potential suitability classification, each tract of land has been evaluated separately for each relevant land utilization type. It may be noted however, that an interpretative class (1.1, 1.3 etc.) indicating a certain degree of suitability may not have the same economic significance when applied to different land use alternatives.
For the "potential suitability" classification the following levels of input have been taken into account.

Input level	Technical Difficulty	Cost
A = low	Low, may require some technical advisory services to the land owner.	Low, can in general be borne by the land owner.
B = moderate	Moderate, requires important technical advisory services to the land owner.	Moderate, can be borne by the land owner with credit facilities.

Input levels C and D which involves high and very high costs respectively have not been taken into account for the land utilization types under consideration in this report.

6.2. Diagnostic criteria.

For the evaluation of the soil and land resources in the surveyed area, the following land qualities were chosen as major diagnostic criteria in assessing the suitability of the land/soil.
(a) Climate - especially amount, distribution and reliability of rainfall.
(b) Availability of soil moisture storage.
(c) Chemical soil fertility.

(d) Possibilities for the use of agricultural implements.
(e) Resistance to erosion.
(f) Presence/hazard of waterlogging.
(g) Present status of overgrazing.

For land evaluation purposes it was needed as a first step to come to a rating of the land qualities. The ratings of the land qualities was done according to "Proposals for rating of land qualities" (K.S.S., 1974). In this rating system the land qualities are classified in terms of grade of availability or of grade of absence of risk. Each major quality is subdivided into five grades.

1. Very high grade of availability/absence of risk.
2. High grade of availability/absence of risk.
3. Medium grade of availability/absence of risk.
4. Low grade of availability/absence of risk.
5. Very low grade of availability/absence of risk.

Details of the characteristics used in the rating of the land qualities are as follows:

(a) For climate - use of ecological zones established in Kenya (see 3.3).
(b) For availability of soil moisture storage* - rating based on soil depth, total readily available moisture in (top)soil and profile hindrance to root development.
(c) For chemical soil fertility* - rating based on C.E.C. in me%, available nutrients (base saturation, exchangeable Al, available P and K, organic matter content), total nutrient content i.e. P, K, Ca, Mg of topsoil.
(d) For possibilities for the use of agricultural implements - rating based on: slope %, slope length, stoniness, rockiness, heavy texture and compactness of the soil (workability).
(e) For resistance to erosion - rating based on slope class, susceptibility to sealing and slope length.
(f) For presence/hazard of waterlogging - rating based on soil drainage classes.
(g) For present status of overgrazing - rating based on visual observations in the field.

A next step is the establishment of specifications for the diagnostic criteria (= land qualities) that will define the interpretative suitability class levels for each land utilization type separately (see table 6a and 6b). After this the qualitative current suitability evaluation of each "mapping unit" for each land utilization type separately is carried out by comparison of the land qualities of that particular "mapping unit" with the specifications prepared for each land utilization type (see table 7).
Before arriving at the potential suitability evaluation following the same lines an identification and appraisal has to be made of desirable major improvements (see 6.4).

The land evaluation data is presented in a tabular form (see table 7). The vertical most left column shows each physiographic tract of the soil map following the sequence of the soil map legend, and taking into account the slope classes. Next to this column are the ratings of the land qualities that determine the interpretative classes. On the right hand side of the table are the land suitability classes for the two specified land utilization types. Each tract of land has been evaluated separately for each relevant land utilization type.

* Because of lack of enough data, some of the ratings have been made in comparison with similar soils in Kindaruma.

Specifications of the diagnostic criteria that define interpretative class levels for the recognized land utilization types.

Table 6a. Land utilization type: Small holders rainfed arable/mixed farming; traditional technology.

		Land qualities					
		Climate (Ecological zones)	Availability of soil moisture storage	Availability of nutrients	Possibilities for the use of agricultural implements	Resistance to erosion	Presence/ hazard of waterlogging
1.1	Highly suitable	II	2	1-2	3	2	2
1.2	Moderately suitable	III	3	2	3	3	2-3
1.3	Marginally suitable	IV	3	2-3	3	3	3
3	Unsuitable	V	4	3	4	4	4

Table 6b. Land Utilization Type - Extensive Range Management

		Land qualities					
		Climate (Ecological zones)	Availability of soil moisture storage	Availability of nutrients	Resistance to erosion	Presence/ hazard of water logging	Present status of overgrazing
1.1	Highly suitable	IV	2	2-3	1	2	2
1.2	Moderately suitable	IV	4	4	2	3	3
1.3.1	Marginally suitable	V	5	5	3	3	4
1.3.2	Very Marginally suitable	IV-V	5	5	3-4	3	4-5

For the small holders rainfed arable/mixed farming (traditional technology), the table gives Current Suitability Classes. For the Extensive range management both current and potential suitability classes are given. This is done by dividing each "cell" into three parts which indicate from left to right the current suitability, the input requirement level and the potential suitability as is shown below.

Current suitability class.	1.3.2	B	1.3.1	Potential suitability class.
		Specification of input level requirement.		

The results of the land evaluation are shown in Land suitability maps in appendices E, F1 and F2.
The reader is advised to colour these maps according to the land suitability classes shown in table 7 for most easy use.

6.3. Land suitability for small holders rainfed arable/mixed farming, traditional technology.

This is the land utilization type mostly practiced in the area at the moment, assuming some ox-farming to be part of the traditional system. Mainly annuals are grown; maize (Katumani Variety), beans, pigeon peas, sorghum etc. Availability of modern inputs (e.g. tractors, pesticides etc.) for farming does not play a role here, since other overriding factors restrict the application of these inputs. Present and future investments are confined to bush clearing prior to cultivation. With regard to recurrent inputs seeds are the only item. Labour is mainly all by hand.
The major limiting land qualities are lack and unreliability of rainfall and chemical soil fertility. To tackle the adverse nature conditions for cropping, more emphasis should be put on perennials, rather than annuals; such as pigeon peas, cassava, mangoes and sweet potatoes. Further emphasis concerns drought resistant grain crops i.e. sorghum and bulrush millet. Because of low returns this farming system has to be combined with livestock keeping, particularly goats in the drier areas and cattle in the parts with higher rainfall.
The land suitability map for this land utilization type is given in appendix E. For the suitability rating see table 7. Only the current suitability rating is given, assuming that bush clearing is included in the definition of the land utilization type. The potential suitability classification is not relevant here as no major improvements are considered for this type.

6.4. Land suitability for Extensive Range Management.

According to Brown (1963) the situation in the area under consideration is that people are unable to subsist in a reliable way on arable farming and are forced to depend in greater or lesser degree upon the surplus production of their livestock. Extensive range management could be a possible alternative to the present situation.
This particular land utilization type can be described as an organization of livestock keeping with central management and substantial investments, whereby a group of farmers (or a co-operative) pool together their animals.

Land Evaluation Data

pping Units	Ratings of land qualities: Climate (Ecological Zones)	Soil Moisture	Chemical Soil Fertility	Use of Agricultural implements	Resistant to Erosion	Presence/Hazard of water Logging	Present status of Overgrazing	Land Suitability Classes: Small holders rainfed arable/ mixed farming traditional technology	Extensive range management	Extent in ha.
XB	IVa	4	4	5	4	1	2	3	1.3.2/B/1.3.2	2300
CFS/D	IVa	2-3	4	4	3	1	2-3	3	1.3.1/B/1.2	850
CFS/CD	IVa	2-3	4	3-4	3	1	2-3	3	1.3.1/B/1.2	500
CFS/BC	IVa	2-3	4	3	2	1-2	2-3	1.3	1.2/B/1.2	250
BQ1/E	IVb-V	4	5	3	3	1	3	3	1.3.2/B/1.3.1	500
BQ1/D	IVb	4	5	2	3	1	3	1.3	1.3.2/B/1.3.1	150
BQ1/C	IVb	4	5	1	2	1	3	1.3	1.3.1/B/1.3.1	1200
BQ1P/E	IVb-V	5	5	4	4	1	3	3	1.3.2/B/1.3.2	1700
BQ1P/D	IVb	5	5	3-4	3	1	3	3	1.3.2/B/1.3.2	250
BUr/C	IV	2	4	2	2-3	1	3	1.3	1.2/B/1.2	4300
BUb1/AB	IV	2-3	4	2	1-2	1	2-3	1.3	1.2/B/1.2	800
BUb1/B	IV	2-3	4	2	2-3	1	2-3	1.3	1.2/B/1.2	1650
BUb1/BC	IV	2-3	4	2	2-3	1	2-3	1.3	1.2/B/1.2	5350
BUb1/C	IV	2-3	4	2	2-3	1	3	1.3	1.2/B/1.2	5850
BUb1/D	IV	2-3	4	3	3-4	1	3	3	1.3.1/B/1.2	300
BUb1m/C	IV	3	4	2	2-3	1	3	1.3	1.2/B/1.2	1000
BUb1m/CD	IV	3	4	2-4	3-4	1	3	3	1.3.1/B/1.2	750
BUb2/B	IV	2-3	4	1	2	1	2-3	1.3	1.3.1/B/1.3.1	2150
BUb2/C	IV	2-3	4	1	2	1	2-3	1.3	1.3.1/B/1.3.1	2050
BUb2p/C	IV	3	4	1	2	1	3	1.3	1.3.1/B/1.3.1	700
BUP/DE	IVb-V	3-4	4	4-5	3-5	1	4	3	1.3.2/B/1.3.1-1.3.2	2200
BUP/D	IVb-V	3-4	4	4-5	3-4	1	4	3	1.3.2/B/1.3.1-1.3.2	2400
BUd/A	IV	2	3	3	1	3	2-3	1.3	1.2/B/1.1	150
BFr1/C	IV	2	3-4	2	2-3	1	4	1.3	1.3.1/B/1.2	1500
BFr1(p)/CD	IV	2-4	3-4	2-4	3-4	1	4	1.3-3	1.3.2/B/1.3.1	1850
BFr2a/BC	IVb-V	2	3-4	2-3	3	1	3	1.3	1.3.1/B/1.3.1	750
BFr2a/C	IV -V	2	3-4	2-3	3	1	3	1.3	1.3.1/B/1.3.1	600
BFr2a/CD	IV -V	2	3-4	2-4	4	1	3	3	1.3.2/B/1.3.1	300
BFr2a/D	IV -V	2	3-4	3-4	4	1	3	3	1.3.2/B/1.3.1	1300
BFr2aP/CD	IV -V	4	3-4	3-4	4	1	3	3	1.3.2/B/1.3.1-1.3.2	1150
BQ1P-BUb2P/C	IV	4-3	5-4	1-2	2	1	2-3	1.3	1.3.2-1.3.1/B/1.3.1-1.3.2	2000
BU/CD	IV -V	2-4	4	2-5	3-4	1	3	1.3-3	1.3.2.-1.3.1/B/1.3.1-1.3.2	11300
BV1/B	IV	2-3	3-4	2-3	2-3	2	2-3	1.3	1.2/B/1.2	500
BV1/BC	IV	2-3	3-4	2-3	2-3	2	2-3	1.3	1.2/B/1.2	1400
BV1/C	IV	2-3	3-4	2-3	2-3	2	2-3	3	1.2/B/1.2	100
BR1/A	IV	2	2	2	1	2-3	2	1.2	1.2/B/1.1	100

The difference between group and co-operative ranching is that the "group" are people of a clan/section who enjoy customary rights over certain areas. Members retain their basic inheritance rights, including the individual rights over their livestock, which they contributed to the scheme. A co-operative is given County Council/State land on which members have no inheritance rights (Luning, 1973).
Rangeland is never likely to be very productive either in terms of shillings or in employment per ha. It should therefore be appreciated that only those areas which offer little scope for arable farming, should be allocated to extensive range schemes. Hence this land utilization type will be found only in areas where climate (among other land qualities) is so adverse that arable farming is not to be recommended. Therefore this land utilization type has to be viewed as a "residual" one.
Pre-requisites for this land utilization type are
(a) Sufficient drinking water should be present and
(b) Livestock numbers should be reduced in order to obtain improved livestock returns, which are now not possible due to overstocking which creates serious overgrazing problems; therefore stock numbers should be brought in line with the carrying capacity of the land (about 6-10 ha/head of cattle or 5 head of sheep and goats).
Major investments cover: water facilities (dams, boreholes), dips, stock handling facilities, fencing, ranch buildings and equipment, the actual stock, and bush clearing.
Recurrent costs cover maintenance of watering places, artificial insemination for livestock improvement, supplementary livestock feeding etc.
The size of a ranch unit is important as economics of scale play a decisive role. Therefore it is of paramount importance that individually registered plots should be amalgamated in these areas where ranching is considered. Group ranches should be encouraged, people bringing in their individual plots. This would be particularly important in this area since everybody has his own small private farm.
Both current and potential suitability classification are presented (see table 7 and the land suitability maps of appendices F1 and F2). It should be noted that land qualities such as availability of drinking water and nutritional value of grazing land are very important in the suitability classification for rangeland. However, due to lack of enough data to quantify, they are not taken into account in this classification.
Input level requirement has been estimated to be in the order of B. The potential suitability classification takes into account improvements such as grazing control, reseeding to improve grass cover, and range exclosures to improve vegetation cover.

7. KNOWLEDGE GAPS AND FURTHER STUDIES REQUIRED.

Very little information or none at all exists on the soil moisture - plant relationship in the survey area like in most parts of Kenya. Therefore studies on available moisture in relation to crop requirements need to be carried out.
Though research work has been going on in the field of crop response and fertilizer application, there is very little research information on the natural fertility of these soils and their productivity. Consequently more research work is necessary in this field.
Climate being one of the advserse limiting factors for agricultural production in this area, it would be worthwhile to conduct research on the possibilities of dry farming techniques.

With regard to soil classification, very little analytical data exists on these soils. Therefore there is a need of a more detailed study of these soils with special emphasis on analytical data, to see where they belong in the various international soil classification systems.

