A SURVEY of SOILS in the KONGWA & NACHINGWEA DISTRICTS of TANGANYIKA

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B. ANDERSON

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by B. Anderson, M.Sc. (Reading)

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INTRODUCTION

The surveys presented in this memoir were carried out for the Overseas Food Corporation, during the period 1950 to 1954, in two districts of Tanganyika in order to provide basic information on the soils of the Corporation's leased land and thus contribute to the development of an economic agricultural system. Originally the Overseas Food Corporation was the outcome of the British Government White Paper " A Plan for the Mechanised Production of Groundnuts in East and Central Africa." H.M.S.O. (1947) and one of the terms of reference of the project was that it should operate in uninhabited or sparsely populated territory. The present study deals with the soils of two of the three areas chosen for development; the first at Kongwa in Central Province where the mean annual rainfall is only about 20 inches and the second at Nachingwea in Southern Province where the rainfall is about 35 inches but where through tsetsefly and other factors the native population was very sparse.

Concerning the Kongwa site, which lies within the tribal territory of Ugogo, Milne had written in 1947 " Ugogo offers an exceptional field for a kind of investigation that is much needed, namely an experimental semi-intensive soil and vegetation survey of a sample semi-arid area." From the first it was clear that a complete detailed survey of all the Corporation's lease would take an unreasonably long time with the limited resources available and therefore it was decided to start with a fairly detailed survey of sample areas. The total area initially scheduled for cropping was about 90 square miles and this was divided into three units on the first of which was sited the Experimental Farm. The field work of surveying and sampling two adjoining portions of this Unit 1, covering an area of about 16 square miles, was completed in 1951, but, owing to drastic changes in the staffing and cropping policy of the corporation about this time, no further survey in the area was undertaken at Kongwa and attention was diverted to the soils of the second site at Nachingwea. Here, too, the selection of sample areas appeared to be the best procedure and three such areas were surveyed in 1952 and 1953 covering about 20 square miles.

Because of lack of laboratory facilities during the first few months of work at Nachingwea the analysis of the profile samples could not have been completed without considerable help from the East African Agricultural and Forestry Research Organisation (E.A.A.F.R.O.) in Kenya and the author is greatly indebted to Dr. H. F. Birch and his staff for some of the data on exchangeable cations, nitrogen contents and mechanical analyses which are included in Appendix 3.

This memoir is based on a thesis for the degree of M.Sc. presented to the University of Reading in 1954 and the work of separation and analysis of the clay fractions was begun at Reading during a leave period in 1951. Subsequently the chemical and mineralogical analyses of selected clay fractions was completed by the staff of the Pedology Department at Rothamsted Experimental Station and grateful thanks are due to Dr. A. Muir and his colleagues for their help and co-operation.

The author has received the help of many others in the course of this work but he is particularly indebted to the following for their helpful criticism and suggestions:—

Mr. W. E. Calton, Government Chemist, Dar es Salaam; Mr. G. H. Gethin Jones of E.A.A.F.R.O.; the late Mr. C. F. Charter of the Gold Coast Soil Survey; and Dr. J. Tinsley of the Department of Agricultural Chemistry, University of Reading, who supervised both the thesis and production of this memoir. To Dr. P. J. Greenway and Dr. B. Verdcourt for the identification of plant specimens; and to Mr. S. Tomi and Mr. H. Mohamedi for their assistance in the work of routine analysis in the author's laboratory.

Finally it is a pleasure to acknowledge that publication of this memoir has been possible only because of the generous help from the following sources:—

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CHAPTER I

The Kongwa Site

A General Features of the District

Situation and Topography

Kongwa lies in the Central Province of Tanganyika on the northern side of the Kiboriani Mountain block, at an altitude of 3,400 feet. Kongwa township is situated on the pediment slopes of the mountain range but the area of this present study lies on a gently undulating plain about 10 miles to the north of the township. On the whole the slopes of this plain rarely exceed five per cent but there are occasional steep-sided inselbergs rising to a height of several hundred to a thousand feet above their surroundings (Figs. 3 and 4). This country is the southern end to the Masai steppe and generally similar topography prevails as far as the mountains Kilimanjaro and Meru 200 miles to the north.

The area studied was that leased by the Overseas Food Corporation (now the Tanganyika Agricultural Corporation) whose boundaries are shown in Fig. 1. Map 1 shows the soils of about 15 square miles in the north-west corner of this lease.

The westerly portion of the lease, known as Unit 1, is drained by a number of small water-courses, running only after heavy rain, which are tributaries of the Kinyasungwe River. This river flows throughout the rains but dries up soon after the beginning of the dry season. The eastern boundary of Unit 1 is roughly the limit of the Kinyasungwe basin. Further east the ground falls steeply to the Mamhumba mbuga[1] on Unit 2. This is a flat stretch of poorly drained land formed by the silting up of a former valley, probably due to earth movements. Normally there is no outlet for water reaching this mbuga except by slow underground seepage, though after heavy rain the mbuga may overflow at its southern end on to the Kongwa mbuga and eventually into the Kinyasungwe.

To the east of the Mamhumba mbuga the ground rises steadily to the Mtanana ridge in Unit 3. Then there is a more rapid fall to the Lubiri mbuga. This is another stretch of flat land but, unlike the Mamhumba mbuga, it is closed at its southern end by a ridge a few feet high so that there is no overflow. After heavy rain water drains into several slightly lower-lying sump areas from which it is gradually lost by evaporation and seepage.

Water-boring operations in the mbugas have shown that the alluvial filling of these former valleys is in places several hundred feet thick. It seems probable that at one period portions at least of these mbugas were lakes since here and there massive sheets of travertine have been noted. At present there is a water-table at a depth of 50 feet or more in the Mamhumba and Lubiri mbugas. This water is rather saline; some typical analyses are given in Table 9 (p. 20).

The Mankhunze mbuga on Unit 1, occupying the southern half of field F7 and portions of fields G6 and E8 (see map 1) differs from the other mbugas mentioned. Although the drainage

1. Mbuga—a flat, seasonally-waterlogged grassy plain, treeless or with a few scattered trees.

results in the deposition of calcium and magnesium carbonates as concretions in the profile. The result might be called a " chemical catena " of soils since the soils differ in pH value, base status and presence or absence of concretions. There is not the redistribution of the sand, silt and clay which Milne (1947) noted in the catenas at Tabora, Shinyanga and Ukiriguru and which is found at Nachingwea.

The soils at the lower end of the catena are developed on accumulations of colluvium. The term " colluvium " is used to include ungraded deposits washed off the upper slopes by vigorous but shortlived surface flow during storms. By " colluvium " is also meant the material accumulating at the foot of the slope as a result of slow downward creep of the whole mantle of soil.

The colluvium is derived from the soils of the upper part of the catena and therefore consists of material already weathered. It does not possess the fertility of alluvium deposited by a large river, which includes a high proportion of unweathered mineral particles resulting from the comminution of pebbles and sand in the higher reaches of the river. The lower catena soils at Kongwa are, however, richer than the upper soils of the same catena because of the movement downhill of calcium, magnesium and other elements.

It is to be noted that the rock weathering extends to a depth of many feet below the surface and that the soil profile develops subsequently on material which is almost completely weathered, i.e. contains only the most resistant of the rock minerals and, apart from quartz, only small quantities of these. In this respect profile development over much of tropical Africa differs from that in temperate latitudes.

B Classification and Description of the Soil Series

The soils studied at Kongwa can be grouped under four main headings:—

1. Red Earths.
2. Pallid Soils (Degraded Upland Soils).
3. Calcareous Valley Soils.
4. Soils derived, at least in part, from lakebed limestone (travertine).

The four main groups have been divided into soil series and in some cases into sub-series. The soils are described in the following sections of this memorandum. Their chief characteristics are summarised in Table 3. Typical profiles are shown diagrammatically in Fig. 7 and the variations with depth of clay, pH value, organic carbon and cation exchange capacity are shown in Fig. 8.

I. RED EARTHS

a) *With red subsoil*

The soils correspond with the Non-laterised Red Earths of Milne, Beckley, Gethin Jones, Martin, Griffith and Raymond (1936).

This red sub-series is found on well-drained sites. The upper 12 cm. or so of the profile is a dark reddish-brown or dark red sandy loam with pH between 6 and 7 and with between 1 and 2 per cent of organic matter. There is no surface organic horizon (Ao) in these, or in any other soil at either Kongwa or Nachingwea since termites or grass fires consume all dead plant material. Below the humus-darkened horizon there is an acid red sandy clay between 50 cm. and several metres in thickness. Below this clay there is a stone-line of subangular quartz fragments. Associated with the stone-line is usually some concretionary ironstone, often with manganese dioxide.