8. DETAILED SOIL SURVEY OF KAMPI YA MAWE AGRICULTURAL EXPERIMENTAL SUBSTATION.

8.1. Introduction.

This chapter describes the soil conditions of Kampi ya Mawe Agricultural Experimental Substation which is situated at Makueni, Machakos District. The station is approximately 49 hectares (122 acres).
The soil survey work was done in September 1974. The field work took one week with a field party of two labourers, one technical assistant, two drivers and one soil surveyor (the author).
The detailed survey of Kampi ya Mawe Agricultural Experimental Substation was carried out as a sample area representative of the surrounding Makueni area which was later surveyed at reconnaissance scale (see appendix D). Most of the soils of the substation occur elsewhere in the surrounding areas. However, in the reconnaissance soil map, owing to the smaller mapping scale, the soils of the substation are placed in the soil mapping units BUb1 and BUb2. The soils of these units are the most extensive in the surrounding Makueni area.

8.2. Survey methods.

The soil mapping was at first done by a rigid grid system. Auger holes to a depth of 2.0 m were made approximately at distances of 100 m apart and sometimes at shorter distances, depending on the variation in the landscape features (see observations map appendix H). However, owing to the intricacy of the soil boundaries, other augerings were made using a method of free survey.
The soils were examined for depth, colour, texture, mottling, stoniness, consistence, concretions etc. Landscape features, land use and other characteristics were carefully recorded on standard soil profile description forms following the standards applied by the Kenya Soil Survey. From representative soils, sites were selected for profile pits to be dug. The pits were 150 - 200 cm deep. The pits were described in detail following Kenya Soil Survey standards which are based on the Soil Survey Manual (U.S.D.A., 1951) and the F.A.O. Guidelines for soil description. Each horizon was sampled for mechanical and chemical analysis in the laboratory.* All the observations were located on a base map at scale 1:1250 surveyed in April 1958. A total of 8 profile pits were fully described and sampled. An additional 150 augerings were made and described (see appendix H). After completing the "final field map" boundaries and symbols were transferred to a translucent 1:1250 topographical map, which was handed over to the draughtsman for reduction to 1:2500.

*. The analysis were done in the routine laboratory of the National Agricultural Laboratories, Kenya. Clay mineralogy was determined by Mr. Hinga (the Senior Soil Chemist, N.A.L.) with an X-ray diffractometer. For the quantitative estimation (%) he followed the method of Theisen and Bellis (1964) except that peak area ratios were considered instead of peak height ratios.

8.3. The soils.

8.3.1. Systematics and nomenclature.

At the highest level on the soil map (Appendix C) the soil mapping units are subdivided according to the kind of parent material on which the soils are developed e.g. soils developed on undifferentiated Basement System rocks; predominantly banded gneisses. At the lowest level the soil mapping units are subdivided on important profile characteristics such as drainage, depth, colour, consistency, texture etc.
Each mapping unit is identified on the map by a mapping symbol, for which a code system is used.
The symbols appearing in the code system are explained below:

I KIND OF PARENT MATERIAL

B = Basement System.
BQ = Basement system rocks - quartz rich.
BU = Basement system rocks - undifferentiated.

II IMPORTANT PROFILE CHARACTERISTICS

Colour :- r = red
b = brown
Consistence :- c = compactness
Depth over rock :- P = depth < 50 cm
Depth over petroplinthite (murram)/rock -
m = depth between 50 - 80 cm.

III C = complex

IV The numerical numbers 1 and 2 refer to different soil types, for example, to differentiate between the two Bur soil types, the codes BUr1 and BUr2 are used.

Different depth classes in the same soil unit are indicated by over-prints (dot screens) taking into account whether the underlying rock consists of hard rock or of petroplinthite.
The various depth classes used are:

Very shallow	0 - 25 cm.
Shallow	25 - 50 cm.
Moderately deep	50 - 80 cm.
Deep	80 - 120 cm.
Very deep	more than 120 cm.

The topography (slope class %) of each mapping unit is indicated in the mapping symbol below the fraction line.

A slope % 0-2%
B^{+} slope % 2 - 3.5%.
B^{++} slope % 3.5 - 5 } B

8.3.2. General properties of the soils.

The soils of the substation may broadly be divided into
(a) soils developed on undifferentiated Basement System rocks; predominantly banded gneisses and
(b) soils developed on quartz-rich Basement System rocks; predominantly granitoid gneisses.

The soils developed on undifferentiated Basement System rocks have a texture finer than sandy loam. They are mainly dark red to red, yellowish brown to dark reddish brown, dominantly deep and well drained. They have moderate infiltration rates and good permeability (see table 8).
The soils developed on quartz rich Basement System rocks are coarse textured with a texture of sandy loam or coarser. They are mainly dark reddish brown in colour. These soils are generally well drained with high infiltration rates and good permeability.
In general the structural development of these soils is weak. The A horizons have a weak to moderately strong sub-angular blocky structure. The B horizons are in many cases porous massive (weakly coherent) with or without a tendency to break into weak angular, subangular or prismatic blocks (see appendix B). The consistency in the moist state is mainly very friable to friable. The soils are porous and therefore favourable to root development.
From the analytical data (appendix B), the soils have low natural fertility. Almost all the soils have a strong or moderate nitrogen and phosphorus deficiency. The potassium status is medium to low. The C.E.C. and the organic matter content are in general low. Thus, fertilizer application is recommended to improve the fertility of these soils. Particularly addition of manure would help to increase the organic matter content. In turn an increase in organic matter would increase the structure stability, C.E.C. and moisture holding capacity of these soils.

Table 8 shows the infiltration rates of some of the soils. From these data

Table 8. Infiltration measurements.

Profile put No.	Soil mapping Unit	Time (in minutes) taken to infiltrate 10 cm of water			
		Topsoil		Subsurface soil	
		Dry run	Wet run	Dry run	Wet run
KM/1*	BUbc1	69	111	111	117
KM/2*	BUr1	42	80	29	58
KM/3* cultivated	BUbm	17	25	16	31
KM/3* uncultivated	BUbm	35	60	33	57
KM/7* cultivated	BUb	70	98	34	68
KM/7* uncultivated	BUb	18	24	16	31

it can be observed that the infiltration rates for soils of units BUb and BUr1 were less in the topsoils than the sub-surface layers in the cultivated sites. This is most probably due to compaction of the subsurface layer by ploughing.
Further it may be worthwhile to note that the soils that were ploughed and left fallow during the dry period had a moist subsoil. This shows that

moisture in these soils can be conserved by ploughing at the end of the rains and leaving the soil fallow during the dry season.

8.3.3. Description of individual mapping units.

8.3.3.1. Soils developed on undifferentiated Basement System rocks; predominantly banded gneisses.

Mapping unit BUr1 (Mumbuni series).

These are well drained, deep to very deep, dark red to red, friable clay soils.

Extent: 7.0 ha.

Parent material: Undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: gently undulating; slopes from 2 to 3.5%.

Profile development: ABC (see appendix B, profile No. KM/2*).

Range of characteristics.

The soils are well drained. The texture of the plough layer (about 0-30 cm) varies from sandy clay loam to clay and the colour varies from dusky red (2.5YR $\frac{3}{2}$ - $\frac{3}{4}$) to reddish brown (5YR $\frac{3}{4}$). The subsoil texture is mainly clay but the colour varies from dark red (2.5YR $\frac{3}{6}$) to red (10R $\frac{4}{6}$). The pH varies from 6.6 in the topsoil to 6.8 in the subsoil. The infiltration rates for the topsoil were less than for the subsoil probably due to compaction of the topsoil by ploughing.

Clay mineralogy.

The topsoil (0-15 cm) contains about 63% illite and 37% kaolin which appears to be a metahalloysite. The peaks of the clay minerals of the subsoil were of low intensity and ill defined. Consequently quantitative determination was not possible.

Differentiating criteria.

This mapping unit differs from unit BUr2 by having heavier textured soils and having no topsoil of loamy sand or sandy loam.

Land use.

The soil is used for agronomical trials. Sorghum, maize and cotton are the main crops. Ploughing is mainly by tractor and this seems to be leading to a development of a plough pan below the plough layer. Fertilizers are applied.

Additional remarks.

Biological activity is considered to play an important role in the morphology of these soils. The presence of flakes of mica in the deeply weathered profile is most probably due to homogenisation brought about by biological activity. Termite mounds are common in the area and these have been ploughed down and flattened. This gives a slightly different colour to the topsoil.

Mapping unit BUr2 (Muvau series).

These are well drained, deep to very deep, dark reddish brown to dark red, very friable, sandy clay to clay soils with topsoil of sandy loam to loamy sand.

Extent: 4.5 ha.

Parent material: undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: gently undulating; slopes from 2 to 5 %.

Profile development: ABC (see appendix B, profile No. KM/5*).

Range of characteristics.

The texture of the topsoil (about 0-20 cm) varies from loamy sand to sandy loam and colour from dark reddish brown ($5YR^3/2$ - $^3/3$) to dark brown ($7.5YR^3/2$). The subsoil texture varies from sandy clay loam to clay and colour from dark reddish brown ($2.5YR^3/4$ - $5YR^3/4$) to dark red ($2.5YR^3/6$). The depth to the bedrock and quartz gravel varies from 100 cm to over 200 cm. The pH varies from 5.9 in the topsoil to 5.7 in the subsoil.

Clay mineralogy.

The topsoil (0-15 cm) contains about 55% kaolin and 45% illite. The subsoil (27-84 cm) contains 68% kaolinite and 32% illite.

Differentiating criteria.

This mapping unit differs from unit BUr1 by having soils with a lighter texture and a sandy topsoil.

Land use.

The greater part of the soils are under natural grass cover and only a small portion of the soil is cultivated.

Additional remarks.

These soils are very porous and have a high biological activity. They have a very deep rooting depth. The sand fraction is mainly coarse sand. Old, overgrown, termite mounds occur in the area.

Mapping unit Bub (Malibani series).

These are well drained, deep to very deep, yellowish red to (dark) reddish brown, friable clay to fine sandy clay soils.

Extent: 11.6 ha.

Parent material: undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: very gently undulating to gently undulating; slopes from 2% to 5%.

Profile development: ABC (see appendix B, profile No. KM/7*).

Range of characteristics.

The texture of the topsoil (about 0-20 cm) varies from fine sandy clay loam to fine sandy clay and colour from very dark greyish brown ($10YR^3/2$) to dark brown ($7.5YR^3/2$). The subsoil texture varies from fine sandy clay to clay and colour from (dark) reddish brown ($5YR^3/4$ - $^4/4$) to yellowish red ($5YR^4/6$). The pH varies from 6.5 in the topsoil to 4.6 in the subsoil.

Clay mineralogy.

A poorly crystallized kaolinite is predominant in addition to traces of illite which is more discernible in the topsoil than in the subsoil.

Differentiating criteria.

This mapping unit differs from unit BUbc1 by having more porous and less compact soils.

Land use.

The soils are mainly used for agronomical trials. Sorghum, maize, cotton and cassava are the main crops. The soils in the Southwestern part of the substation are under a bush cover.

Additional remarks.

These soils show very little profile differentiation. The structural development is weak. In places where the soils have been ploughed and left fallow for sometime, the subsoil remains moist. This shows that moisture can be conserved by ploughing and leaving the land fallow during the dry period. Termite mounds have been ploughed down and flattened in the cultivated areas. This consequently gives patches of the topsoil with different colours.

Mapping unit BUbm (Malibani series, moderately deep phase).

This is a moderately deep phase of unit BUb. The soils are similar but moderately deep over petroplinthite (murram)/rock.

Extent: 8.7 ha.

Parent material: (see unit BUb).

Macro relief: very gently undulating to gently undulating; slopes from 2 to 5%.

Profile development: ABC (see appendix B, profile No. KM/3*).

Range of characteristics.

The topsoil texture varies from sandy clay loam to sandy clay and colour from very dark greyish brown ($10YR^3/2$) to dark brown ($10YR^3/3$ - $7.5YR^3/2$). The subsoil texture varies from sandy clay to clay and colour from (dark) reddish brown ($5YR^3/3$ - $^4/4$) to yellowish red ($5YR^4/6$ - $^4/8$). The pH varies from 6.3 in the topsoil to 6.4 in the subsoil. The depth of the soil to petroplinthite (murram)/rock varies from 50 to 80 cm.

Clay mineralogy.

The topsoil (0-10 cm) contains 43% kaolinite and 57% illite. The subsoil (20-55 cm) contains 51% kaolinite and 49% illite. The clay minerals are reasonably well crystallized in the topsoil but poorly so in the subsoil.

Differentiating criteria.

This mapping unit differs from unit BUbc2m by having no sandy topsoil and having less compact soils.

Land use.

Cotton in cultivated places and natural grass cover in the rest of the area.

Additional remarks.

In many places, a lot of quartz gravel is found above the petroplinthite. In a few places, stones occur on the surface.

Mapping unit BUbc1 (Ngosini series).

These are well drained, very deep, dark reddish brown to reddish brown, firm (compact) clay soils.

Extent: 3.3 ha.

Parent material: undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: flat to very gently undulating; slopes < 2%.

Profile development: ABC (see appendix B, profile No. KM/1*).

Range of characteristics.

The texture of the topsoil varies from fine sandy clay loam to fine sandy clay and colour from very dark grey ($10YR^3/1$) to very dark greyish brown ($10YR^3/2$). The subsoil texture varies from fine sandy clay to clay and colour from yellowish red ($5YR^4/6$) to dark reddish brown ($5YR^3/3$ - $^4/4$). The pH varies from 6.9 in the topsoil to 6.0 in the subsoil.

Clay mineralogy.

The topsoil (0-14 cm) contains 39% kaolinite, 51% illite and 10% smectite. The subsoil (80-105 cm) contains 66% kaolinite, 34% illite and a very slight trace of smectite. The intensity of the peaks is moderate and the smectite shows up as a "hump" suggesting interstratification.

Differentiating criteria.

This mapping unit differs from unit BUb by having more compact and less porous soils.

Land use.

These soils are under a natural grass cover intended to be a pasture for livestock keeping.

Additional remarks.

These soils are characterized by a high biological activity (mainly termites) in the topsoil. A few, old, inactive termite mounds occur in the area.

Mapping unit BUbc2m (Mwaani series).

These are well drained, moderately deep, dark reddish brown, friable to firm, sandy clay loam soils with topsoil of loamy sand.

Extent: 2.5 ha.

Parent material: undifferentiated Basement System rocks; predominantly banded gneisses.

Macro relief: gently undulating; slopes from 2 to 5%.

Profile development: ABC (see appendix B, profile No. KM/10*).

Range of characteristics.

The texture of the transition horizon between the A and B (AB, about 20 - 40 cm) varies from sandy loam to sandy clay loam. The colour of the topsoil varies from very dark greyish brown ($10YR^3/2$) to dark brown ($7.5YR^3/2$). The colour of the subsoil varies from dark reddish brown ($5YR^3/2$ - $^4/4$) to dark brown ($7.5YR^4/4$). The depth to petroplinthite (murram)/rock varies from 50 to 70 cm. The pH varies from 5.8 in the topsoil to 5.1 in the subsoil.

Differentiating criteria.

This mapping unit differs from unit BUbm by having soils with a sandy top and more compact. It differs from unit BQ1m by having heavier textured soils.

Land use.

Partly cotton and partly under grass cover after cultivation.

Additional remarks.

In places where the soils were cultivated and abandoned, erosion took place, leaving behind some quartz gravel on the surface.

Mapping unit BUbc2P (Mwaani series, shallow phase).

This is a shallow phase of mapping unit BUbc2m. The soils are similar but shallow over petroplinthite (murram)/rock.

Extent: 0.6 ha.

Parent material: see unit BUbc2m.

Macro relief: gently undulating; slopes from 2 to 3.5%.

Profile development: AR.

Range of characteristics.

The texture of the soil varies from loamy sand to sandy clay loam. The depth of the soil to petroplinthite (murram)/rock varies from 25 to 50 cm.

Differentiating criteria.

This mapping unit differs from unit BQ1P by having soils which are heavier textured.

Land use: under natural grass cover.

Additional remarks.

These soils are shallow and there is some quartz gravel on the surface. The grass cover is rather poor.

8.3.3.2. Soils developed on quartz rich Basement System rocks; predominantly granitoid gneisses.

Mapping unit BQ1 (Kampi ya Mawe series).

These are well drained, deep, dark yellowish brown, loose coarse loamy sand soils.

Extent: 1.8 ha.

Parent material: quartz rich Basement System rocks; predominantly granitoid gneisses.

Macro relief: gently undulating; slopes from 2 to 3.5%.

Profile development: ABC.

Range of characteristics.

The colour of the topsoil varies from very dark greyish brown ($10YR^{3}/2$) to dark brown ($7.5YR^{3}/2$) and that of the subsoil varies from dark yellowish brown ($10YR^{4}/4$ - $^{5}/4$) to dark brown ($7.5YR^{4}/4$). The texture varies from coarse loamy sand to coarse sandy loam.

Clay mineralogy: (see unit BQ1m).

Differentiating criteria.

This mapping unit differs from all the other mapping units by having coarse textured soils.

Land use.

Only a very small portion of these soils is under cultivation, most of the soil is under natural grass cover. In the cultivated portion; cotton trials were going on.

Additional remarks.

These soils have a low moisture holding capacity and are deeply weathered. The infiltration rates are high and the permeability is rapid.

Mapping unit BQ1m (Kampi ya Mawe series, moderately deep phase).

This is a moderately deep phase of unit BQ1. The soils are similar but moderately deep over petroplinthite (murram)/rock.

Extent: 4.5 ha.

Parent material: (see unit BQ1).

Macro relief: very gently undulating to gently undulating; slopes from < 2% to 5%.

Profile development: ABC (see appendix B, profile No. KM/6*).

Range of characteristics.

The topsoil colour varies from very dark greyish brown ($10YR^3/2$) to dark brown ($7.5YR^3/2$). The subsoil colour varies from dark yellowish brown ($10YR^4/4$) to dark brown. The depth of the soil varies from 50 to 80 cm. Locally where the slopes are concave, the soils are moderately well drained.

Clay mineralogy.

The topsoil (0-15 cm) contains 31% kaolin, 58% illite, and 11% smectite. The subsoil (25-50 cm) contains 29% kaolin, 60% illite and 11% smectite. Illite is predominant and is the best crystallized of the three. Smectite shows up as a "hump", its expansion is from 15.22 to 17.66 A^o which is typical of montmorillonite. Kaolin is poorly crystallized and the asymmetrical nature of the peak is suggestive of metahalloysite.

Differentiating criteria.

This mapping unit differs from unit BUbm by having coarse textured soils.

Land use.

Partly cultivated under cotton trials and partly under natural grass cover.

Mapping unit BQ1P (Kampi ya Mawe series, shallow phase).

This is a shallow phase of unit BQ1. The soils are similar but shallow over rock.

Extent: 0.3 ha.

Parent material: (see unit BQ1).

Macro relief: very gently undulating to gently undulating; slopes from < 2% to 3.5%.

Profile development: AR.

Range of characteristics.

The depth of the soil to the rock varies from 40 to 50 cm.

Differentiating criteria.

This mapping unit differs from unit BUbc2P by having coarse textured soils.

Land use: natural grass cover.

8.3.3.3. Complexes.

Mapping unit C1.

This is a heterogeneous complex consisting of mostly well drained, very shallow to shallow, (very) dark greyish brown, loose to friable, stony, dominantly loamy sandy soils with scattered rock outcrops.

Extent: 3.3 ha.

Parent material: Basement System rocks.

Macro relief: gently undulating; slopes from 2 to 5%.

Profile development: mainly AC or AR.

Range of characteristics.

The texture of the soils varies from loamy sand to sandy clay loam. The colour varies from very dark greyish brown ($10YR^{3}/2$) to dark greyish brown ($10YR^{4}/2$). The depth of the soil ranges from bare rock to 50 cm. However, along the gullies, there are pockets of moderately well drained soils developed on colluvial deposits.

Differentiating criteria.

This complex differs from the complex C1 by having pockets of soils developed on colluvial deposits and less pronounced rock outcrops.

Land use: under natural grass cover.

Mapping unit C2.

This complex consists mainly of rock outcrops and some very shallow rocky and stony, dark red, loose to friable, loamy sand to sandy loam soils.

Extent: 1.1 ha.

Parent material: Basement System rocks; banded gneisses and granitoid gneisses.

Macro relief: very gently undulating to gently undulating; slopes from < 2% to 3.5%.

Profile development: mainly AR.

Range of characteristics.

The soils range from bare rock to very shallow soils.

Differentiating criteria.

This complex differs from the complex C1 by having many rock outcrops.

Land use: mostly built up area.

8.4. Soil classification.

The soils of this survey have been classified up to subgroup level according to both the new U.S.D.A. (1970) Soil Taxonomy and the F.A.O./ UNESCO (1970, 1973). Classification for their Soil Map of the World Legend. However, owing to lack of sufficient analytical data, such as thin sections, flocculation index, natural clay, SiO_2/Al_2O_3 ratio etc., several difficulties in classification of these soils were experienced. As a result, for several soils more than one classification name has been suggested. The soil classification of the various mapping units is presented in Table 9.
In appendix B1, the soil classification of each representative profile is given after the profile description.

Table 9. Soil Classification - Detailed Soil Survey

Mapping Unit	Profile No.	Soil Classification Units	
		F.A.O.(1970,1973)	U.S.D.A. (1970)
BUr1	KM/2*	Chromic Luvisols	Udic Rhodustalfs
BUr2	KM/5*	Orthic Acrisols (Dystric Nitosols)	Ustoxic Paleustults
BUb	KM/7*	Orthic Acrisols	Ustoxic Haplustults
BUbm	KM/3*	Chromic Luvisols (Orthic Acrisols Petroplinthic phase)	Ultic Haplustalfs Ustoxic Haplustults
		Chromic Cambisols	Typic Ustropepts
BUbc1	KM/1*	Luvic Phaeozem	Udic Paleustoll
		Eutric Nitosol	Udic Paleustalfs
BUbc2m	KM/10*	Ferric Luvisols	Oxic Haplustalfs
BUbc2P		Ferric Luvisols (Lithic phase)	Lithic Haplustalfs
BQ1		Ferralic Arenosols (Cambic Arenosols)	Typic Ustorthents (Oxic Quartzipsamments)
BQ1m	KM/6*	Cambic Arenosols (Plinthic phase)	Typic Ustorthents
BQ1P		Cambic Arenosols (Lithic phase)	Lithic Ustorthents
C1		Mainly Regosols (Lithic phase)	Lithic Ustorthents
C2		Rock outcrops + Dystric Lithosols	Lithic Ustorthents

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Appendix A

The woody species found in the survey area (see 3.4) are listed in alphabetical order with a notation of abundance (a = abundant, c = common, f.c. = fairly common, r = rare).

Acacia brevispica	f.c.	
" drepanolobium	c	(only on Vertisols)
" hockii	c	
" mellifera	f.c.	
" nilotica	f.c.	
" polyacantha	c	(in valleys only)
" senegal	c	
" seyal	f.c.	
" tortilis	c to a	
Albizia amara	f.c.	
" anithelmintica	f.c.	
" harveyi	f.c.	
Belanites aegyptiaca	c	
Combretum apiculatum	a	
" collinum	f.c.	
" molle	f.c. to r	(west to east)
" zeyheri	f.c.	
Commiphora africana	c	
" campestris	f.c. to r	
Croton dichogamus	c	
Dombeya dawei	f.c. to r	
Entada leptostachya	f.c.	
Erythrina burtii	r	(very local)
" abyssinica	f.c.	(in valleys)
Harrisonia abyssinica	c	
Kigelia aethiopium	r	
Launea floccosa	f.c.	
" stuhmannii	r	
Rhus natalensis	f.c.	
Selero caryabirrea	r	
Terminalia brownii	f.c.	

Some of the grasses identified were:

Andropogon sp.
Aristida adoensis
" keniensis
Bothrioehloa insculpta.
Cenchrus ciliaris
Chloris gayana (cultivated at Kampi ya Mawe Experimental Farm)
Chloris roxburghiana
Digitaria macroblephara (or milanjiana)
Euteropogon macrostachyus
Eragrotis caespitosa
" superba
Eustachys paspaloides
Hyparrhenia sp
Panicum maximum
Pennisetum mexianum
Rhynchelytrum repens (very common as a weed on cultivated fields)
Sporobolus fimbriatus
Themeda triandra.

Appendix B1.

Description of Representative Profiles. Detailed Survey of Kampi ya Mawe.

Mapping unit BUbc1		Observation site KM/1*
Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Flat to very gently undulating
Relief, meso	:	Termite mounds, inactive, diameter 2-3 m., some flattened, > 30 m. apart
Vegetation/land use	:	Bush grassland/Grazing
Erosion	:	Nil
Rock outcrops	:	Nil
Overwash/overblow	:	Very slight, locally washed sand
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Very slow
General ground water level	:	Very deep
Slope gradient	:	1%
Salinity/alkalinity	:	Nil
Human influences	:	Bush clearing
Surface sealing	:	10 mm, moderate to strong
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep > 120 cm.
Perched ground water level	:	Nil

Description of profile

A_1	0 - 14 cm.	Very dark greyish brown (10YR^4/3 dry, 10YR^3/2 moist), sandy clay; weak, medium subangular blocky structure; hard when dry, friable to firm when moist, slightly sticky and slightly plastic when wet; many, very fine and fine pores, many, medium to coarse pores; many, fine roots, few, medium roots; a lot of termite activity; clear and smooth transition to:
A_3	14 - 33 cm.	Dark brown (7.5YR^4/4 dry, 7.5YR^3/2 moist), clay; weak, medium to coarse subangular blocky structure falling apart to weak, medium angular blocks; extremely hard when dry, firm when moist, slightly sticky and plastic when wet; common, very fine and fine pores, many, medium pores; few, fine roots; gradual and smooth transition to:
B_{21}	33 - 80 cm.	Reddish brown (5YR^5/6 dry, 5YR^4/4 moist), clay; porous massive breaking to some weak, medium subangular blocks; hard when dry, firm when moist, slightly sticky and plastic when wet; common medium pores; few, fine roots; gradual and smooth transition to:
$B2_{2t}$	80 - 105 cm.	Yellowish red (7.5YR^5/6 dry, 5YR^4/6 moist), clay; porous massive breaking to some weak, coarse prismatic blocks; hard when dry, firm when moist, slightly sticky and plastic when wet; few, weak/thin clay cutans; few, very fine and fine pores; few fine roots; diffuse and smooth transition to:

B_{31t} 105 - 150 cm. Yellowish red ($7.5YR^{5}/6$-$^{5}/8$ dry, $5YR^{4}/6$ moist), clay; porous massive breaking to some weak, coarse prismatic blocks; slightly hard when dry, friable when moist, slightly sticky and plastic when wet; few, weak/thin clay cutans; few, very fine and fine pores; few fine roots; diffuse and wavy transition to:

B_{32} 150 - 190 cm. Yellowish red ($7.5YR^{5}/6$-$^{5}/8$ dry, $5YR^{4}/6$ moist), clay; porous massive; slightly hard when dry, friable when moist, slightly sticky and plastic when wet; few, fine pores; few fine roots.

Soil Classification:

Diagnostic horizons:	0 - 33 cm	Mollic epipedon
	33 - 150 cm	Argillic horizon
F.A.O. (1970,1973):	Luvic Phaeozem (Eutric Nitosol)	
U.S.D.A. (1970) :	Udic Paleustoll. (Udic Paleustalf)	

Appendix B_1

Analytical Data

Profile No.: KM/1*

Laboratory number/74	7541	7542	7543	7544	7545	7546
Horizon	A_1	A_3	B_{21}	B_{22}	B_{31}	B_{32}
Depth in cm	0-14	14-33	33-80	80-105	105-150	150-190
Texture (hydrometer) class	SC	C	C	C	C	C
Sand %	52	32	32	26	20	26
Silt %	8	16	8	6	14	12
Clay %	40	52	60	68	66	62
pH-H_2O (1:1 susp.)	6.9	6.2	6.0	6.0	6.9	6.2
pH-KCl (1:1 susp.)	5.6	4.9	4.7	4.9	4.9	5.0
EC(1:1 susp.)in mmhos/cm	0.23	0.10	0.08	0.08	0.08	0.15
C %	1.38	1.27	0.68	0.53	0.79	0.38
N %	0.13	0.09				
Cation Exchange Capacity m.e. %	14.3	13.2	12.2	12.6	12.8	11.2
Exchangeable Ca me %	6.8	4.4	3.4	4.4	4.0	4.4
" Mg "	4.3	1.9	3.6	3.8	4.6	3.8
" k "	1.29	1.09	0.52	0.34	0.20	0.26
" Na "	0.20	0.20	0.25	0.35	0.50	0.45
Sum of Base	12.6	7.6	7.8	8.9	9.3	9.0
Base Saturation %	88	58	64	71	73	80
E.S.P.	<5	<5	<5	<5	<5	<5
Hp m.e. %	0					
Available Ca m.e. %	6.0	4.6				
" Mg "	4.4	4.2				
" K "	0.82	0.60				
" Na "	0.03	0.03				
" Mn "	0.78	0.64				
" P ppm	13	11				

Moderate N, P deficiencies.