Below the stone-line and concretionary horizon there is weathered rock. This is almost completely weathered to clay, iron oxides and quartz sand and in its upper part is not very different in appearance from the red sandy clay above the stone-line. Feldspar fragments are common in this weathered rock but in half the pits dug no identifiable rock fragments were

TABLE 3. *Soil series at Kongwa*

Soil series	Colour*	Texture of surface	Texture of subsoil	Reaction	Drainage	Parent material	Topographical position	Natural vegetation
RED EARTHS								
Pauling	red to orange	sandy loam	sandy clay	acid to very acid	good to excessive	weathered gneiss	hill tops	Commiphora thicket
Chamaye	red to orange	sandy loam	sandy clay	moderately acid	good to fair	weathered gneiss	hill slopes and minor drainage lines	Commiphora thicket
PALLID SOILS								
Mtanana ..	yellow to very pale brown	loamy sand to sandy loam	sandy clay	acid to very acid	fair to poor	weathered gneiss	hill tops and hill slopes	Commiphora thicket
Drainage Channel	yellow	loamy sand to sandy loam	sandy clay	very acid	poor	weathered gneiss	drainage lines	Commiphora thicket
CALCAREOUS VALLEY SOILS								
Mankhunze ..	brown	loam or sandy loam	sandy clay	neutral	fair	colluvium or alluvium	foot of slope	grassland
Lubiri	grey	loam or sandy loam	sandy clay	alkaline	poor	colluvium or alluvium	level flats (Mbuga)	grassland
Travertine ..	reddish brown to grey	sandy loam	sandy clay	slightly acid to alkaline	good to poor	travertine* colluvium or alluvium	various	various

*Colour of subsoil, or of surface after removal of organic matter.

N.B. This table does not include Red Earths or Pallid soils with recent development of carbonate at depth.

recovered. In the remainder of the pits the rock obtained was acid gneiss, except for three in which it was a gneiss rich in hornblende tending towards Temperley's plagioclase-amphibolite. However, as mentioned in the previous section, there is little correlation between soil and rock and it is probable that the soil in any particular spot has developed on mixed material and is not necessarily related to the rock immediately underlying.

The clay is kaolinitic and there is little or no development of crumb or clod structure in the profiles. The top two or three centimetres of the soil are often fairly friable, or even loose, particularly if the surface has been protected from direct impact of rain. Below this shallow surface horizon the profile is massive with no tendency to break down into crumbs or clods. Penetration of water is probably mainly along termite and ant tunnels and old root channels; earthworms are rarely found. In the dry season widely-spaced irregular vertical cracks, 2 to 3 mm. in width, extend to depths of a metre or more and assist the penetration of the first showers of the wet season.

In most profiles there are only scattered ironstone pisolites in the concretionary horizon but in some lower-lying sites horizons of 50 to 100 cm. thickness have been seen.

(b) *With orange subsoil*

In the red soils just described the colour of the lower horizons, i.e. where the soil colour is not influenced by organic matter, is about 2·5YR in hue (Munsell notation). There are also soils very similar in general morphology but showing orange colours in the subsoil—5 or 7·5YR in hue. These occur in minor drainage lines and other depressions or, in the case of the shallow Pauling soils, where there is impervious rock fairly near the surface. They are evidently associated with somewhat moister conditions than are the red soils.

The orange colour is probably due to the free iron oxide being in a more hydrated form than in the red soils but loss by solution is possible in some of the lower-lying members of the sub-series, which grade into the leached drainage channel soils. In the drainage channel soils there is little doubt that iron has been removed.

These orange soils have been classed as a subsection of the red soils, instead of being given independent status, because they differ little from the red soils in profile characteristics. In agricultural behaviour, also, there seems little to distinguish the soils. In some cases plant growth seemed more vigorous on the orange soils, probably due to a somewhat better water supply, but no better yields have been noted by the farm managers. It is possible that the orange colours developed during a cycle of higher rainfall than the present day.

Formation of Stonelines

The concentration of the quartz stones, the gravel and the ironstone concretions into a stoneline appears to be due to the activity of the soil fauna, chiefly termites. The process has been described by Nye (1954) for soils in the Gold Coast. The weathered rock zone below the stoneline consists of mineral particles of all sizes still in situ though possibly chemically altered. Former quartz veins in the rock become bands of quartz fragments when weathered. Where this weathered material comes within range of the termites the smaller particles become liable to be carried to the surface for the building of galleries. The quartz stones and gravel and larger ironstone concretions are too large to be carried away and accumulation in the stoneline.

Classification of the Red Earths

The red soils have been divided into two series and each series divided into four sub-series. In each case two of these four sub-series are soils without carbonate in any horizon of the profile. These are the commoner forms and consist of the following four sub-series.

(1) Pauling series
  (a) red subsoil.
  (b) orange subsoil.
(2) Chamaye series
  (a) red subsoil.
  (b) orange subsoil.

The other four sub-series are similar to the above in the upper horizons but contain calcareous concretions in the lower part of the profile. These calcareous subseries are described on p. 10.

(1) *Pauling Series*

This series comprises the shallower red earths, with a stone line at a depth of about 75 cms. (Fig. 10). Stones are brought to the surface from this depth by burrowing animals and falling trees and are found scattered on the surface and throughout the profile. Pauling soils usually occupy the crests of ridges and consequently outcrops are fairly common in stretches of these soils. A typical profile of the red sub-series is described below; analytical figures are given in Tables 23 and 24*.

PROFILE 59

Kongwa, Unit 1, south of field C.7 (Map 1). On a gentle slope (ca. 2 per cent) near the top of a ridge. Altitude 3,300 feet.

0- 12 cm.	Yellowish red sandy loam (5YR 5/6, dry). Fairly hard and containing a very few sub-angular quartz stones (ca. 2 cm. diam.) and some quartz gravel. Merging into:—
12- 40 cm.	Similar but redder (2·5YR 4/8). Merging into:—
40- 95 cm.	Red sandy clay (2·5YR 5/8). More friable than previous horizon, massive. Containing quartz gravel and a little feldspar and concretionary ironstone.
At 95 cm.	Sparse stoneline of subangular quartz and concretionary ironstone.
96-105 cm.(+)	Weathered hornblende gneiss.

Drainage. Good. Roots of trees and shrubs penetrate below the stoneline.

Vegetation. *Commiphora* thicket, including:—

Commiphora spp. (mainly *C. caerulea* B. D. Burtt).
Adansonia digitata L. (Baobab).
Strophanthus eminii Asch. and Pax.

This particular profile is strongly acid in all horizons. More often the surface horizons, and sometimes the lower horizons also, are only slightly acid. Some examples are given below in Table 4. Those profiles with a strongly acid surface horizon may have suffered some surface erosion. The less acid profiles have a better exchangeable calcium status and a base saturation of about 70 per cent.

TABLE 4. *pH values, in water, for three Pauling profiles*

P64: red		P85: red		P72: orange	
Depth (cm.)	pH	Depth (cm.)	pH	Depth (cm.)	pH
0-10	5·70	0-10	5·95	0- 5	7·20
10-40	4·65	10-40	4·75	5-55	5·20
40-80	4·95	40-80	4·55	55-90	5·00
Stoneline at 80 cm.		Weathered rock at 80 cm.		Stoneline at 90 cm.	

*These Tables contain the analytical data for the sample profiles of all the series mapped at Kongwa. They are to be found in Appendix 3.

A

In the Pauling series the red variant is the common form and the orange sub-series is of very restricted occurrence. Only one profile of the orange sub-series has been examined (profile 72, Table 4, from field G. 7) and analysis did not show any significant differences between this and a typical red profile. The rather high pH in the surface horizon (7·2) is probably due to wood ash from bush clearing operations.

(2) *Chamaye Series*

The deeper red soils, with the stoneline at a depth of over one metre and without stones in the upper portion of the profile, have been named the Chamaye series. In general the stoneline lies at a depth of one to two metres but in one pit, on Unit 2, a depth of four metres was reached without finding a stoneline. The profiles with deep stonelines are found near the foot of the slope.

Stonelines occurring at depths of more than 1·5 to 2 metres are probably " buried," i.e. there has been an increase in the thickness of the overlying layer since they were formed and they are now no longer within the range of termite activity.

The Chamaye soils with a stoneline in the top metre or two of the profile are found on the upper slopes. It is probable that there is some downhill creep of the upper part of the profile but the material above the stoneline is continually being added to, by the activity of the termites, from the weathered rock zone below the stoneline.

The lower Chamaye soils, having stonelines at greater depths, are developed on a mantle of weathered rock and soil which shrouds the lower slopes of many of the hills and ridges in the district. The accumulation of this mantle is presumably due to the inadequacy of the rainfall to carry away the products of weathering from the hill or ridge in which they were formed. It is probably significant that the four-metre profile mentioned above, and a similar one not quite as deep, were both situated near the edge of a silted up valley (the Mamhumba mbuga). In the Chamaye Farm area (Map 1), which is connected with the still active Kinyasungwe river, shallow profiles of 1 to 2 metres to the stoneline were the rule.

It is not clear whether these mantles are built up by slow creep down the slope of all the material above the weathering rock (somewhat like an ice-sheet) or whether they are built up by successive surface depositions of material eroded from the higher lying soils. They show no sign of stratification, as do some red soils of the alluvial fans developed around the Kiboriani range by sudden spates coming from the mountains. But if the process of deposition has been slow the activity of soil fauna will have mixed each successive deposit with the underlying soil and will have obliterated any stratification.

(a) *Red sub-series*

Two representative profiles of the red sub-series are described below. Profile 47 is a relatively shallow profile fairly high up on the slope; profile 2 is a deeper profile from a lower position in the catena.

PROFILE 2

Kongwa, southern boundary of Unit 1. In a shallow drainage line in gently undulating country, slope about 2 per cent. Altitude 3,200 feet.

0- 5 cm.	Yellowish red sandy loam (5YR 4/6, dry). Few fibrous roots; stoneless. Merging into:—
5- 10 cm.	Similar but redder (2·5YR 4/6). Merging into:—
10-155 cm.	Red sandy clay (2·5YR 4/8). Massive, hard, when dry. Harder below 60 cm. than above perhaps because of lower moisture content below. Roots throughout horizon.
155-235 cm.(+)	Red sandy clay (2·5YR 4/6) with much quartz and feldspar gravel and much pisolitic ironstone with MnO_2.

Drainage. Apparently freely drained.

Vegetation. *Commiphora* thicket, including:—

Commiphora spp. (mainly *C. caerulea* B. D. Burtt).
Adansonia digitata L. (Baobab).
Grewia similis K. Sch.
Croton menyhartii Pax and *C. scheffleri* Pax.
Bauhinia fassoglensis Kotschy.

PROFILE 47

Kongwa, Unit 1, south-east of Experimental Farm. On upper slopes of ridge; slope 3 to 4 per cent. Altitude 3,400 feet.

0- 12 cm.	Red sandy loam (2·5YR 4/6, dry). Weak, fine subangular blocky structure, with many pores. Slightly hard (dry). Stoneless. Gradual transition to:—
12- 35 cm.	Red sandy loam (2·5YR 4/8, dry). Massive but with many pores. Slightly hard consistence (dry). Stoneless. Gradual transition to:—
35-120 cm.	Red sandy loam (2·5YR 4/8, dry). Soft, friable consistence (dry) becoming slightly harder below 100 cm. Pores decreasing with increasing depth. Some quartz gravel. Clearly defined from:—
120-135 cm.(+)	Red sandy loam (2·5YR 4/8, dry) with about 20 per cent dark red mottling. Much quartz and feldspar gravel; a few subangular quartz stones up to 5 cm. across in upper part of horizon. Hard (dry). Structure of rock (hornblende gneiss) visible in lower part of horizon.

Drainage. Good.

Vegetation. *Commiphora* thicket with a sparse ground flora of annual grasses and herbs. Roots reach to bottom of pit (135 cm.) but there are very few fibrous roots in any horizon.

Typical of Chamaye soils is the decrease in pH from a value a little below 7 at the surface to a minimum of about 5 at 50 cm. depth and a subsequent increase at greater depths. There is also a characteristic rise in clay content from about 20 per cent at the surface to 30 or 40 per cent at about 50 cm. depth. In many profiles, including the two described, routine mechanical analysis figures suggest a diminution in clay at greater depths but this is believed to be due to incomplete dispersion of the clay fraction. In profile 2, for example, the diminution in clay is accompanied by a rise in silt and fine sand and the appearance of fine iron oxide concretions (pseudo-sand) in the fine sand fraction. It appears that some of the clay of the lower horizon has been aggregated by secondary iron oxide. In profile 47, also, there is a rise in silt and fine sand in the lower horizons. In this profile it was found that separation of the silt and clay by repeated sedimentation, after addition to the suspension of a few drops of dilute NaOH, eventually gave higher figures for the clay than did the pipette method with only a single dispersion. After many repeated stirrings and sedimentations (40 to 50 for the lowest horizon) the following figures were obtained:—

Horizon	*Silt, %*	*Clay, %*
0- 10 cm.	2·1	22·4
45- 55 cm.	2·3	44·2
105-115 cm.	7·8	40·2

The figures are for a fresh sampling of the profile 47 and are not strictly comparable with those given in Table 23. They do indicate, however, that there is no appreciable reduction in clay content in the lower horizons of the profile. The fact that there is no reduction in base exchange capacity in the lower horizon (Table 24) supports this view.

The greater development of concretionary ironstone in profile 2 is typical of the lower-lying Chamaye soils. The 32·8 per cent " stones and gravel " of the lowest horizon of this profile was predominantly " pea ironstone." In profile 47, on the other hand, the 49·7 per cent " stones and gravel " in the horizon 140-150 cm. was almost entirely quartz, feldspar and weathered gneiss.

In one profile of this series, lying a short distance up the slope from a calcareous valley soil, no stones or concretions were met with but from 230 cm. depth to 285 cm. (bottom of pit) there was a massive layer of cemented sandy clay. The cementing agent was probably iron oxide precipitated at the high pH (7·4) existing at this depth. Fig. 6 shows what appears to be a similar cemented horizon overlying concretionary limestone in a valley to the south of Kongwa. In this case severe erosion has removed everything above the cemented horizon.

In general the Chamaye soils have a higher exchangeable calcium content and a more saturated exchangeable base complex than the Pauling soils. The Chamaye soils also appear to have a better water supply, as is to be expected from their lower position in the catena. Average values for pH, exchangeable cations and available phosphorus for a number of Chamaye red soils are given below in Table 5. The samples were of the uppermost horizon of the profile, usually the top 6 inches (15 cm.).

TABLE 5. *Chamaye red sandy loams. Mean values for topsoil samples*

Origin	No. of Samples	pH (water)	Exch. cations m.e./100 g.			Available P mg./100 g.
			Ca.	Mg.	K.	
Chamaye Farm	9	6·8	5·4	2·3	1·1	0·12
Other parts of Unit 1 ..	3	5·9	3·4	1·7	1·1	0·44
Unit 2	5	5·7	4·7	2·3	1·3	0·32

(b) *Orange sub-series*

In minor valleys and drainage lines the red Chamaye soil is frequently replaced by the orange sub-series. A typical profile is described below:

PROFILE 63

Kongwa, Unit 1, field C7. In a shallow drainage line; slope about 1½ per cent. Altitude 3,300 feet.

0- 10 cm.	Light yellowish brown sandy loam (10YR 6/4). Top 5 cm. loose, hard below. Plough layer.
10- 40 cm.	Reddish yellow sandy loam (7·5YR 6/6). Massive and very hard. Stoneless. Merging into:—
40-150 cm.	Reddish yellow sandy clay (7·5YR 6/8). Massive but becoming progressively less hard with increasing depth. A few soft ironstone concretions in the bottom 20 cm.
150-185 cm.(+)	Similar, but with many soft, irregular ironstone concretions.

Drainage. Apparently well drained; receives water from higher ground. Most roots in first 100 cm. but some deeper (relics of original thicket vegetation).

Vegetation. Cleared from *Commiphora* thicket three years previously and cropped twice since.

At the red end of the scale these soils merge with the red sub-series of the Chamaye soils; at the yellow end they merge with the leached Drainage Channel soils. The lower horizons of the profile just described are strongly acid, suggesting affinities with the Drainage Channel soils, but other profiles are less acid.

RED AND ORANGE SOILS WITH CONCRETIONARY LIMESTONE

In the area mapped there are frequent occurrences of soils in which the upper horizons are typical of the Pauling or Chamaye series but the lower horizons, at a depth of one to two metres, contain concretionary calcium carbonate. Similar concretionary carbonate is sometimes found in lower horizons of the normally strongly acid Mtanana and Drainage Channel soils.

There are two types of these profiles. In the valley occupying the centre of Chamaye Farm there are in places thick sheets of travertine, sometimes buried to a depth of several feet and sometimes exposed at the surface. They are probably lake-bed deposits; the lake has been drained either by earth movements or by the cutting back of a tributary of the Kinyasungwe river. One type of these profiles with concretionary limestone has arisen by the movement downhill of a soil profile formed under leaching conditions above the former shoreline. The profile described below is of this type since at the bottom of the profile there is now a layer of rock fragments overlying the limestone.

PROFILE 78

Kongwa, Unit 1, field E6. On a hillside at a slope of about 2 per cent. Altitude 3,350 feet.

0- 10 cm.	Reddish brown sandy loam (5YR 4/4, dry), friable, stoneless. Plough layer.
10-125 cm.	Red sandy clay (2·5YR 4/6), massive, very hard from 10 to 25 cm., less hard below. Stoneless.
125-135 cm.	Angular fragments of acid gneiss, with some red sandy clay.
135-145 cm.(+)	Blocks of concretionary limestone (travertine), 20 to 25 cm. across.

Drainage. Well drained.

Vegetation. Cleared from *Commiphora* thicket three years previously and cropped twice since.

The pH figures show the sharp change at 125 cm. The exchangeable calcium in the profile as a whole is slightly higher than usual for a Chamaye soil due to cycling of the calcium by plants and insects.

In the second type of these acid profiles with concretionary limestone the limestone is in small nodular concretions and has evidently formed in situ. This type is much commoner than the one represented by profile 78 and always occurs in drainage lines. An example is described below; in this case the upper profile is an orange Chamaye soil but similar profiles occur with a red soil overlying the calcareous layer.

PROFILE 81

Kongwa, Unit 1, field E7. Near the bottom of a minor valley; slope slight. Altitude 3,300 feet.

0- 12 cm.	Brown sandy loam (10YR 4/3, dry). Moderately hard, stoneless. Merging into:—
12- 25 cm.	Dark brown sandy loam (7·5YR 4/4). Slightly harder than horizon above. Massive, stoneless.
25-165 cm.	Yellowish red sandy clay (5YR 4/8) of similar hardness to previous horizon, grading to strong brown (7·5YR 5/8) at bottom of horizon.
165-190 cm.	Strong brown clayey sand (7·5YR 5/8) with a few earthy ironstone concretions and a little quartz gravel. MnO_2 present. Sharply defined from:—
190-195 cm.(+).	Nodular limestone (nodules ca. 6 cm. diameter).

Drainage. Possibly temporarily water-logged in lower horizons during the rains.

Vegetation, Commiphora thicket, including:—

Commiphora caerulea (B. D. Burtt).
Cassia abbreviata Oliv.
Acacia spirocarpa Hochst. ex A. Rich.
Albizzia anthelmintica (A. Rich) A. Brongn.