Mapping unit BUr1		Observation site KM/2*
Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief macro	:	Very gently undulating
Relief meso	:	A few termite mounds, inactive, all have been ploughed and flattened
Vegetation/land use	:	-/.cultivation - cotton, maize, sorghum
Erosion	:	Nil
Rock outcrops	:	Nil
Overwash/overblow	:	Very slight; locally washed sand
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Very slow
General ground water level	:	Very deep
Slope gradient	:	2%
Salinity/alkalinity	:	Nil
Human influences	:	Bench terracing, mechanical ploughing
Surface sealing	:	8 mm, weak
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep, > 120 cm.
Perched ground water level	:	Nil

Description of profile

Ap	0 - 15 cm.	Dark reddish brown ($5YR^{3}/3$ dry, $5YR^{3}/3$-$^{3}/4$ moist) clay; weak, fine and medium subangular blocky structure breaking to some weak, fine angular blocks; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; many, fine roots; clear and smooth transition to:
B_1	15 - 25 cm.	Dark reddish brown ($2.5YR^{4}/6$ dry, $2.5YR^{3}/4$ moist) clay; weak, fine to medium subangular blocky structure breaking to some fine angular blocks; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; many, fine roots; gradual and smooth transition to:
B_{21t}	25 - 61 cm.	Dark red ($2.5YR^{4}/6$-$^{5}/8$ dry, $10R^{3}/6$ moist), clay; porous massive breaking to some weak, medium and coarse subangular blocks; slightly hard when dry, friable when moist, sticky and slightly plastic when wet; few, weak/thin clay cutans; many, very fine pores, common, fine pores; few, fine roots; diffuse and smooth transition to:
B_{22t}	61 - 90 cm.	Dark red ($2.5YR^{4}/8$ dry, $10R^{3}/6$ moist), clay; porous massive breaking to some weak, medium and coarse subangular blocks; slightly hard when dry, friable when moist, sticky and slightly plastic when wet; common, thin clay cutans; common, fine and medium pores; few, fine roots; clear and wavy transition to:

B_3 90 - 110 cm. Dusky red ($2.5YR^4/8$ dry, $10R^3/4$ moist) gravelly clay; porous massive breaking to some weak, medium and coarse subangular blocks; slightly hard when dry, friable when moist, sticky and slightly plastic when wet; common fine medium pores; few, fine roots.

C 110 cm+ Quartz gravel and weathered bedrock with pockets of soil.

Soil Classification:

Diagnostic horizons: 0 - 25 cm Ochric epipedon

25 - 90 cm Argillic horizon

F.A.O. (1970,1973): Chromic Luvisol.

U.S.D.A. (1970) : Udic Rhodustalf.

Analytical Data

Profile No.: KM/2*

Laboratory number/74	7547	7547	7549	7550	7551
Horizon	Ap	B_1	B_{21t}	B_{22t}	B_3
Depth in cm	0-15	15-25	25-61	61-90	90-110+
Texture (hydrometer) class	C	C	C	C	C
Sand %	42	40	32	32	28
Silt %	14	12	14	8	14
Clay %	44	48	54	60	58
pH-H_2O (1:1 susp.)	6.6	6.5	6.8	6.9	6.8
pH-KCl (1:1 susp.)	5.0	5.2	5.6	5.7	5.5
EC(1:1 susp.) in mmho's/cm	0.10	0.12	0.15	0.23	0.13
C %	0.97	0.68	0.59	0.21	0.21
N %	0.10	0.09			
Cation Exchange capacity m.e. %	14.8	13.6	14.4	15.2	14.3
Exchangeable Ca m.e. %	8.9	6.8	7.8	8.0	8.0
" Mg "	2.5	2.7	4.0	3.6	3.6
" K "	1.50	1.30	0.20	0.81	0.32
" Na "	0.40	0.25	0.35	0.52	0.80
Sum of Base	13.3	11.1	12.4	12.9	12.7
Base saturation %	90	82	86	85	89
E.S.P.	<5	<5	<5	<5	5.6
Hp m.e. %	-	-			
Available Ca m.e. %	8.0	6.1			
" Mg "	3.6	3.2			
" K "	0.90	0.86			
" Na "	Trace	Trace			
" Mn "	0.76	0.52			
" P ppm	20	22			

Strong N, moderate P deficiency.

Mapping unit BUbm — Observation site KM/3*

Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Gently undulating
Relief, meso	:	A few termite mounds, inactive, all have been ploughed and flattened
Vegetation/land use	:	Grass/cotton
Erosion	:	Nil to slight sheet
Rock outcrops	:	Nil
Overwash/overblow	:	Very slight
Flooding	:	Nil
Surface stoniness	:	Very few
Surface runoff	:	Slow
General ground water level	:	Very deep
Slope gradient	:	4%
Salinity/alkalinity	:	Nil
Human influences	:	Bench terracing, mechanical ploughing
Surface sealing	:	9 - 10 mm, weak
Internal drainage class	:	Well drained
Effective soil depth	:	55 cm, moderately deep
Perched ground water level	:	Nil

Description of profile

Ap	0 - 10 cm.	Dark brown ($10YR^4/3$ dry, $7.5YR^4/4$ moist), sandy clay; weak, fine subangular blocky structure; slightly hard to hard when dry, friable when moist, slightly sticky and slightly plastic when wet; few, very fine and fine pores, common, medium pores; many, fine roots; high biological activity; clear and smooth transition to:
AB	10 - 20 cm.	Dark brown ($7.5YR^5/6$ dry, $7.5YR^4/4$ moist), clay; weak, fine and medium subangular blocky structure; hard when dry, friable when moist, sticky and slightly plastic when wet; many, very fine pores, common, fine pores, few medium pores; few, fine roots; gradual and wavy transition to:
B_2	20 - 55 cm.	Reddish brown ($5YR^5/6$ dry, $5YR^4/4$ moist), clay; porous massive breaking to some weak, medium and coarse subangular blocks; slightly hard to hard when dry, friable when moist, sticky and slightly plastic when wet; many, very fine pores, common, fine and medium pores; few, very fine roots; clear and irregular transition to:
B_3	55 cm+	Many, fine angular and subangular quartz gravel, many hard rounded (not cemented) iron and manganese concretions (5 - 15 mm, 40%)/petroplinthite.

Soil Classification:

Diagnostic horizons: 0 - 10 cm Ochric epipedon

10 - 55 cm Argillic horizon or cambic horizon

Remark

The argillic horizon is identified here on the basis of the clay differences since in the field no clay skins were observed. Clay mineralogical analysis shows presence of 2:1 clays (illite). Hence possibilities of a cambic horizon. Consequently, three possibilities of the subgroups into which the profile is likely to fall are given owing to lack of sufficient analytical data e.g. thin section analysis.

F.A.O. (1970.1973): Chromic Luvisol (petroplinthic phase)
(Orthic Acrisol)

Chromic Cambisol (" ")

U.S.D.A. (1970) : Ultic haplustalf
(Ustoxic Haplustults)

Typic Ustropept

Analytical Data

Profile No.: KM/3*

Laboratory number/74	7552	7553	7554
Horizon	Ap	AB	B_2
Depth in cm	0-10	10-20	20-55
Texture (hydrometer) class	SC	C	C
Sand %	48	38	36
Silt %	12	8	10
Clay %	40	54	54
pH-H_2O (1:1 susp.)	6.3	6.3	6.4
pH-KCl (1:1 susp.)	4.8	4.6	4.8
EC(1:1 susp.)in mmho's/cm	0.10	0.08	0.08
C %	0.68	0.76	0.44
N %	0.08	0.07	
Cation Exchange capacity m.e. %	12.4	14.8	15.2
Exchangeable Ca m.e. %	6.0	5.2	7.6
" Mg "	1.6	0.9	1.2
" K "	1.02	0.34	0.20
" Na "	0.25	0.25	0.25
Sum of Base	8.9	6.7	9.3
Base saturation %	72	45	61
E.S.P.	-	-	-
Hp m.e. %	0	-	-
Available Ca m.e. %	5.8	5.0	
" Mg "	2.4	2.3	
" K "	0.71	0.30	
" Na "	Trace	Trace	
" Mn "	0.38	0.16	
" P ppm	14	14	

Strong N, moderate P deficiency.

Mapping unit BUr2 — Observation site KM/5*

Geological formation	:	Basement complex
Local petrography	:	Ubdifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Gently undulating to undulating
Relief, meso	:	Few termite mounds, inactive, 2 m. diameter, 1 m high
Vegetation/land use	:	Grassland/Grazing pasture
Erosion	:	Nil
Rock outcrops	:	Little rocky (only one rock outcrop)
Overwash/overblow	:	Slight
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Slow to rapid
General ground water level	:	Very deep
Slope gradient	:	5 %
Salinity/alkalinity	:	Nil
Human influences	:	Wood cutting and Bush clearing
Surface sealing	:	5 - 10 mm, weak
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep > 120 cm.
Perched ground water level	:	Nil

Description of profile

A_1	0 - 15 cm.	Dark reddish brown ($5YR^4/4$ dry, $5YR^3/4$ moist), coarse sandy loam; weak, very fine and fine subangular blocky structure; loose when dry, friable when moist, non sticky and non plastic when wet; many, very fine and fine pores, common, medium pores; some termite channels; many medium and coarse roots; clear and smooth transition to:
AB	15 - 27 cm.	Dark reddish brown ($5YR^5/6$ dry, $5YR^3/4$ moist), coarse sandy clay loam; porous massive breaking to some weak, fine and medium subangular blocks; slightly hard when dry friable when moist, slightly sticky and slightly plastic when wet; few coarse pores, many, very fine and fine pores, common medium pores; krotovina, 3-4 cm diameter; common, fine and medium roots; gradual and smooth transition to:
B_{21}	27 - 84 cm.	Dark red ($2.5YR^5/6$ - $^5/8$ dry, $2.5YR^3/6$ moist), sandy clay loam; porous massive; slightly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; many, very fine pores, common, fine pores; common fine and medium roots; diffuse and smooth transition to:
B_{22}	84 - 130 cm.	Dark red ($2.5YR^4/6$ - $^5/6$ dry, $2.5YR^3/6$ moist), sandy clay; porous massive; slightly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; common, fine roots; gradual and smooth transition to:
B_3	130 - 160+cm.	Dark red ($2.5YR^5/6$ dry, $2.5YR^3/6$ moist), gravelly clay; porous massive, slightly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; many, fine subangular, and angular quartz gravels; common, fine roots.

Soil Classification

Diagnostic horizon: 0 - 27 cm Ochric epipedon.

Remark

From the analytical data the clay differences are sufficient for an argillic horizon (27-160 cm) but no clay skins were observed in the field. The profile has no oxic horizon since the C.E.C. is too high (greater than 16 me/100 gm clay). Clay mineralogical data shows presence of 2:1 clays (32% illite) but Kaolinitic clays are dominant (68%). No weatherable primary minerals were observed in the field and no colour differences in the underlying horizons to qualify for a cambic horizon.
Therefore this profile has been classified as having an argillic horizon on the basis of textural increase since there is no thin section analytical data to show absence or presence of clay skins.

F.A.O. (1970,1973): Orthic Acrisol
(Dystric Nitosol)

U.S.D.A. (1970) : Ustoxic Paleustult

Note

The subgroup level in the U.S.D.A. is not given but comparing the subgroup level with that of the Haplustult the profile shows some oxic characteristics, hence the subgroup Ustoxic.

Analytical Data

Profile No.: KM/5*

Laboratory number/74	7559	7560	7561	7562	7563
Horizon	A_1	AB	B_{21}	B_{22}	B_3
Depth in cm.	0-15	15-27	27-84	84-130	130-160
Texture (hydrometer) class	SL/SCL	SCL	SCL	SC	SC
Sand %	72	68	56	54	48
Silt %	8	8	12	8	12
Clay %	20	24	32	38	40
pH-H_2O (1:1 susp.)	5.9	5.6	5.7	5.3	5.7
pH-KCl (1:1 susp.)	4.4	4.3	3.9	3.9	3.8
EC(1:1 susp.) in mmho's/cm.	0.10	0.08	0.08	0.08	0.08
C %	0.35	0.26	0.15	0.26	0.24
N %	0.04	0.04			
Cation Exchange capacity m.e. %	5.6	6.0	8.4	7.8	8.2
Exchangeable Ca m.e. %	1.8	1.6	2.0	2.0	2.0
" Mg "	0.4	0.1	0.2	0.2	0.3
" K "	0.50	0.08	0.28	0.25	0.28
" Na "	0.20	0.05	0.10	0.20	0.21
Sum of Base	2.9	3.0	2.6	2.7	2.8
Base saturation %	52	50	31	35	34
E.S.P.	<5	<5	<5	<5	<5
Hp m.e. %	-				
Available Ca m.e. %	1.8	1.6			
" Mg "	0.7	0.7			
" K "	0.37	0.31			
" Na "	Trace	Trace			
" Mn "	0.22	0.06			
" P ppm	11	4			

Strong N, P deficiency.