It is possible that the limestone in this profile could have arisen by solution of some of the lake-bed limestone higher up the slope and its redeposition lower down, following the draining of the former lake. Similar profiles were found, however, in the southern portion of the map, e.g. field C7, well away from any lake-bed limestone. The most likely explanation of such profiles seems to be that an acid profile was formed first, under a higher rainfall, and that more recently there has been a reduction in the rainfall and the calcium leached from the soils on the higher ground is no longer being carried beyond the nearest drainage line. In two of these calcareous profiles, profile 74 in field F6 and profile 76 in field E7 (the latter a calcareous Mtanana profile) the carbonate occurred in small concretions within a horizon of concretionary ironstone. It is difficult to imagine a soil solution which could precipitate limestone and iron oxide simultaneously. Also, if the limestone had been precipitated first the evidence of other profiles suggests that the iron would have been precipitated in the horizon above the limestone. It seems probable that the iron was precipitated while the reaction in the horizon was still on the acid side of neutral and that subsequently the horizon became alkaline, with precipitation of calcium carbonate.

The presence of a calcareous horizon in an otherwise acid profile can usually be recognised in the field by the presence of carbonate fragments in the rings of subsoil material deposited by ants around the entrance to their colony. This carbonate will help to raise the calcium status of the whole profile. In the four profiles which have been analysed the exchangeable calcium is rather higher than usual for the normal acid form of the same series.

In these profiles there is often a slight accumulation of soluble salts, shown by a rise in conductivity, in the calcareous horizon. Most of this is probably bicarbonate since a water extract of the calcareous horizon of profile 78 showed only 0·002 per cent of sulphate and a trace of chloride.

Hardpans

When dry, the Pauling and Chamaye soils display a hard, massive structure, with only slight cracking, at all levels in the profile except sometimes the top few centimetres. In some sites the horizon extending from about 10 to 25 cm. below the surface is particularly hard. When such a horizon is broken up by ploughing the clods brought to the surface are very resistant to breakdown by raindrop impact.

Profile 78, described on p. 11, possessed such a hardpan. Analysis disclosed no significant differences between the hardpan horizon (10-25 cm.) and the underlying softer material (25-45 cm.) (see Tables 23 and 24). On the cleared land the hardpan may have been produced, at least in part, by the passage of land-clearing and agricultural machinery. This cannot be a complete explanation since a few profiles in the undisturbed bush showed what appeared to be a similar horizon.

The legend " shallow hardpan " on the soil map indicates where such a horizon was noted.

Clay Minerals in the Red Earths

Kaolinite has been shown to be the clay mineral in two Chamaye soils of the red sub-series (Muir, Anderson and Stephen—1957). Goethite and haematite were associated with the clay. Extraction of the clay fraction of profile 2 with hydrosulphite according to the method of Deb (1950) removed 6 per cent of Fe_2O_3 and 1·5 per cent of Al_2O_3.

Figures for the chemical composition of the clay for three horizons of profile 47 are given in Appendix I.

No examinations of the clay of an orange sub-series Chamaye soil or of a Pauling soil have been made but there is little doubt that in these also the clay is kaolinite.

Natural Vegetation on the Red Earths

Before clearing, the Pauling and Chamaye soils in the area surveyed carried an almost continuous blanket of *Commiphora* thicket interrupted only by game trails, footpaths and a small native clearing in field E7. The main species of *Commiphora* on these soils are:—

Commiphora caerulea B. D. Burtt and
C. hornbyi B. D. Burtt.

Associated with the Commiphora species were baobabs (density about 2 per acre on Unit 1), candelabra trees (*Euphorbia bilocularis* N.E. Br.), *Albizzia anthelmintica* A. Brongn., *Cassia abbreviata* Oliv. and, in drainage lines, *Acacia spirocarpa* Hochst. Besides these larger trees there were a large number of shrubs. The following are some of the commoner species:—

Bauhinia fassoglensis Kotschy.
Combretum longispicatum Engl. and Diels
Croton menyhartii Pax.
C. polytrichus Pax.
Grewia similis K. Schum and other spp.
Lantana sp.
Strophanthus eminii Asch. & Pax.

The close canopy produced by the thicket prevents the development of much of a ground flora. The most conspicuous herbaceous plants are the climbers, many of them species of *Ipomoea. Hibiscus mastersianus* Hiern. often comes up in dense stands after clearing the thicket and must therefore have been widespread before clearing even if never very noticeable in the bush.

Along the western edge of the Mamhumba mbuga the grassland of the mbuga extended several hundred yards up the slope on to soils of Chamaye series. This was almost certainly the result of grass fires spreading from the mbugas aided by the prevailing east winds of the dry season. On the eastern edge of this mbuga the thicket came right down to the edge of the calcareous soils of the level floor of the mbuga.

Fertility of the Red Earths

On the Pauling soils yields of agricultural crops have usually been poor, even with the help of fertilisers. It seems that these soils are too freely drained for good crop growth under the existing rainfall. Frequent rock outcrops and boulders make many stretches of Pauling soils unsuitable for mechanical cultivation.

The Chamaye soils are more useful and in years of favourable rainfall have given good yields of maize, sorghum and groundnuts without the use of fertilisers. In fertiliser experiments responses to superphosphate have usually been obtained but the increase has rarely been economic. A summary of the experiments has been given by Le Mare (1953). In spite of the low values for phosphorus extracted both by 0·3N HCl and 1 per cent citric acid the Chamaye soils do not appear to be very deficient in this nutrient, at any rate in the first few years after clearing.

The carbon/nitrogen ratio of the Kongwa Red Earths is usually about 11. The decomposition of the organic matter appears to produce enough nitrogen for normal crops of maize, sorghum and sunflower and responses to sulphate of ammonia have been slight. This is in strong contrast to the experience at Nachingwea where the Red Earths have a much higher carbon/nitrogen ration and yields of maize and sorghum are poor without additional nitrogen.

The calcium status of the soils is adequate for the crops tried and no responses were obtained to lime.

The main obstacle to successful arable farming at Kongwa has been the frequency with which the rain has been inadequate or badly distributed in the season. Yields are small if the seasonal rainfall is much below 20 inches. Most of the land cleared is now used for the ranching of cattle. Fig. 13 is a photograph of a sorghum crop on Chamaye Farm taken before arable cropping was discontinued.

Other Red Earths in the vicinity of Kongwa

The Red Earths of the southern Masai steppe, an area which includes Kongwa, were divided by Milne (1947) into two classes. The first contained soils which have remained in place or have been subjected only to gradual colluvial shift; this class corresponds to the Pauling and Chamaye series. The second class contained soils in which the original red earth material has been transported to lower ground by violent denudation.

This second kind of Red Earth profile occurs in alluvial fans at many places around the Kiboriani range. These fans develop where small intermittent streams arising in the range reach the pediment slopes of the range and lose velocity. Stratified deposits of various composition are formed and many of these consist of red sandy clay eroded from the slopes of the hills. The profile often contains layers of sandy or gravelly material. Some of these red fansoils have calcareous concretions in the lower part of the profile. These probably arise from the evaporation of calcium-rich waters draining off the hills. Calcareous deposits are frequently to be seen around springs in the hills, e.g. at Kongwa maji behind Kongwa township. None of these stratified profiles has been seen within the area of the Corporation's lease.

II. PALLID SOILS

The Red Earths have been described as occupying the crests and slopes of undulations and small hills. Frequently, however, at a site where a Red Earth might be expected there is found a grey, yellow or pale brown soil with a marked horizon of iron concretions. These soils are frequently known in Central and East Africa as Plateau Soils, a term which appears to have been first used by Milne *et al.* (1936) with a rather wide significance. Similar Plateau Soils from southern Tanganyika have been described in the Report on the Central African Rail Link Development Survey (1952) as low humic yellow latosols and low humic reddish yellow latosols. Plateau Soils in Uganda were considered to be Degraded Red Earths by Griffith (1948).

The common characteristics of these soils are:—

(1) a fairly sandy texture.
(2) a pallid appearance—yellow or very pale brown in the subsoil.
(3) concretionary ironstone prominent in the subsoil.
(4) low fertility arising from a severely leached profile.

Classification of the Pallid Soils

Two series of these Pallid soils have been distinguished in the present survey.

(i) Mtanana series

This is the soil just mentioned which is found on the crests and slopes of gentle undulations.

(ii) Drainage Channel series

This is a soil occurring in minor drainage lines in similar situations to the orange sub-series of the Chamaye soil.

Each of these series is divided into a normal form without calcareous concretions and a less common form with calcareous concretions in the lower part of the profile.

(1) *Mtanana series*

This is much the commonest of the two series of Pallid soils in the Kongwa district. Two profiles are described below. Profile 3, from the eastern boundary of Unit 1, has a somewhat better base status than many Mtanana soils; profile 39, from a site to the east of Unit 3, is an example of the particularly acid soils. Profiles from outside the area covered by the soil map have been chosen because the Mtanana profiles within the area proved to have a rather better base status than is usual for this series. This is probably because the areas of this soil included in the map are small and are influenced by the general high base status of the surrounding soils.

Profile 3

Kongwa, on eastern boundary of Unit 1, 1¼ miles from southern boundary. Near the summit of a ridge; slope about 1 per cent. Altitude 3,600 feet.

0- 15 cm.	Brown very sandy loam (7·5YR 5/5, dry). Single grain structure, soft consistence. Many pores. Gradual transition to:—
15- 30 cm.	Reddish-yellow sandy loam (7·5YR 6/6, dry), with much quartz gravel and a few ironstone concretions. Structure massive but with some pores; slightly hard consistence.
30- 50 cm.	Similar, but colour becoming 5YR 6/8. Abrupt lower boundary.
50- 85 cm.	Gravel and concretionary horizon. Above 70 cm. mainly quartz gravel with numerous subangular quartz stones up to 12 cm. across; below 70 cm. concretionary ironstone predominates. The gravel and concretions are set in a yellowish-red sandy loam (5YR 5/8, dry), massive and compact; consistence slightly hard. Below 60 cm. about 10 per cent medium-sized red mottles. Gradual transition to:—
85-110 cm.(+)	Weathering pegmatite. Yellowish-red (5YR 5/8, dry) with much red-brown coarse mottling (2·5YR 4/4) and whitish weathering feldspar. Much soft concretionary ironstone. The whole is massive, compact and hard.

Drainage. Probably impeded in lower horizons.

Vegetation. *Commiphora* thicket, with sparse ground flora. There are some roots at all depths but few fibrous roots in any horizon. Baobabs (*Adansonia digitata* L.) were growing near site.

PROFILE 39

Kongwa, 2 miles east of Lubiri mbuga. Slightly sloping ground near the summit of a ridge. Altitude 4,200 feet.

0- 12 cm.	Pale brown loamy sand (10YR 6/3, dry). Fairly soft; single grain. Merging into:—
12- 50 cm.	Light yellow-brown clayey sand (10YR 6/4), with a little quartz and feldspar gravel and concretionary ironstone. Slightly hard, massive. Merging into:—
50-105 cm.	Light yellow-brown clayey sand (10YR 6/5). Rather more quartz gravel and ironstone than above. Massive, but soft.
105-150 cm.	Numerous somewhat rounded quartz stones (6 cm. diam.) and subspherical ironstone concretions (to 15 mm.) in light yellow-brown earthy material; iron-staining.
150-160 cm.(+)	Decomposed rock, with ironstone concretions, feldspar fragments, quartz grains and reddish yellow earthy material.

Drainage. Apparently freely drained.
Vegetation. *Commiphora* thicket, including:—
Commiphora spp.
Albizzia brachycalyx Oliv. (?)
Acacia pennata (L) Willd.
Croton polytrichus Pax and *C. scheffleri* Pax.

In general, the clay content of Mtanana profiles is in no horizon above 25 per cent. The concretionary horizon is well developed, lies at a depth of from 50 to 100 cm. below the surface and may consist of loose pisolites or be somewhat cemented. The underlying rock was unidentified in most profiles. There has usually been decomposition of the iron-containing minerals in the weathered rock and local redeposition as scattered earthy concretions. In two profiles the rock was recognizably an acid gneiss, in one profile a pegmatised gneiss and in a fourth profile a hornblende gneiss. Taking into account also that the distribution of Mtanana soils in an area of predominantly Chamaye soil bears no apparent relation to the prevailing east-west strike of the country rock (see Map 1) it seems unlikely that the composition of the rock is an important factor in deciding whether a Red Earth or Mtanana soil shall develop.

Mtanana soils are highly leached and pH values a short distance below the surface are often 4·5 or lower. Organic matter, exchangeable bases and available phosphorus are also usually low.

In spite of the low clay content these soils can set hard on drying, with little cracking. This is probably due to a combination of the interlocking of the angular coarse sand grains and the small shrinkage of the kaolinitic clay on drying. Because of this setting the dry soil is very abrasive to agricultural implements, though perhaps no more so than the Red Earths.

Entry of water into the profile appears to be slow, at any rate on bare or only partly covered land. This is probably due to compaction of the surface by raindrop impact since it seems unlikely that the whole profile will often be waterlogged under Kongwa conditions. Evidence of periodic waterlogging in the lower horizon of the profile is provided by the bleaching of the weathering rock and the presence of montmorillonite at this level in profile 3. This is the only profile in which the clay minerals have been determined (see p. 17).

Further, in places where the Mtanana soils are extensively developed, e.g. on the Mtanana ridge in the western part of Unit 3, there are often numerous large termite mounds. At Nachingwea raised termite mounds are characteristic of periodically waterlogged soils; in well-drained soil underground termitaria with a short chimney above the surface are found. This again points to at least occasional waterlogging of the Mtanana profiles. It is possible that the bleached rock, the montmorillonite and the termite mounds are all relics of a wetter climate in the past and that waterlogging no longer occurs, but it seems unlikely that any recent changes in the climate have been so large.

Analyses of six topsoil samples of Mtanana soils are given in Table 6. The high acidity of the samples from Units 2 and 3 is typical of the wide stretch of Mtanana soils in the eastern part of Unit 2 and the western part of Unit 3.

TABLE 6. *Analyses of Mtanana soils in the Kongwa area*
(The samples are of the top six inches of the profile)

Sample	Situation	pH	Exch. cations m.e./100 g. soil			Available P mg./100 g.
			Ca	Mg	K	
S 1494	Unit 1	5·0	1·9	1·5	0·97	0·31
1501	,,	5·9	2·0	1·6	0·64	0·30
1483	Unit 2	4·6	2·2	1·2	0·94	0·24
1491	,,	4·5	1·4	1·4	0·67	0·17
1487	Unit 3	4·4	1·0	0·7	0·85	0·23
1500	,,	4·1	1·8	1·1	0·77	0·20

MTANANA SOILS WITH CONCRETIONARY LIMESTONE

In the Chamaye Farm area there are some Mtanana soils showing secondary development of calcium carbonate in the lower horizons of the profile. They are analagous to the Red Earth profiles with carbonate. An example of these soils is described below:

PROFILE 76

Kongwa, Unit 1, field E7. In a shallow drainage line. Slope slight. Altitude 3,300 feet.

0- 10 cm.	Dark grey-brown sandy loam (2·5Y 4/2). Hard and massive. Stoneless. Merging into:—
10- 40 cm.	Light yellow-brown sandy clay (10YR 6/4). Very hard; stoneless. Merging into:—
40- 75 cm.	Very pale brown sandy clay (10YR 7/4). Somewhat less hard than horizon above. Massive; stoneless. Slight carbonate.
75-130 cm.(+)	Lightly cemented concretionary ironstone with quartz stones and a little concretionary carbonate. Very pale brown (10YR 7/4) with red mottles.

Drainage. Probably impeded in lower horizons.

Vegetation. This land had been prepared for mechanised cultivation three years previously. The very high phosphorus figures suggest that the site was an old cattle compound. There were remains of huts and pottery in the vicinity.

The calcium carbonate in the subsoil has raised the calcium status of the whole profile. The clay content of this profile is unusually high, probably because the profile is situated in a drainage line.

(2) *Drainage Channel Soils*

These soils, which have not yet been given a series name, occur in drainage lines in analagous situations to soils of the Chamaye orange sub-series. Examples appear in the soil map (Map 1). Although the mapped occurrences of this soil are in drainage lines within areas of Chamaye soil it is probable that similar soils are to be found in drainage lines in extensive areas of Mtanana soils. No such areas have, however, been surveyed in detail.

A typical profile is described below.

PROFILE 89

Kongwa, Unit 1, field E5. In the bottom of a minor valley. Slope about 1 per cent. Altitude 3,400 feet.

0- 18 cm.	Brown loamy sand (10YR 5/3, dry). Rather loose. Plough layer. Clearly defined from:—
18- 32 cm.	Light yellowish brown sandy clay (10YR 6/4), with descending tongues of the upper horizon. Hard; stoneless. Merging into:—
32-160 cm.	Brownish yellow sandy clay (10YR 6/6 to 6/4). Very hard down to 45 cm. somewhat less hard below. Stoneless.
160-180 cm.(+)	Light yellowish-brown sandy clay (10YR 6/4) with much red earthy concretionary ironstone. Some white mottles. A little quartz gravel and " shot " ironstone. Moist (at end of dry season).

Drainage. Impeded in lower horizons.

Vegetation. Cleared from *Commiphora* thicket three years previously, but allowed to go out of cultivation after one or two years cultivation. Now carrying a rather sparse flora of grass and woody herbs, including *Hibiscus mastersianus* Hiern., *Solanum delagoense* Dunal and *Tephrosia* sp.

The " stones and gravel " fraction above 160 cm. depth was mainly quartz, with some " shot " ironstone. The earthy concretions below 160 cm. were up to 15 mm. across. No stoneline was seen. This profile was still moist in its lowest horizon when the Pauling, Chamaye and Mtanana soils had completely dried out; seepage from higher levels probably continues after the end of the rains. In this profile the decrease in hardness below 45 cm. depth may have been due to increasing moisture and not to hardpan formation above this level.

The characteristics of these Drainage Channel soils are the pale colour, the considerable depth of soil above the concretionary horizon (compared with the Mtanana series) and the low pH, exchangeable calcium and organic matter content.

The ironstone in the concretionary horizon consisted of rather soft earthy concretions, i.e. with a high proportion of quartz sand and clay. The concretions had probably formed by deposition of iron oxide in situ in this horizon. The small amounts of " shot " ironstone occurring throughout the profile had probably been formed elsewhere and carried to their present position along with the remainder of the " parent material " of the profile.

These soils have been grouped with the Mtanana series owing to the general similarity in their profiles.