Mapping unit BQ_1m — Observation site KM/6*

Geological formation	:	Basement complex
Local petrography	:	Quartz rich Basement System rocks
Physiography	:	Uplands
Relief, macro	:	Gently undulating to undulating
Relief, meso	:	Nil
Vegetation/Land use	:	Grassland/cultivated places; cotton
Erosion	:	Nil
Rock outcrops	:	Nil
Overwash/overblow	:	Nil
Flooding	:	Nil
Surface stoniness	:	Very few stones
Surface runoff	:	Very slow
General ground water level	:	Very deep
Slope gradient	:	5 %
Salinity/alkalinity	:	Nil
Human influences	:	Cultivation, bench, terracing
Surface sealing	:	10 mm, weak
Internal drainage class	:	Well drained
Effective soil depth	:	55 cm. moderately deep
Perched ground water level	:	Nil

Description of profile

Ap	0 - 15 cm.	Very dark greyish brown ($10YR^5/3$ dry, $10YR^3/2$ moist), coarse loamy sand; weak, very fine and fine subangular blocky structure; slightly hard when dry, loose when moist, non sticky and non plastic when wet; common, very fine and fine pores; few earthworm and termite channels; many fine roots; clear and smooth transition to:
AB	15 - 25 cm.	Dark brown ($10YR^5/3$ dry, $10YR^3/3$ moist), coarse sandy loam; porous massive; slightly hard when dry, loose when moist, non sticky and non plastic when wet; many, very fine and fine pores; occasional termite channels; common, fine roots; gradual and smooth transition to:
B_2	25 - 55 cm.	Dark brown ($10YR^5/3$ dry, $10YR^4/3$ moist), coarse sandy loam; porous massive; slightly hard when dry, loose when moist, slightly sticky and non plastic when wet; many, very fine pores, common, fine pores; few, hard iron and manganese nodules (5%, 5-10 mm); few, fine roots, clear and wavy transition to:
B_{3cn}	55 - 73 cm.	Dark yellowish brown ($10YR^5/4$ dry, $10YR^4/4$ moist), gravelly, coarse sandy loam; massive; slightly hard when dry, loose when moist, slightly sticky and non plastic when wet; many, fine pores, few, medium pores; many, hard rounded, iron and manganese nodules (10%, 5-10 mm); some angular fine quartz gravel; very few, fine roots.

Soil Classification

Diagnostic horizon: 0 - 25 cm Ochric epipedon.

Remark

Clay mineralogical data shows that the profile consists dominantly of illitic clays (25-50 cm, 60% illite, 29% kaolinite, 11% smectite). Therefore it shows characteristics of a cambic B horizon but texture is too coarse. This together with a clay content of less than 15%, puts the soil in the Arenosols (F.A.O.).

F.A.O. (1970,1973): Cambic Arenosols (Petroplinthic phase)

U.S.D.A. (1970) : Typic Ustorthent

Analytical Data

Profile No.: KM/6*

Laboratory number/74	7564	7565	7566	7567
Horizon	Ap	AB	B_2	B_{3cn}
Depth in cm.	0-15	15-25	25-50	50-73
Texture (hydrometer) class	LS	LS	SL/LS	SL
Sand %	80	84	78	76
Silt %	12	4	12	12
Clay %	8	12	10	12
pH-H_2O (1:1 susp.)	6.3	6.3	6.1	5.7
pH-KCl (1:1 susp.)	4.6	4.5	4.9	4.2
EC(1:1 susp.) in mmho's/cm	0.08	0.08	0.15	0.08
C %	0.26	0.08	0.09	0.08
N %	0.03	0.02		
Cation Exchange capacity m.e. %	5.1	3.6	3.2	3.8
Exchangeable Ca m.e. %	2.4	2.0	1.4	0.6
" Mg "	0.3	0.3	0.6	0.6
" K "	0.28	0.18	0.20	0.24
" Na "	0.10	0.05	0.30	0.25
Sum of Base	3.1	2.6	2.5	1.7
Base saturation %	61	72	78	45
E.S.P.	<5	<5	<5	<5
Hp m.e. %	-			
Available Ca m.e. %	1.7	1.4		
" Mg "	0.6	0.7		
" K "	0.21	0.14		
" Na "	0.52	Trace		
" Mn "	0.30	0.28		
" P ppm	6	3		

Strong N, P deficiency.

Mapping unit BUb	:	Observation site KM/7*
Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Very gently undulating
Relief, meso	:	A few termite mounds, 2-3 m diameter, some have been ploughed and flattened
Vegetation/Land use	:	Cultivated/maize, cotton, cassava
Erosion	:	Very slight sheet
Rock outcrops	:	Nil
Overwash/overblow	:	Very slight, locally washed sand
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Slow
General ground water level	:	Very deep
Slope gradient	:	$2\frac{1}{2}$ %
Salinity/alkalinity	:	Nil
Human influences	:	Mechanical ploughing, bench terracing
Surface sealing	:	-
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep, > 120 cm.
Perched ground water level	:	Nil

Description of profile

Ap	0 - 15 cm.	Dark reddish brown ($5YR^4/6$ dry, $5YR^3/4$ moist), fine sandy clay; moderate, fine subangular blocky structure; Slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common fine pores; some termite channels; common, fine, medium and coarse roots; clear and wavy transition to:
AB	15 - 35 cm.	Yellowish red ($5YR^5/6$ dry, $5YR^4/6$ moist), fine sandy clay; porous massive breaking to some weak, medium and coarse subangular blocks; slightly hard to hard when dry; friable when moist, slightly sticky and slightly plastic when wet; common fine pores; few, medium and coarse roots; gradual and smooth transition to:
B_{21}	35 - 80 cm.	Yellowish red ($5YR^5/8$ dry, $5YR^5/6$ moist), fine sandy clay; porous massive breaking to some weak, fine and medium subangular blocks, friable when moist, slightly sticky and slightly plastic when wet; common fine pores; few fine roots; diffuse and smooth transition to:
B_{22}	80 - 130 cm.	Yellowish red ($7.5YR^5/6$ dry, $5YR^5/6$ moist), fine sandy clay; porous massive breaking to some weak, fine and medium subangular blocks; friable when moist, slightly sticky and slightly plastic when wet; few patchy, thin clay cutans (not enough for a B_{2t} horizon); many fine pores; few fine roots; gradual and smooth transition to:
B_3	130 - 170 cm+	Yellowish red ($5YR^5/6$ moist), fine sandy clay; porous massive; friable when moist, slightly sticky and slightly plastic when wet; many fine pores; few fine roots.

Note

The profile was moist as from 55 cm, a rather "smeary" feeling in the B_{22} and B_3.

Soil Classification

Diagnostic horizons: 0 - 15 cm Ochric epipedon
15 - 170 cm Argillic horizon

Remark

The clay difference is sufficient for an argillic horizon but there was not enough evidence of clay skins in the field. Clay mineralogical analysis indicates that kaolinite is the dominant mineral. No weatherable primary minerals observed in the field. Therefore no cambic horizon. C.E.C. greater than 16 me/100 g clay. Therefore no oxic horizon.

F.A.O. (1970,1973): Orthic Acrisol

U.S.D.A. (1970) : Ustoxic Haplustult

Analytical Data

Profile No.: KM/7*

Laboratory number/74	7568	7569	7570	7571	7572
Horizon	Ap	AB	B_{21}	B_{22}	B_3
Depth in cm.	0-15	15-35	35-80	80-130	130-170+
Texture (hydrometer) class	C	C	C	C	C
Sand %	38	32	32	10	14
Silt %	10	8	8	22	10
Clay %	52	60	60	68	78
pH-H_2O (1:1 susp.)	6.5	4.9	4.6	4.8	4.8
pH-KCl (1:1 susp.)	5.1	3.9	3.8	3.9	4.0
EC(1:1 susp.) in mmho's cm.	0.13	0.13	0.20	0.10	0.13
C %	0.35	0.38	0.29	0.12	0.21
N %	0.07	0.06			
Cation Exchange capacity m.e. %	11.2	12.0	11.1	12.8	14.1
Exchangeable Ca m.e. %	6.0	3.6	2.0	1.8	2.0
" Mg "	1.6	0.8	1.4	1.5	2.5
" K "	1.22	0.82	0.34	0.28	0.24
" Na "	0.25	0.52	0.25	0.30	0.35
Sum of Base	9.1	5.7	4.0	4.1	5.1
Base saturation %	81	48	36	32	36
E.S.P.	<5	<5	<5	<5	<5
Hp m.e. %	0				
Available Ca m.e. %	5.7	3.2			
" Mg "	2.3	1.3			
" K "	0.60	0.34			
" Na "	0.04	Trace			
" Mn "	0.66	0.28			
" P ppm	8	2			

Strong N, P deficiency.

Mapping unit BUbc2m — Observation site KM/10*

Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Gently undulating
Relief, meso	:	Nil
Vegetation/Land use	:	Grass/abandoned cultivation
Erosion	:	Nil
Rock outcrops	:	Nil
Overwash/overblow	:	Nil
Flooding	:	Nil
Surface stoniness	:	Little stony
Surface runoff	:	Slow
General ground water level	:	Very deep
Slope gradient	:	2.5 %
Salinity/alkalinity	:	Nil
Human influences	:	Previous mechanical ploughing
Surface sealing	:	10 mm weak to moderate
Internal drainage class	:	Well drained
Effective soil depth	:	Moderately deep, 65 cm.
Perched ground water level	:	Nil

Description of profile

Ap	0 - 24 cm.	Very dark greyish brown ($10YR^{5}/3$ dry, $10YR^{3}/2$ moist), coarse sandy loam; weak, fine and medium subangular blocky structure; loose when dry, loose when moist, non sticky and non plastic when wet; many, fine pores, common, medium pores; occasional termite channels; common, fine roots; clear and smooth transition to:
AB	24 - 35 cm.	Dark brown ($10YR^{4}/4$ dry, $7.5YR^{4}/4$ moist), sandy clay loam; porous massive; slightly hard when dry, friable to firm when moist, slightly sticky and slightly plastic when wet; common, fine pores; few, fine roots, gradual and smooth transition to:
B_2	35 - 65 cm.	Dark brown ($7.5YR^{5}/6$ dry, $7.5YR^{4}/4$ moist), sandy clay loam; porous massive; slightly hard when dry, friable to firm when moist, slightly sticky and slightly plastic when wet; few, fine pores; few fine roots; abrupt and wavy transition to:
B_{3cn}	65 - 80 cm.	Mainly hard, rounded, weakly cemented iron and manganese nodules (> 50%, 5-10 mm)/petroplinthite.

Soil CLassification

Diagnostic horizons: 0 - 24 cm Ochric epipedon

24 - 65 cm Argillic horizon.

Remark

The clay difference is sufficient for an argillic horizon but no evidence of clay skins in the field. C.E.C. too high for an oxic horizon. No weatherable minerals, therefore no Cambic horizon.

F.A.O. (1970,1973): Ferric Luvisol

U.S.D.A. (1970) : Oxic Haplustalf

Analytical Data

Profile No.: KM/10*

Laboratory number/74	8707	8708	8709	8710
Horizon	Ap	AB	B_2	composite sample
Depth in cm.	0-24	24-35	35-65	0-20
Texture (hydrometer) class	SL	SCL	SCL	SL
Sand %	72	58	54	75
Silt %	8	14	18	8
Clay %	20	28	28	17
pH-H_2O (1:1 susp.)	5.8	4.9	5.1	6.5
pH-KCl (1:1 susp.)	5.3	4.3	4.4	5.8
EC(1:1 susp.) in mmho's/cm.	0.12	0.12	0.13	0.17
C %	0.53	0.38	0.41	0.47
N %	0.04			0.04
Cation Exchange capacity m.e. %	4.3	6.2	6.1	4.1
Exchangeable Ca m.e. %	1.6	1.9	2.2	1.6
" Mg "	1.2	1.0	1.4	0.9
" K "	0.6	0.2	0.3	0.4
" Na "	0.1	0.1	0.1	0.1
Sum of Base	3.5	3.2	4.0	3.0
Base saturation %	81	52	66	73
E.S.P.	<5	<5	<5	<5
Hp m.e. %				0
Available Ca m.e. %				2.4
" Mg "				1.0
" K "				0.85
" Na "				Trace
" Mn "				0.42
" P ppm				18

Strong N, moderate P deficiency.

Appendix B_2

Representative profiles - Reconnaissance soil map of part of Makueni area.

Mapping unit BUd		Observation site 163/3 - 9*
Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Nearly level to very gently undulating
Relief, meso	:	Gilgai relief, slight to moderate 15 - 30 cm high
Vegetation/Land use	:	Bush grassland/Grazing
Erosion	:	Very slight sheet
Rock outcrops	:	Nil
Overwash/overblow	:	Nil
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Ponded
General ground water level	:	Deep
Slope gradient	:	2 %
Salinity/alkalinity	:	($CaCO_3$ in form of lime concretions)
Human influence	:	Wood cutting, Grazing
Surface sealing	:	5 - 10 mm, weak to moderate
Cracking	:	Huge cracks, 5-10 cm wide, > 30 cm deep
Internal drainage class	:	Imperfectly drained
Effective soil depth	:	Very deep, > 115 cm.
Perched ground water level	:	Nil

Description of profile

A_1 0 - 30 cm. Black ($10YR^{3}/1$ dry, $10YR^{2.5}/1$ moist), clay; moderate, coarse prismatic structure breaking to some moderate, medium and coarse subangular blocks; hard when dry, firm when moist, sticky and plastic when wet; few weak slickensides; few, very fine and fine pores, few medium pores; wide cracks (5-10 cm wide), few termite burrows; common fine roots; clear and smooth transition to:

C_1 ca 30 - 61 cm. Very dark grey (N4/dry, N3/moist), cracking clay; strong, coarse prismatic structure falling apart to strong, coarse angular blocks; extremely hard when dry, very firm when moist, very sticky and very plastic when wet; few, fine, distinct, strong brown mottles ($7.5YR^{5}/8$); abundant, strong slickensides (oriented at angles between 30 and 45^{o}); few, very fine pores; many $CaCO_3$ concretions (15%, 2-5 mm) moderately calcareous; few, fine roots; diffuse and smooth transition to:

C_2 ca 61 - 115+cm. Very dark grey (N4/dry, N3/moist), cracking clay; strong, coarse prismatic structure breaking to some strong, coarse angular blocks; extremely hard when dry, very firm when moist, very sticky and very plastic when wet; few, fine distinct strong brown mottles ($7.5YR^{5}/8$); common strong slickensides (oriented at angles between 30 and 45^{o}); few, very fine pores; many $CaCO_3$ concretions (20%, 2-5 mm), moderately calcareous; very few fine roots.