Clay minerals in the Pallid soils

Examination of the clay materials has only been carried out on one pallid soil (Profile 3 of the Mtanana series, described above). The results, reported by Muir, Anderson and Stephen (1957), show that in the upper part of the profile the clay is mainly halloysite, with some illite. Treatment with hydrosulphite extracted 3 per cent of Fe_2O_3 and about 1 per cent of Al_2O_3. In the weathering rock below the profile, however, there was a considerable amount of montmorillonite, suggesting that drainage is impeded above the underlying rock.

Chemical analyses of the clay fraction (less than 1 μ) for the 0-10 cm. and 30-50 cm. horizons of profile 3 are given in Appendix I. The silica/sesquioxide ratio is very near 2 for both horizons, as might be expected from the mineralogical analysis.

Natural Vegetation

The Mtanana soils support a *Commiphora* thicket differing little from that on the Red Earths. However baobabs are rarely found on Mtanana soils; this tree appears to demand a fairly high calcium status in its soil.

The Drainage Channel soils probably carried *Commiphora* thicket but all the areas of this soil examined had been completely cleared.

Fertility of the Pallid soils

A number of fertiliser experiments have been laid down on Mtanana soils. On the whole crops were poor or a complete failure, even in the presence of nitrogen, phosphate and potash. Rather better results were obtained on the Mtanana soils with a higher calcium status on Unit 1; responses on these soils were similar to those obtained on the Red Earths. Experimental work on the very acid Mtanana soils on Unit 3 (see Table 6) showed that reasonable crops of maize could be obtained by the application of lime, phosphate and nitrogen (Overseas Food Corporation, 1952) but this is an expensive procedure.

There are no records of crop yields on the Drainage Channel soils but these soils are almost certainly of low fertility.

III. CALCAREOUS VALLEY SOILS

These are soils of low-lying poorly-drained sites. Their greatest development is on the Mamhumba and Lubiri mbugas of Units 2 and 3. These mbugas occupy former valleys which have become silted up to depths of several hundred feet, probably as the result of earth movements. It seems likely that the first stage in the silting-up was the formation of a lake in the valley and that this was followed by the gradual filling of the lake with somewhat calcareous sediments. Brown and grey calcareous loams and clays have now developed on these sediments.

Similar soils are found in gently-graded valleys with rather sluggish drainage in the Chamaye area (Map 1). Here the soil appears to have developed on colluvial material very similar to the parent material of the Chamaye series soils. Although there is in places a considerable amount of residual travertine much of the parent material of these soils is non-calcareous and some of the calcium carbonate in the soils is the result of the evaporation of subsoil water with a high calcium content.

CLASSIFICATION OF CALCAREOUS VALLEY SOILS

Two series have been recognised:—

(1) Mankhunze series

Brown loams in the better-drained sites.

(2) Lubiri series

Grey loams and clays in poorer-drained sites.

(1) *Mankhunze series*

The upper horizons of the Mankhunze soils are brown to dark brown in colour, of a sandy to a heavy loam in texture and with a pH value of about 7. Small fragments of calcium carbonate, probably brought up from the lower horizons by soil fauna, may also be present. At a depth of about one metre there is a sharp transition to a concretionary carbonate horizon of considerable thickness (Fig. 11).

These soils are usually under natural grassland or open savannah woodland and perhaps for this reason the organic matter content of the top horizon is about 2 per cent, rather higher than in the upland soils. In profile 65, which is described below, the vegetation had been *Commiphora* thicket and the organic matter was only 1·4 per cent; this is about the same as for a Chamaye soil. Where the soil has been under grass there is a definite crumb structure in the uppermost horizon.

TABLE 7

Total soluble salts and water soluble chloride and sulphate for Mankhunze and Lubiri soils

Profile	Horizon (cm.)	Total solids %	Chloride (Cl) %	Sulphate (SO_4) %
65 (Mankhunze) ..	0- 12	0·09	0·0005	0·009
	12- 40	0·11	0·001	0·014
	40-100	0·08	0·001	0·002
5 (Lubiri)	15- 25	0·07	0·001	0·002
	45- 55	0·05	0·001	0·001
	65- 75	0·10	0·002	0·004
9 (Lubiri)	0- 5	0·09	nil	0·001
	10- 15	0·08	0·001	0·002
	15- 30	0·08	0·0005	0·003
	30- 50	0·07	0·001	0·002
	50- 80	0·12	0·001	0·003

The Mankhunze soils have a considerably higher base status than the Red Earths and Pallid soils. The conductivity figures show the presence of slight amounts of soluble salts in the lower horizons of the profile. Determination of sulphates and chlorides for profile 65 showed that these anions are present in very small amounts so the soluble salts are probably largely bicarbonates (Table 7).

A typical profile is described below. Some further information for a further five Mankhunze soils from Chamaye Farm is given in Table 8; the figures are for the top six inches (15 cm.) of the profile.

PROFILE 65

Kongwa Experimental Farm, near crossing of traces D and 7. In a valley bottom near an incised watercourse. Slope ca. 1 per cent. Altitude 3,300 feet.

0- 12 cm.	Dark brown loam (10YR 4/3), fairly friable. Plough layer.
12- 40 cm.	Dark brown loam (10YR 4/3). Hard when dry. A few fragments of quartz and ironstone. Merging into:—
40-100 cm.	Grey brown loam (10YR 5/2). Hard when dry. A few fragments of quartz, feldspar and ironstone.
100 cm.(+)	Concretionary limestone. Nodules about 2 cm. across.

Drainage. Fairly well-drained; roots (of former trees and shrubs) to full depth of profile.

Vegetation. *Commiphora* thicket up to three years prior to sampling. Received fertiliser (N and P) for last crop.

TABLE 8. *Analytical figures for five Mankhunze soils, surface horizon only, from Chamaye Farm*

	pH	Exch. bases m.e./100 g.			Available P. mg./100 g.	Clay %
		Ca	Mg	K		
Mean values	7·3	12·1	4·4	1·8	0·19	24
Range	6·6-8·2	9·3-14·3	2·2-6·6	1·1-2·7	0·04-0·65	14-33

(2) *Lubiri series*

The Lubiri series occupies only a small area of the soil map but is the predominant soil of the Mamhumba and Lubiri mbugas. Here the Mankhunze soils are restricted to a narrow fringe occupying the slightly higher ground round the mbuga margins.

The Lubiri soils (Fig. 12) consist of a grey loam or sandy loam, somewhat darkened by humus in the top 15 cm. or so, and passing sharply at a depth of about 50 cms. into a concretionary carbonate horizon. The upper horizons are slightly to strongly alkaline in reaction, with pH values ranging from 7 to 9, and always contain fragments of carbonate. In the concretionary layer the pH is above 8. The concretionary horizon appears to be a metre or so in thickness, at any rate on the Mamhumba mbuga. In profile 5 the concretionary horizon contains about 40 per cent $CaCO_3$. Below this are the calcareous sediments of the old lake-bed, containing about 20 per cent $CaCO_3$.

Values for soluble salts in Lubiri soils are similar to those of the Mankhunze profile 65 (see Table 7). Much higher values occur in the ground-water below these mbugas. Figures for borehole samples from the Mamhumba and Lubiri mbugas, together with some for a borehole situated a mile north of Kongwa township, are given in Table 9.

A considerable range of texture is found in the Lubiri soils. On Chamaye Farm the clay content was about 30 per cent in the lower horizons and only 10 to 15 per cent in the uppermost horizon. On the Mamhumba and Lubiri mbugas the soils are heavier. Profile 5 (see below) with 30 to 40 per cent of clay seems to be typical of a large area. Profile 9 is rather heavier, with 50 per cent of clay. In spite of this high clay content the soils are fairly friable, or even powdery, when dry. There is a little development of crumb structure due, in part at least, to the rather poor growth of grass on these soils.

TABLE 9. *Analyses of Kongwa borehole waters*

	Mamhumba *mbuga*	Lubiri *mbuga*	Kongwa *mbuga*
Alkalinity (as $CaCO_3$) ..	27·5	n.d.	n.d.
Total hardness	124·0	36·1	202·6
Carbonate (CO_3)	17·8	n.d.	n.d.
Sulphate (SO_4)	41·2	10·7	269·8
Chloride (Cl)	48·0	22·0	42·7
Calcium (Ca)	20·3	n.d.	n.d.
Magnesium (Mg)	6·7	n.d.	n.d.
Sodium (Na)	30·7	n.d.	n.d.
Silica (SiO_2)	2·5	3·7	6·3
Total dissolved solids ..	170	86·5	386

(1) All results are expressed as parts per 100,000.
(2) n.d. signifies not determined.
(3) These analyses were done by the Government Chemist, Dar-es-Salaam.

Organic matter contents are about the same as in the Mankhunze soils. The dark colour of these soils, in spite of only moderate amounts of organic matter, is probably due to the particular type of organic matter found in the presence of free carbonate. This question has been discussed by Mohr and van Baren (1954, page 424) and Singh (1954) amongst others.

Two Lubiri profiles are described below:—

PROFILE 5

Kongwa, Mamhumba mbuga, on southern boundary of Unit 2. Level ground. Altitude 3,400 feet. See Figs. 12 and 14.

0- 15 cm. Very dark grey loam (10YR 3/1, dry). A few cracks to 3 mm. wide (dry season) and a few pores. Weak, medium crumbs, slightly hard consistence when dry. Gradual transition to:—

15- 60 cm. Dark grey-brown loam (10YR 4/2, dry). A few cracks and pores but becoming more compact with depth; weak crumb at 15 cm., becoming massive with depth. Slightly hard consistence (dry). Abrupt lower boundary.

60 cm.(+) Cemented nodular calcareous concretions (10YR 8/1, white) with a little interstitial earth.

Drainage. Occasionally flooded but profile fairly permeable.

Vegetation. Short grass and scattered thorn trees, including:—

Grasses	*Thorn trees*
Aristida adscencionis L.	*Acacia spirocarpa* Hochst.
Chloris virgata Stapf	*Dichrostachys glomerata* Chiov.
C. pycnothrix Trinius	

PROFILE 9

Kongwa, southern end of the Lubiri mbuga. Level ground. Altitude 3,750 feet.

0- 30 cm. Grey loam (10YR 5/1, dry) easily powdered between the fingers. A few coarse quartz grains and fragments of carbonate. Some fibrous roots.

30- 50 cm. Grey loam (10YR 6/1). Harder than the horizon above and with increasing concretionary carbonate.

50- 80 cm. Light grey loam (10YR 7/1). Similar to preceding horizon. Sharply defined from:—

80 cm.(+) Nodular concretionary limestone.

Drainage. The profile appears to be fairly permeable.

Vegetation. Natural short grassland, with low shrubs, including:—

Grasses: *Cenchrus ciliaris* Linn.
Heteropogon contortus P. Beauv.
Themeda triandra Forsk.
Rottboelia exaltata Vahl.

Herbs: *Cyathula orthacantha* (Hochst.) C.B.Cl.
Phyllanthus amarus Sch. and Thonn.
Commicarpus plumbagineus (Cav.) Standley
Heliotropum undulatifolium Turrill
Shrubs: *Solanum delagoense* Dunal.
Croton menyhartii Pax.

Clay Minerals in the Calcareous Valley soils

The only soil from which the clay minerals have been identified is a Lubiri profile, profile 5. In this illite predominated in the clay fraction, with some accessory kaolinite. Iron and aluminium oxides removed by hydrosulphite treatment were low in amount (about one per cent).

Natural Vegetation

The calcareous valley soils normally carry short grass with scattered trees (Fig. 14). Gall acacia and *Acacia seyal* were noted on the Lubiri mbuga. *Dichrostachys glomerata* grows on some of the better-drained of the Lubiri soils and baobabs are found on some of the Mankhunze soils of the Mamhumba mbuga. Tree growth was fairly vigorous on the Mankhunze soils of the Chamaye area and in places these soils carry *Commiphora* thicket. If it were not for the annual grass fires it is possible that woodland would drive the grass from the Mankhunze soils. The Lubiri soils are probably unsuitable for most trees species owing to the periodic water-logging of the upper horizons of the soil and to the alkalinity of the lower horizons.

Fertility of the Valley Soils

Agriculturally the Mankhunze soils are the most useful soils of the area studied. In the years of better rainfall they have produced good crops of maize, groundnuts and sorghum. The available phosphorus, chemically determined, is low but significant increases in crop yields from applications of superphosphate have not in general been obtained in field experiments.

Fertiliser experiments on Lubiri soils on the Lubiri and Mamhumba mbugas have shown that superphosphate will increase the yield of maize, sorghum and sunflower but the increases have barely been economic. Good yields of these crops were obtained without fertiliser. On the whole the Lubiri soils are too alkaline for groundnuts, which suffer from an alkali-induced iron deficiency when the pH is above about 8. Even in areas of the Lubiri soils where the surface pH is between 7 and 8 there are numerous circular patches of pH about 8·5. These patches are about 10 yards across and appear to be caused by ants. At the centre of the patch is the entrance to the colony and the high surface pH is due to fragments of subsoil carbonate brought up by the ants and distributed round the colony entrance. These patches may correspond to the light-coloured circular areas commonly visible from the air on mbugas in Tanganyika.

IV. SOILS DERIVED FROM TRAVERTINE AND THE ERODED CALCAREOUS VALLEY SOILS

This is a somewhat mixed group of soils. They have in common a derivation from calcium carbonate, either lake-bed travertine deposits or nodular carbonate originally formed in the lower horizons of Mankhunze or Lubiri profiles. They vary in the extent to which non-calcareous alluvium or colluvium has contributed to the profile.

The " Travertine Soils " on the soil map of Chamaye Farm are shallow brown sandy loams overlying old lake-bed travertine at a depth of a foot or so. They have affinities with the Chamaye red soils overlying limestone, e.g. profile 78, but in the Travertine soils the proximity of the limestone to the surface has affected the colour of the overlying horizons. In places on the Lubiri mbuga massive travertine outcrops at the surface and the soils consist of a light grey calcareous loam lying in depressions and cracks in the surface of the travertine.

The Eroded Mankhunze and Lubiri profiles, found in the Chamaye area (field E9) are former Mankhunze and Lubiri soils which have been eroded down to their concretionary horizon.

The natural vegetation of the very shallow Travertine soils and of the eroded Mankhunze and Lubiri soils is sparse grass with scattered lime-tolerating shrubs. The deeper Travertine soils on Chamaye Farm probably carried woodland but they had all been cleared for cultivation before this survey was started.

No profile pits have been dug in any of these soils.

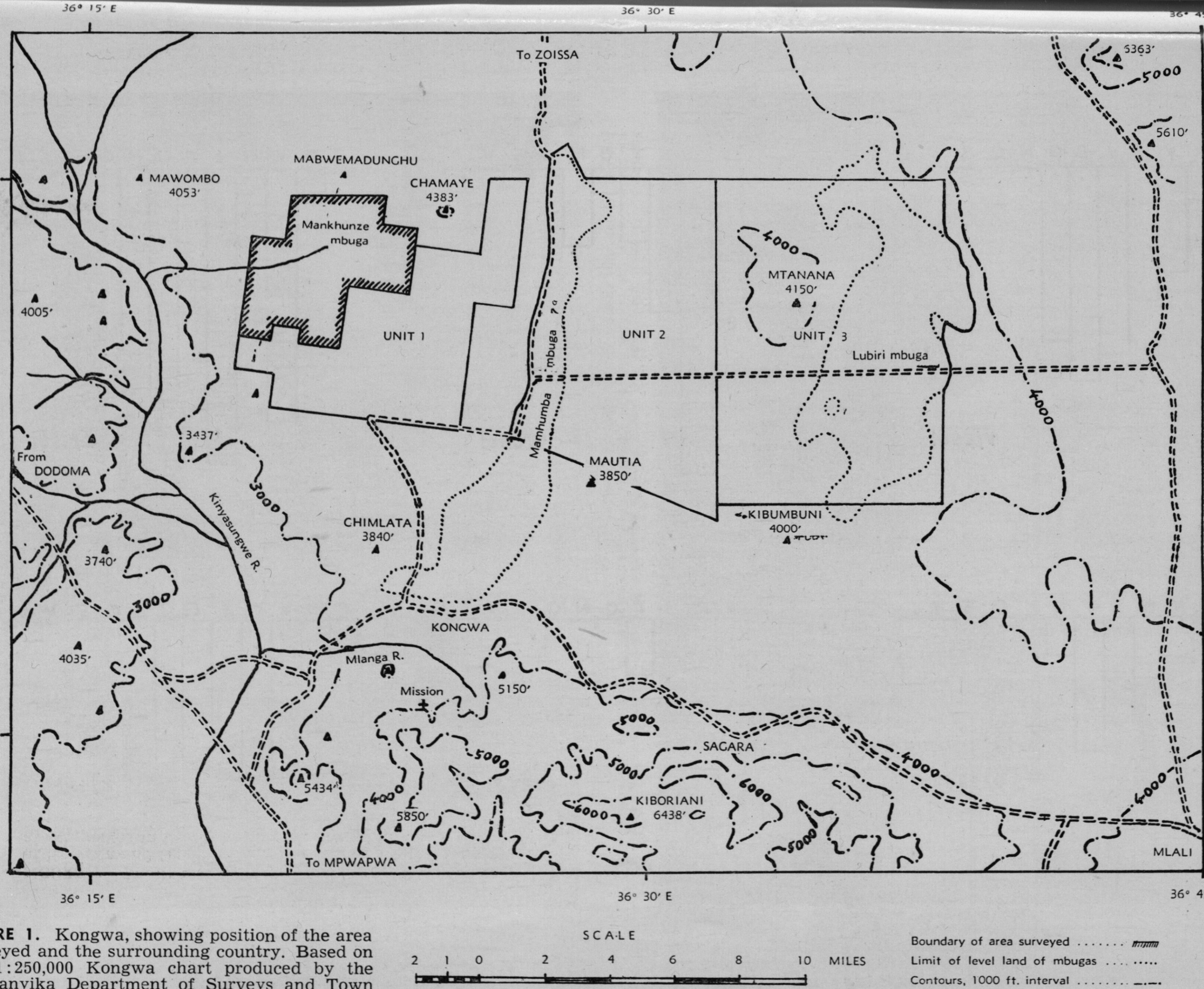

FIGURE 1. Kongwa, showing position of the area surveyed and the surrounding country. Based on the 1:250,000 Kongwa chart produced by the Tanganyika Department of Surveys and Town Planning, 1950.

B

FIGURE 2. Monthly distribution of rain for three seasons at Kongwa and Nachingwea. The values are the averages at all gauges in use in any particular month.