Soil Classification

F.A.O. (1970,1973): Pellic Vertisols (sodic phase)

U.S.D.A. (1970) : Typic Pellustert

Analytical Data

Profile No.: 163/3-9*

Laboratory number/74	8176	8177	8178
Horizon	A_1	C_1ca	C_2ca
Depth in cm.	0-30	30-61	61-115
Texture (hydrometer) class	C	C	C
Sand %	32	36	30
Silt %	20	12	10
Clay %	48	52	60
pH-H_2O (1:1 susp.)	6.8	8.7	9.0
pH-KCl (1:1 susp.)	5.1	7.4	7.4
EC(1:1 susp.) in mmho's/cm.	0.15	0.55	0.70
C %	0.97	0.39	0.29
N %	0.11		
Cation Exchange capacity m.e. %	30.4	32.0	36.2
Exchangeable Ca m.e. %	12.4	15.5	21.2
" Mg "	8.0	10.3	7.8
" K "	0.30	0.28	0.29
" Na "	2.3	4.9	7.6
Sum of Base	23	31.0	36.9
Base saturation %	76	97	>100
E.S.P.	7.6	15.3	21.0
Hp m.e. %	0		
Available Ca m.e. %	15.8		
" Mg "	6.4		
" K "	0.11		
" Na "	0.57		
" Mn "	0.22		
" P ppm	20		

Strong N, moderate P, K deficiency.

Profile drawing

One profile drawing belonging to profile no. 163/3-9* has been made. The drawing was originally made on a plastic sheet by fixing it on the face of the profile pit. Afterwards the drawing was photographically reduced. The legend used is as follows:

horizon boundary

cracks

huge cracks

$CaCO_3$ concretions

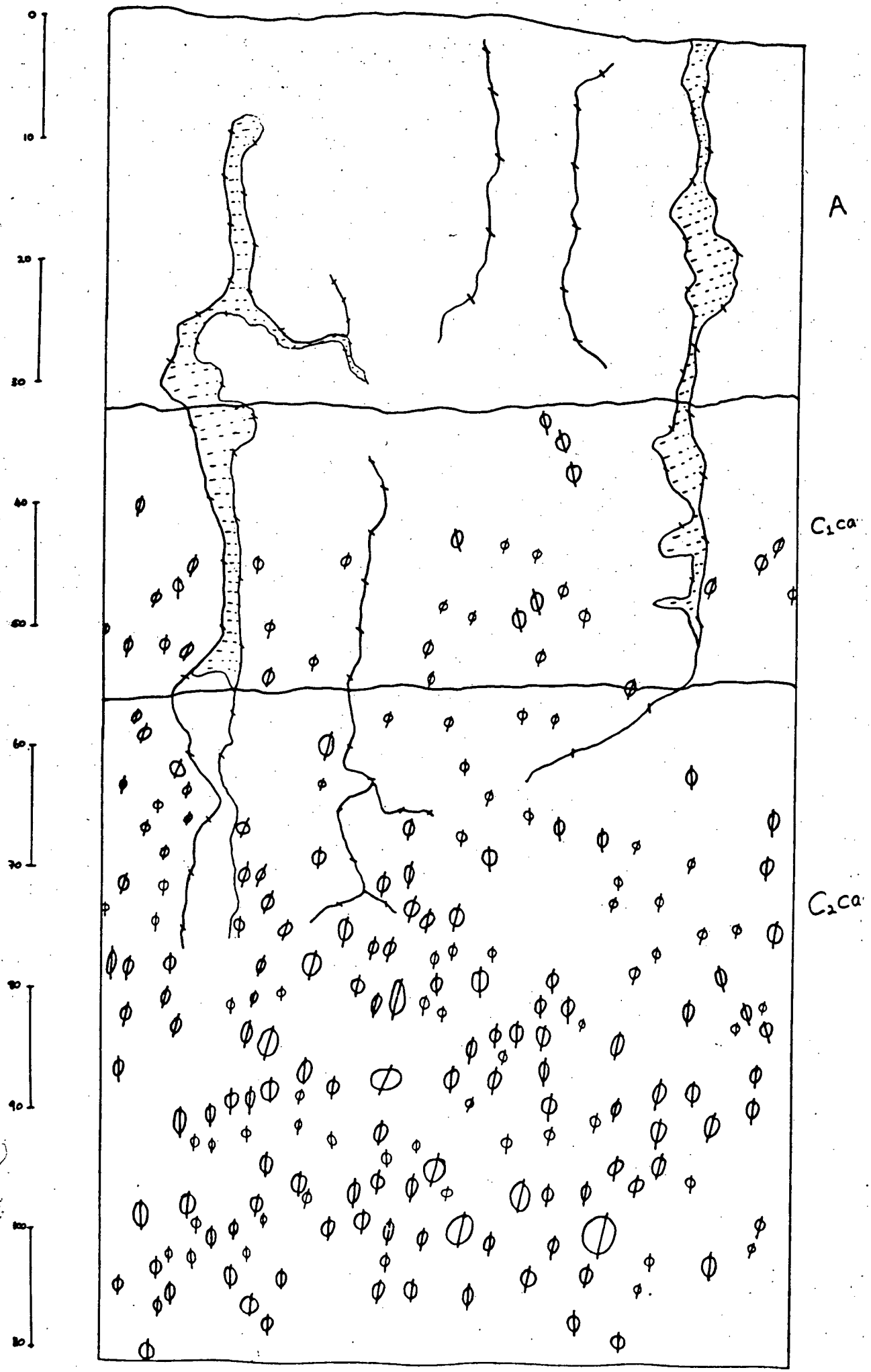


Fig. 16 Profile drawing belonging to profile no. 1623-9*

Mapping unit BUb_2 — Observation site 163/3-12*

Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Gently undulating
Relief, meso	:	A few termite mounds, inactive
Vegetation/Land use	:	Bushland/grazing
Erosion	:	Slight sheet
Rock outcrops	:	Nil
Overwash/overblow	:	Slight, locally washed sand
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Slow
General ground water level	:	Very deep
Slope gradient	:	2 %
Salinity/alkalinity	:	Nil
Human influences	:	Wood cutting, overgrazing
Surface sealing	:	9 mm, moderate
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep > 120 cm.
Perched ground water level	:	Nil

Description of profile

A_1	0 - 20 cm.	Very dark greyish brown ($10YR^4/2$ dry, $10YR^3/2$ moist) coarse sandy loam; moderate, fine and medium subangular blocky structure; loose when dry, loose when moist, non sticky and non plastic when wet; common, very fine and fine pores; few, medium pores; many termite burrows; few, medium and coarse roots; clear and smooth transition to:
AB	20 - 40 cm.	Brown to dark brown ($10YR^4/4$ dry, $10YR^4/3$ moist) coarse sandy clay loam; porous massive breaking to some weak fine and medium subangular blocks; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; few, medium roots; clear and smooth transition to:
B_{21}	40 - 75 cm.	Strong brown ($7.5YR^5/8$ dry, $7.5YR^5/6$ moist), sandy clay; porous massive; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common fine pores; few fine roots; gradual and smooth transition to:
B_{22}	75 - 110 cm.	Yellowish brown ($10YR^5/8$ dry, $10YR^5/6$ moist), sandy clay; porous massive; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; few, fine, faint red mottles ($2.5YR^5/6$); common, fine pores; few, fine roots; gradual and smooth transition to:
B_3	110 - 130+cm.	Strong brown ($10YR^5/8$ - $^6/8$ dry, $7.5YR^5/6$ moist), sandy clay; massive; slightly hard to hard when dry, friable when moist, slightly sticky and slightly plastic when wet; few, fine, distinct red mottles ($2.5YR^5/6$); few, fine pores; few iron and manganese concretions (5-10%, 2-5 mm); few, fine roots.
C	130+cm.	Weathered bedrock.

Soil Classification

Diagnostic horizons:	0 - 20 cm	Ochric epipedon
	20 - 110 cm	Argillic horizon (clay differences sufficient but in the field no clay skins were observed)

Remark

The C.E.C. of B_{22} horizon (75-110 cm) is 16 me/100 g clay. This just qualifies for an oxic horizon. No weatherable primary minerals were observed in the field. However, there is no analytical data on heavy and light minerals to ascertain absence of weatherable minerals. Consequently the possibility of the profile having an oxic horizon should be taken tentatively.

F.A.O. (1970,1973): Ferric Luvisol
(Xanthic Ferralsol)

U.S.D.A. (1970) : Oxic Haplustalf
(Tropeptic Haplustox)

Analytical Data

Profile No.: 163/3-12*

Laboratory number/74	8715	8716	8717	8718	8719
Horizon	A_1	AB	B_{21}	B_{22}	B_3
Depth in cm.	0-20	20-40	40-75	75-110	110-130
Texture (hydrometer) class	SL	SCL	SC	SC	SC
Sand %	76	62	58	56	50
Silt %	8	6	6	4	10
Clay %	16	32	36	40	40
pH-H_2O (1:1 susp.)	5.2	5.3	5.4	5.7	5.1
pH-KCl (1:1 susp.)	4.8	4.8	4.8	5.0	4.5
EC(1:1 susp.) in mmho's/cm.					
C %	0.53	0.38	0.53	0.38	0.47
N %	0.07				
Cation Exchange capacity m.e. %	6.6	5.4	6.0	6.4	7.5
Exchangeable Ca m.e. %	1.7	1.5	2.8	1.2	1.8
" Mg "	1.1	1.3	1.2	1.8	1.8
" K "	0.3	0.3	0.5	0.3	0.2
" Na "	0.1	0.1	0.1	0.4	0.2
Sum of Base	3.2	3.2	4.6	3.7	4.0
Base saturation %	48	59	77	58	53
E.S.P.	<5	<5	<5	<6.2	<5
Hp m.e. %	0				
Available Ca m.e. %	1.6				
" Mg "	1.2				
" K "	0.30				
" Na "	0.0				
" Mn "	0.32				
" P ppm	14				

Strong N, moderate P deficiency.

Mapping unit BUb1 — Observation site 163/3-13*

Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Gently undulating
Relief, meso	:	A few termite mounds, 2-3 m high, 1 m diameter
Vegetation/Land use	:	Bush grassland/grazing
Erosion	:	Nil
Rock outcrops	:	Nil
Overwash/overblow	:	Slight
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Very slow
General ground water level	:	Very deep
Slope gradient	:	2 %
Salinity/alkalinity	:	Nil
Human influences	:	Wood cutting
Surface sealing	:	8 mm, moderate
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep > 170 cm
Perched ground water level	:	Nil

Description of profile

A_1	0 - 15 cm.	Very dark greyish brown ($10YR^3/3$ dry, $10YR^3/2$ moist), fine sandy clay loam; moderate, fine and medium subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many, very fine pores, common, fine and medium pores, few coarse pores; many termite burrows; common, fine roots, few coarse roots; clear and smooth transition to:
A_3	15 - 50 cm.	Strong brown ($7.5YR^5/8$ dry, $7.5YR^5/6$ moist), clay; porous massive breaking to some weak medium and coarse subangular blocks; slightly hard to hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores, few, medium and coarse pores; few fine roots; gradual and smooth transition to:
B_{21}	50 - 115 cm.	Strong brown ($7.5YR^5/8$ dry, $7.5YR^5/6$ moist), clay; porous massive breaking to some weak, coarse prismatic structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; very few fine roots; clear and wavy transition to:
B_{22}	115 - 170+cm.	Yellowish brown ($10YR^6/8$ dry, $10YR^5/8$ moist), clay; porous massive; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, prominent red mottles (2-15 mm); common, very fine and fine pores; very few fine roots; few, rounded iron and manganese nodules (3%, 3-4 mm).

Soil Classification

Diagnostic horizons:	0 - 15 cm	Ochric epipedon
	15 - 170 cm	Argillic horizon
or	15 - 115 cm	Cambic horizon

Remark

The clay difference is sufficient for an argillic horizon but no clay skins were observed in the field. Also there is a textural increase up to 170 cm. The horizon 15 to 115 cm qualifies as cambic (redder hue). No weatherable primary minerals were observed in the field but since no mineralogical data are available, the possibilities of a cambic horizon has been taken into account in this classification. The C.E.C. is too high for an oxic horizon.

F.A.O. (1970,1973): Dystric Nitosol
(Ferralic Cambisol)

U.S.D.A. (1970) : Oxic Paleustalf
(Ustoxic Dystropept)

Analytical Data

Profile No.: 163/3-13*

Laboratory number/74	8673	8674	8675	8676
Horizon	A_1	A_3	B_{21}	B_{22}
Depth in cm.	0-15	15-50	50-115	115-170+
Texture (hydrometer) class	SCL	C	C	C
Sand %	64	40	40	36
Silt %	10	8	4	4
Clay %	26	52	56	60
pH-H_2O (1:1 susp.)	5.9	4.9	4.6	5.0
pH-KCl (1:1 susp.)	5.4	4.3	4.1	4.2
EC(1:1 susp.) in mmho's/cm.	0.12	0.06	0.05	0.04
C %	1.19	0.63	0.39	0.18
N %	0.11			
Cation Exchange capacity m.e. %	10.5	12.9	12.7	10.6
Exchangeable Ca m.e. %	4.0	4.0	2.5	2.4
" Mg "	2.6	3.2	0.2	1.9
" K "	0.9	0.1	0.2	0.1
" Na "	0.2	0.1	0.3	0.4
Sum of Base	7.7	7.4	5.2	4.8
Base saturation %	73	57	41	45
E.S.P.	<5	<5	<5	<5
Hp m.e. %	0			
Available Ca m.e. %	5.6			
" Mg "	2.6			
" K "	0.58			
" Na "	0.08			
" Mn "	0.36			
" P ppm	12			

Moderate N, strong P deficiency.

Mapping unit BUr — Observation site 163/4-14*

Geological formation	:	Basement complex
Local petrography	:	Undifferentiated Basement System gneisses
Physiography	:	Uplands
Relief, macro	:	Undulating
Relief, meso	:	Nil
Vegetation/Land use	:	/Maize, beans, pigeon peas
Erosion	:	Sheet to gully erosion, severe in places
Rock outcrops	:	Nil
Overwash/Overblow	:	Nil
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Slow to moderately rapid
General ground water level	:	Very deep
Slope gradient	:	8%
Salinity/alkalinity	:	Nil
Human influences	:	Bench terracing
Surface sealing	:	8 mm, moderate
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep > 120 cm.
Perched ground water level	:	Nil

Description of profile

Ap 0 - 14 cm. Dark reddish brown ($5YR^4/3$ dry, $5YR^3/3$ moist), sandy clay loam; weak, fine and medium subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; some termite burrows; few fine roots; clear and smooth transition to:

A_3 14 - 38 cm. Dark reddish brown ($5YR^4/4$ dry, $2.5YR^3/4$ moist), sandy clay; porous massive breaking to some weak, fine and medium subangular blocks; slightly hard to hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common very fine and fine pores, few medium pores; some krotovinas (5 cm diameter); some termite burrows; few, fine roots; gradual and smooth transition to:

B_{21} 38 - 77 cm. Dark reddish brown ($2.5YR^3/6$ dry, $2.5YR^3/4$ moist), sandy clay; porous massive breaking to some weak; fine and medium subangular blocks; slightly hard to hard when dry; friable to firm when moist, slightly sticky and slightly plastic when wet; few, weak/thin clay cutans (not enough for a B_{21t} horizon); few, very fine and fine pores; very few, fine roots; diffuse and smooth transition to:

B_{22} 77 - 135 cm. Dark reddish brown ($2.5YR^3/6$ dry, $2.5YR^3/4$ moist), sandy clay; porous massive breaking to some weak, medium subangular blocks; slightly hard to hard when dry, friable when moist, slightly sticky and slightly plastic when wet; few, weak/thin clay cutans (not enough for a B_{22t} horizon); few, very fine and fine pores; diffuse and smooth transition to:

B_3 135 - 160 cm. Dark reddish brown ($2.5YR^4/6$ dry, $2.5YR^3/4$ moist), sandy clay; porous massive; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; few fine pores; clear and wavy transition to:

C 160+cm. Weathering rock.

Soil Classification

Diagnostic horizons: 0 - 14 cm Ochric epipedon

14 - 135 cm Argillic horizon

Remark

The clay difference is sufficient for an argillic horizon. Also in the field there was some evidence of patchy clay skins not sufficient for a B_{2t}. The C.E.C. is too high for an oxic horizon. No weatherable minerals for a cambic horizon observed in the field.

F.A.O. (1970,1973): Eutric Nitosol

U.S.D.A. (1970) : Rhodic Paleustalf

Analytical Data

Profile No.: 163/4-14*

Laboratory number/74	8677	8678	8679	8680	8681	8682
Horizon	Ap	A_3	B_{21}	B_{22}	B_3	Composite sample
Depth in cm.	0-14	14-38	38-77	77-135	135-160	0-20
Texture (hydrometer) class	SCL	SC	SC	SC	SC	
Sand %	70	56	50	54	56	
Silt %	10	4	6	6	4	
Clay %	20	40	44	40	40	
pH-H_2O (1:1 susp.)	6.0	6.1	6.3	6.4	6.0	
pH-KCl (1:1 susp.)	5.4	5.3	5.5	5.2	5.7	
EC(1:1 susp.) in mmho's/cm.	0.12	0.12	0.13	0.22	0.25	
C %	0.27	0.27	0.24	0.18	0.21	
N %	0.02					
Cation Exchange capacity m.e. %	5.3	12.3	13.0	10.9	8.3	
Exchangeable Ca m.e. %	2.4	5.0	3.6	3.9	3.2	
" Mg "	1.2	2.0	3.0	3.9	3.2	
" K "	0.4	0.6	0.5	0.2	0.2	
" Na "	0.1	0.2	0.2	0.2	0.2	
Sum of Base	4.1	7.8	7.3	7.5	7.2	
Base saturation %	77	63	56	68	87	
E.S.P.	<5	<5	<5	<5	<5	
Hp m.e. %						0
Available Ca m.e. %						4.0
" Mg "						1.2
" K "						0.58
" Na "						-
" Mn "						0.49
" P ppm						79

Very strong N deficiency.

Mapping unit BQ_1 — Observation site 163/3-15*

Geological formation	:	Basement complex
Local petrography	:	Quartz rich Basement System rocks (Granite)
Physiography	:	Uplands
Relief, macro	:	Undulating
Relief, meso	:	Termite mounds, inactive, 2-3 m diameter 1 m high
Vegetation/Land use	:	Bushland/Grazing, in cultivated places maize, pigeon peas
Erosion	:	Nil
Rock outcrops	:	Only one rock outcrop, 100 m away
Overwash/Overblow	:	Slight
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Slow to moderate
General ground water level	:	Very deep
Slope gradient	:	5 %
Salinity/alkalinity	:	Nil
Human influences	:	Wood cutting
Surface sealing	:	8-9 mm, weak
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep, > 120 cm
Perched ground water level	:	Nil

Description of profile

A_1	0 - 30 cm.	Very dark greyish brown ($10YR^5/3$ dry, $10YR^3/2$ moist), coarse loamy sand; massive breaking to some weak fine and medium subangular blocks; loose when dry, loose when moist, non sticky and non plastic when wet; common, very fine and fine pores; many, fine and medium roots; clear and smooth transition to:
AB	30 - 50 cm.	Brown to dark brown ($10YR^5/2$ dry, $10YR^4/3$ moist), coarse loamy sand; massive; loose when dry, loose when moist, non sticky and non plastic when wet; many, very fine pores; many, fine roots; gradual and smooth transition to:
B_{21}	50 - 81 cm.	Dark brown ($7.5YR^5/6$ dry, $7.5YR^4/4$ moist), coarse sandy loam; massive; loose when dry, loose when moist, slightly sticky and non plastic when wet; common, very fine and fine pores; few, very fine and fine roots; diffuse and smooth transition to:
B_{22}	81 - 130+cm.	Yellowish red ($5YR^5/8$ dry, $5YR^4/6$ moist), coarse sandy loam; massive; loose when dry, loose when moist, slightly sticky and slightly plastic when wet; common very fine pores; few fine roots.

Soil Classification

Diagnostic horizons:	0 - 30 cm	Mollic epipedon
	50 - 130 cm	Argillic horizon

Remark

The clay difference is sufficient for an argillic horizon. However, no clay skins were observed in the field. Also the horizon lacks a blocky structure (mainly massive). The clay content of 20% disqualifies the profile from Arenosols*. No weatherable primary minerals for a cambic horizon. C.E.C. is too high for an oxic horizon.

F.A.O. (1970,1973): Luvic Phaeozem
(Haplic Phaeozem)

U.S.D.A. (1970) : Udic Argiustoll
(Udorthentic Haplustoll)

* From the texture estimations in the field most of the B horizons from the augerings in this mapping unit had a loamy sand to sandy loam texture. Only one profile pit was dug. Therefore the bulk of the soils in this mapping unit may be Arenosols (see Table 9 for the alternative classification names).

Analytical Data

Profile No.: 163/3-15*

Laboratory number/74	8683	8684	8685	8686	8687
Horizon	A_1	AB	B_{21}	B_{22}	Composite sample
Depth in cm.	0-30	30-50	50-81	81-130	0-15
Texture (hydrometer) class	LS	LS	SL	SL	
Sand %	80	78	72	68	
Silt %	10	14	8	12	
Clay %	10	8	20	20	
pH-H_2O (1:1 susp.)	5.8	4.9	4.5	4.3	
pH-KCl (1:1 susp.)	4.5	4.5	4.0	3.8	
EC(1:1 susp.) in mmho's/cm.	0.22	0.03	0.04	0.02	
C %	0.89	0.33	0.21	0.03	
N %	-				
Cation Exchange capacity m.e. %	4.8	3.2	8.0	7.9	
Exchangeable Ca m.e. %	2.2	1.2	3.6	2.2	
" Mg "	0.8	0.3	1.4	1.2	
" K "	0.35	0.30	0.45	0.28	
" Na "	0.4	0.2	0.3	0.4	
Sum of Base	3.7	2.0	5.8	4.1	
Base saturation %	77	65	73	52	
E.S.P.	8.3	6.3	5	5.1	
Hp m.e. %					0
Available Ca m.e. %					3.3
" Mg "					0.9
" K "					0.42
" Na "					0.01
" Mn "					0.19
" P ppm					28

Strong N, slight P deficiency.

Mapping unit BFr2a

Observation site 163/4-16*

Geological formation	:	Basement complex
Local petrography	:	Amphibolite - rock rich in ferromagnesian minerals
Physiography	:	Uplands
Relief, macro	:	Gently undulating to undulating
Relief, meso	:	Nil
Vegetation	:	/Maize, peas, beans
Erosion	:	Sheet erosion on upper slopes
Rock outcrops	:	Nil
Overwash/Overblow	:	Slight, coarse sand along the rills
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Slow to moderate
General ground water level	:	Very deep
Slope gradient	:	5 %
Salinity/alkalinity	:	Nil
Human influences	:	Ploughing (contour ploughing)
Surface sealing	:	8 mm, moderate to strong
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep, > 124 cm.
Perched ground water level	:	Nil

Description of profile

A_p(ploughed B_1)	0 - 16 cm.	Dark red ($5YR^4/6$ dry, $2.5YR^3/6$ moist), sandy clay; moderate, medium and coarse subangular blocky structure; slightly hard to hard when dry, friable when moist, sticky and plastic when wet; common, fine and medium pores; common, fine roots; clear and smooth transition to:
B_{21t}	16 - 38 cm.	Dark red ($2.5YR^3/6$ dry, $2.5YR^3/6$ moist), clay; moderate, coarse prismatic structure breaking to strong, medium angular blocks; very hard when dry, firm when moist, very sticky and plastic when wet; few, moderate, clay cutans; few, fine pores, few, medium and coarse pores; common, fine roots; gradual and smooth transition to:
B_{22t}	38 - 102 cm.	Dark red ($2.5YR^3/6$ dry, $2.5YR^3/6$ moist), clay; moderate, coarse prismatic structure breaking to strong medium angular blocks; very hard when dry, firm when moist, very sticky and very plastic when wet; abundant, strong clay cutans; few, fine pores; few, fine roots; some weatherable minerals; clear and wavy transition to:
BC_t	102 - 124 cm.	Dark red ($2.5YR^3/6$ dry, $2.5YR^3/6$ moist), clay; weak, coarse prismatic structure breaking to weak medium angular blocks; hard when dry, firm when moist, very sticky and very plastic when wet; few, weak/thin clay cutans; few fine pores; very few fine roots; many flakes of mica and amphiboles; abrupt and wavy transition to:
C	124 - 138+cm.	Weathering bedrock rich in ferromagnesian minerals.

Soil Classification

Diagnostic horizons: 0 - 16 cm Ochric epipedon
16 - 102 cm Argillic horizon

F.A.O. (1970,1973): Chromic Luvisol

U.S.D.A. (1970) : Udic Rhodustalf

Analytical Data

Profile No.: 163/4-16*

Laboratory number/74	8688	8689	8690	8691	8692
Horizon	Ap	B_{21t}	B_{22t}	BC_t	Composite sample
Depth in cm.	0-16	16-38	38-102	102-124	
Texture (hydrometer) class	SC	C	C	C	
Sand %	52	48	40	48	
Silt %	8	4	10	8	
Clay %	40	48	50	44	
pH-H_2O (1:1 susp.)	6.3	6.1	6.1	7.0	
pH-KCl (1:1 susp.)	5.7	5.2	5.2	6.8	
EC(1:1 susp.) in mmho's/cm.	0.22	0.20	0.26	0.52	
C %	0.71	0.48	0.30	0.27	
N %	0.10				
Cation Exchange capacity m.e. %	15.2	16.6	16.1	15.5	
Exchangeable Ca m.e. %	6.8	7.8	6.4	7.8	
" Mg "	2.3	3.4	5.1	5.2	
" K "	0.9	0.34	0.12	0.41	
" Na "	0.3	0.2	0.4	0.3	
Sum of Base	10.3	11.7	12.0	13.7	
Base saturation %	67	70	75	88	
E.S.P.	<5	<5	<5	<5	
Hp m.e. %					0
Available Ca m.e. %					7.0
" Mg "					1.8
" K "					0.58
" Na "					0.03
" Mn "					0.78
" P ppm					37

Only strong N deficiency.

Mapping unit BFr1 — Observation site 163/1-18*

Geological formation	:	Basement complex
Local petrography	:	Basement System rocks rich in ferromagnesian minerals
Physiography	:	Uplands
Relief, macro	:	Undulating
Relief, meso	:	A few termite mounds
Vegetation/Land use	:	Bushland/Grazing
Erosion	:	Severe sheet erosion
Rock outcrops	:	Nil
Overwash/Overblow	:	Slight, coarse sand on surface
Flooding	:	Nil
Surface stoniness	:	Nil
Surface runoff	:	Moderately rapid
General ground water level	:	Very deep
Slope gradient	:	6%, lower middle slope
Salinity/alkalinity	:	Nil
Human influences	:	Wood cutting, overgrazing
Surface sealing	:	Moderately strong
Internal drainage class	:	Well drained
Effective soil depth	:	Very deep > 120 cm.
Perched ground water level	:	Nil

Description of profile

A_1	0 - 18 cm.	Dark reddish brown ($2.5YR^4/4$ dry, $2.5YR^3/4$ moist), sandy clay; moderate fine and medium subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many, very fine and fine pores, few medium pores; many, fine and medium roots; clear and smooth transition to:
AB	18 - 35 cm.	Dusky red ($2.5YR^3/4$ dry, $10R^3/4$ moist), clay; moderate, fine and medium subangular blocky structure; slightly hard when dry, friable to very friable when moist, slightly sticky and plastic when wet; many very fine pores, common, fine and medium pores; many fine and medium roots; gradual and smooth transition to:
B_{21}	35 - 105 cm.	Dark red ($2.5YR^4/6$ dry, $2.5YR^3/6$ moist), clay; porous massive breaking to some weak, very fine and fine subangular blocks; slightly hard when dry, friable to very friable when moist, slightly sticky and plastic when wet; many, very fine and fine pores, few, medium pores; many fine roots; diffuse and smooth transition to:
B_{22}	105 - 160+cm.	Dark red ($2.5YR^4/8$ dry, $2.5YR^3/6$ moist), clay; porous massive breaking to some weak, very fine and fine subangular blocks; slightly hard when dry, friable to very friable when moist, slightly sticky and plastic when wet; many, very fine and fine pores; many fine roots.

Soil Classification

Diagnostic horizons: 0 - 35 cm Ochric epipedon
35 - 105 cm Oxic horizon

F.A.O. (1970,1973): Rhodic Ferralsol

U.S.D.A. (1970) : Tropeptic Haplustox

Note

From 35 - 160 cm, there is sufficient clay difference for an argillic horizon but no clay skins were observed in the field. However, from the analytical data of some other profiles in the same mapping units, there is a possibility of the soils falling into the Paleustalfs (U.S.D.A., 1970) or to Dystric Nitosols (F.A.O.) but there is no sufficient data to confirm this.

Analytical Data

Profile No.: 163/1-18*

Laboratory number/74	8698	8699	8700	8701
Horizon	A_1	AB	B_{21}	B_{22}
Depth in cm.	0-18	18-35	35-105	105-160+
Texture (hydrometer) class	C	C	C	C
Sand %	44	40	34	34
Silt %	10	8	6	6
Clay %	46	52	60	60
pH-H_2O (1:1 susp.)	5.2	4.6	4.5	4.8
pH-KCl (1:1 susp.)	5.1	4.2	4.3	4.0
EC(1:1 susp.) in mmho's/cm.	0.30	0.13	0.06	0.06
C %	0.89	0.47	0.39	0.15
N %	0.11			
Cation Exchange capacity m.e. %	7.6	8.2	9.6	10.0
Exchangeable Ca m.e. %	2.4	1.7	1.9	1.6
" Mg "	1.8	1.4	1.4	1.8
" K "	0.6	0.4	0.2	0.2
" Na "	0.2	0.1	0.3	0.2
Sum of Base	5.0	3.6	3.6	3.8
Base saturation %	66	44	38	38
E.S.P.				
Hp m.e. %	0			
Available Ca m.e. %	2.8			
" Mg "	2.4			
" K "	0.78			
" Na "	0.03			
" Mn "	0.76			
" P ppm	14			

Strong N, moderate P deficiency.

APPENDIX C DETAILED SOIL MAP OF KAMPI YA MAWE AGRICULTURAL EXPERIMEITAL SUBSTATION

LEGEND

BU soils developed on undifferentiated Basement System rocks; predominantly banded gneisses

(Mumbuni Series)
- BUr1 well drained, deep to very deep, dark red to red, friable clay

(Muvau Series)
- BUr2 well drained, deep to very deep, dark reddish brown to dark red, very friable, sandy clay to clay with topsoil of sandy loam to loamy sand

(Malibani Series)
- BUb well drained, deep to very deep, yellowish red to (dark) reddish brown, friable clay to fine sandy clay

(Malibani Series, moderately deep phase)
- BUbm like BUb, but moderately deep over petroplinthite (murram)/rock

(Ngosini Series)
- BUbc1 well drained, very deep, dark reddish brown to reddish brown, firm (compact) clay

(Mwaani Series)
- BUbc2m well drained, moderately deep over petroplinthite (murram)/rock, dark reddish brown, friable to firm, sandy clay loam with topsoil of loamy sand

(Mwaani Series, shallow phase)
- BUbc2P like BUbc2m, but shallow over petroplinthite (murram)/rock

BQ soils developed on quartz rich Basement System rocks; predominantly granitoid gneisses

(Kampi ya Mawe Series)
- BQ1 well drained, deep, dark yellowish brown, loose, coarse loamy sand

(Kampi ya Mawe Series, moderately deep phase)
- BQ1m like BQ1, but moderately deep over petroplinthite (murram)/rock

(Kampi ya Mawe Series, shallow phase)
- BQ1P like BQ1, but shallow over rock

C complexes
- C1 mostly well drained, very shallow to shallow, (very) dark greyish brown, loose to friable, stony, dominantly loamy sand with scattered rock outcrops
- C2 rock outcrops and some very shallow rocky and stony, dark red, loose to friable, loamy sand to sandy loam soil

The names between parenthesis reflect the scientific soil classification according to the FAO/UNESCO legend for their "Soil Map of the World" programme; prefixes marked with * are tentative terms, awaiting international agreement on nomenclature for intergrading soil units.

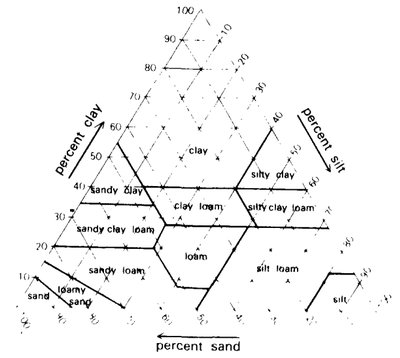
KEY TO SLOPE CLASSES

slope %	slope class symbol
0-2	A
2-3.5	B+
3.5-5	B++
	B

KEY TO DEPTH CLASSES

thickness soil in cm	symbol: over rock	symbol: over petroplinthite	name
0-25			very shallow
25-50	P		shallow
50-80		m	moderately deep
80-120			deep
more than 120			very deep

TEXTURAL CLASSES



KEY

- fence
- road
- boundary of experimental station
- contour line (altitude in feet relative to bench mark)
- narrow bench terrace
- building
- water tank
- bench mark
- soil boundary
- slope class boundary
- BUbm ..... soil mapping symbol
- BUbm ..... depth class symbol
- B+ ..... slope class symbol

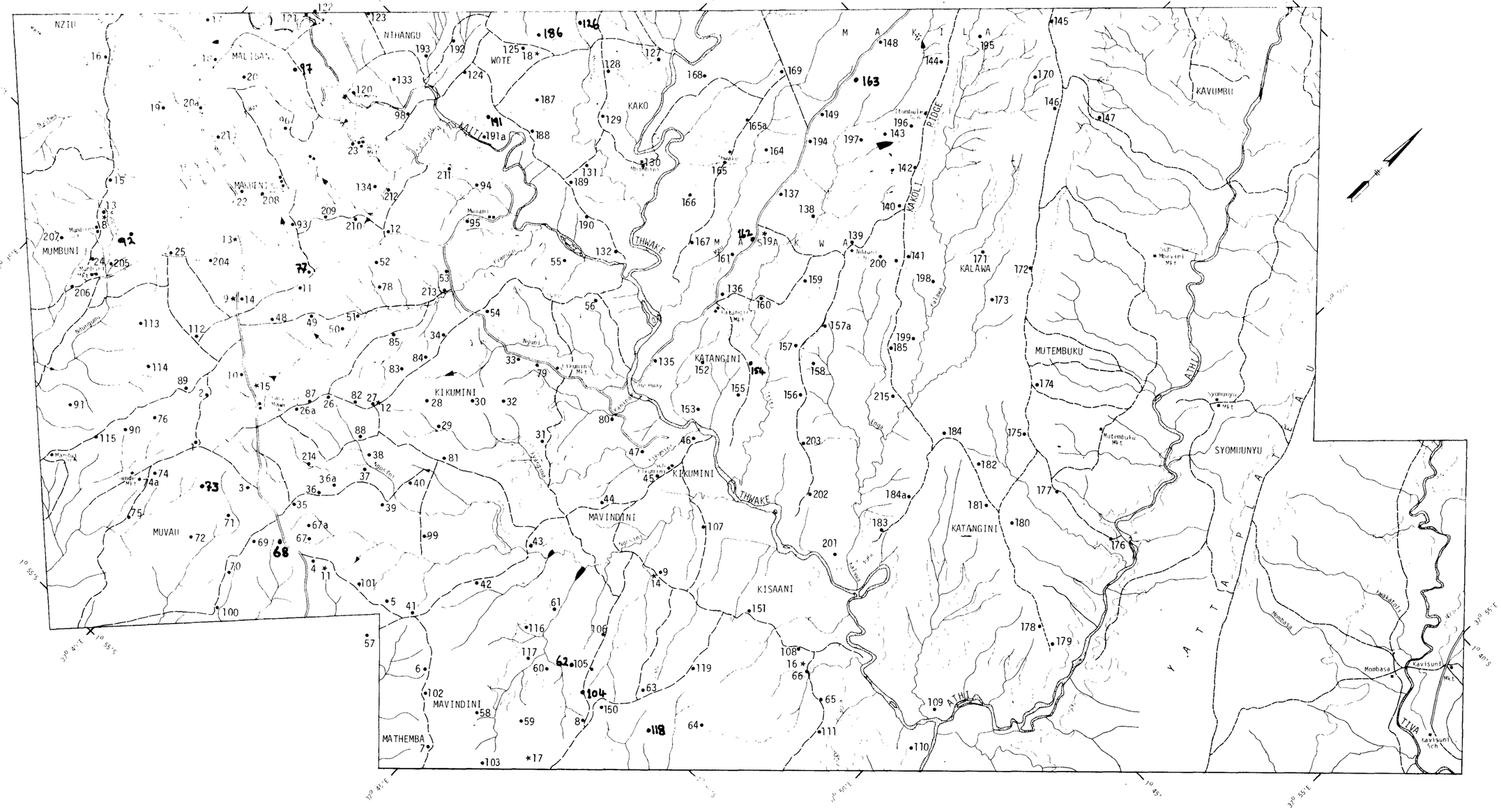
4cm² = 1/4 ha

Prepared by Kenya Soil Survey
Surveyed by J.N. Muchena Sept. 1974
Drawing No 74014

APPENDIX G

LOCATION OF PROFILE PITS AND AUGERINGS

Reconnaissance soil map of part of the Makueni area



*11 profile pits with number
•58 augering with number

SCALE 1:100,000

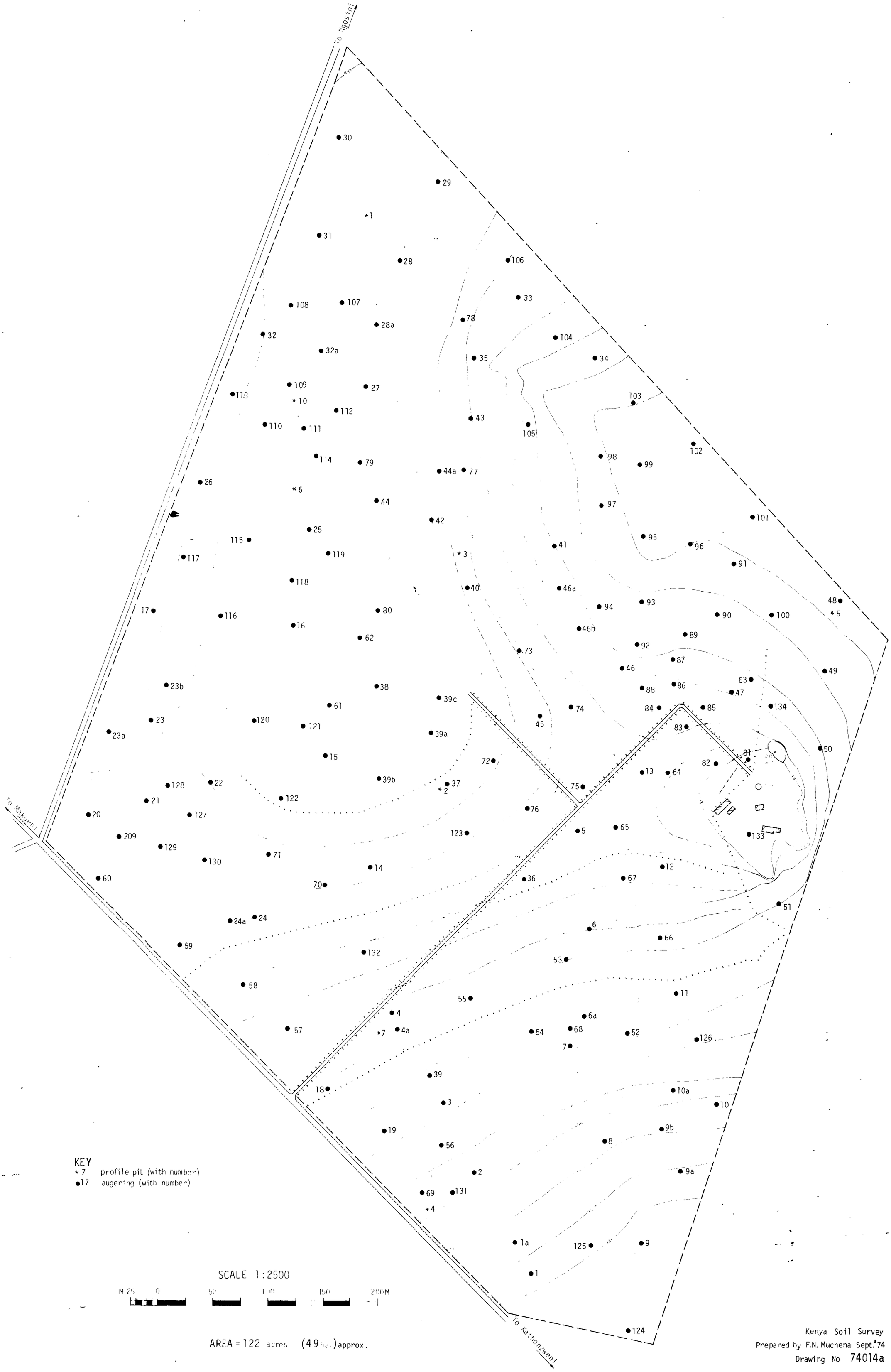
m 1000 0 1 2 3 4 5 6 7Km

KEY

- all weather road
- track
- river
- dam
- market
- school
- contours in feet

Drawn by Kenya Soil Survey
Surveyed by F.N. Muchena in Sept.-Oct. 1974
Drawing No 74015c

APPENDIX H LOCATION OF PROFILE PITS AND AUGERINGS "KAMPI YA MAWE SUBSTATION"



Kenya Soil Survey
Prepared by F.N. Muchena Sept. '74
Drawing No 74014a