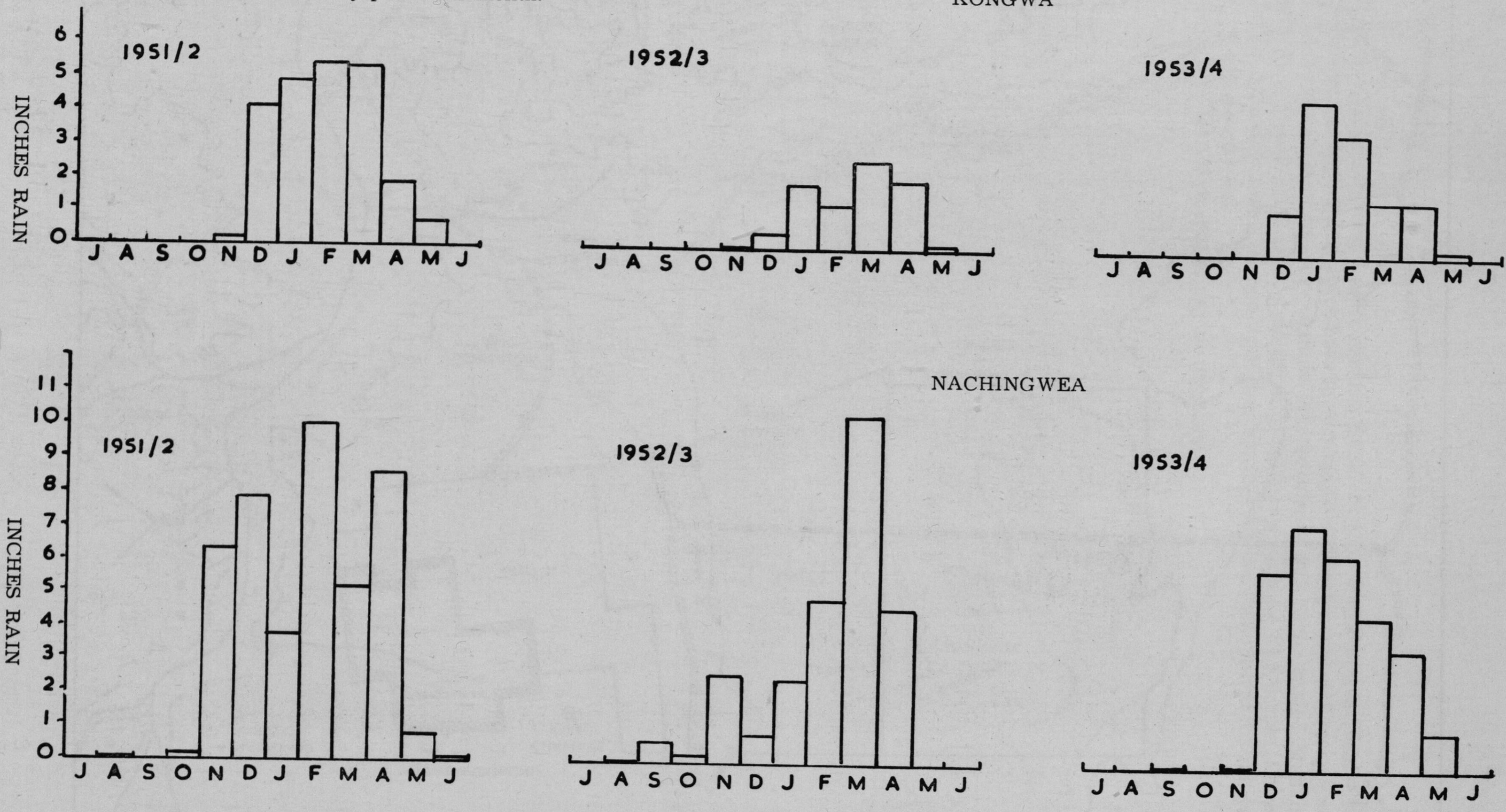

FIGURE 3. General view over the Kongwa plain from the Kiboriani mountain range. Kongwa township lies in the middle distance. The inselberg Mabwemadungha is visible just below the horizon, above and slightly to the right of Kongwa.

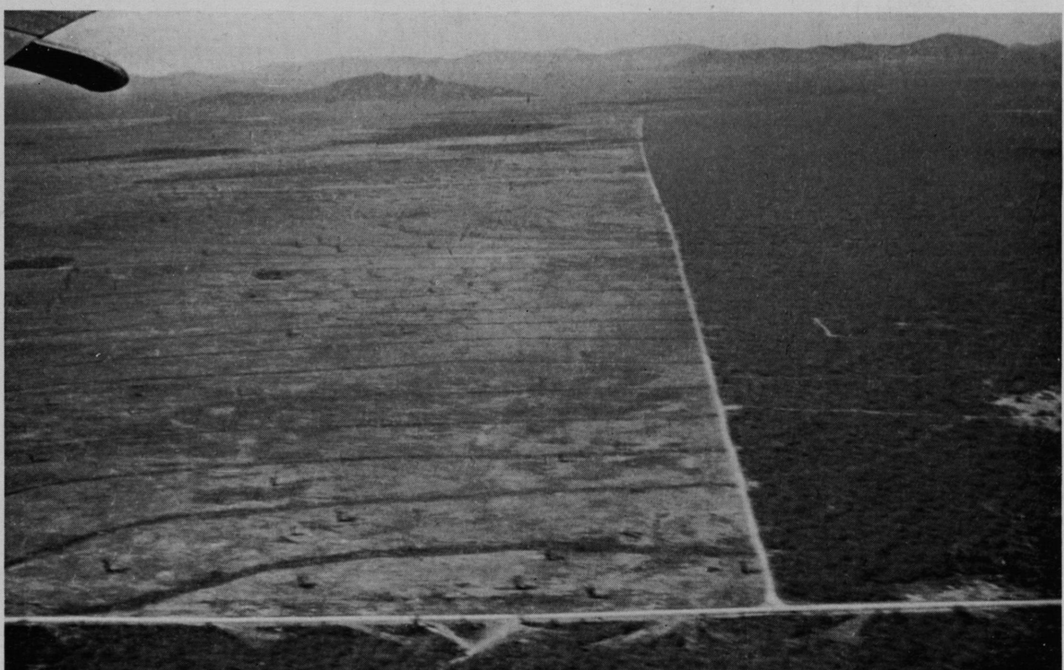

FIGURE 4. The south-east corner of Unit 1, Kongwa, looking north to Chamaye Hill. The contour banks are clearly visible on the cleared land. Photograph taken from the air.

FIGURE 5. Commiphora thicket at the site of Profile 3. Dry season aspect.

FIGURE 6. Eroded land in the Mlanga valley, to the south of Kongwa, showing the indurated red earth horizon about a foot thick overlying concretionary limestone. The soil horizons originally overlying the indurated layer have been lost by erosion.

FIGURE 9. Bending of fractured quartz strata as a result of soil creep. This photograph is of a section through a steep slope in the Kiboriani mountain range. On such a slope erosion is too rapid to allow the accumulation of a stoneless layer of earth above the quartz fragments.

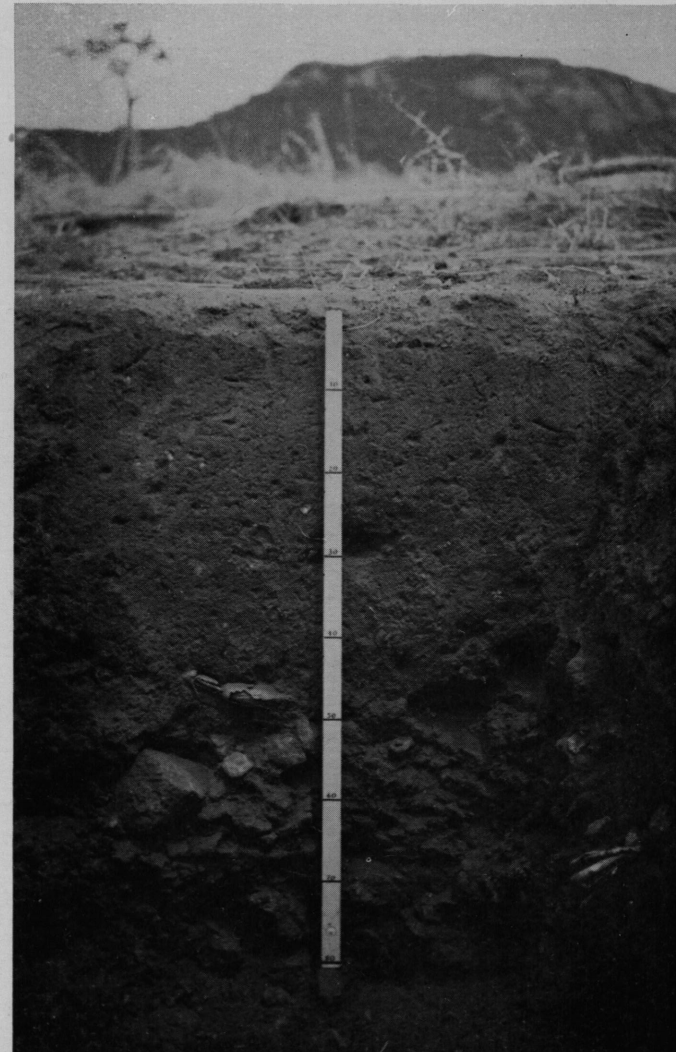

FIGURE 10. Profile pit in Pauling soil on Chamaye Farm. The stone-line is prominent below 50 cm. depth. (The rule is marked at 10 cm. intervals).

FIGURE 11. A Mankhunze soil on the edge of the Lubiri mbuga, Kongwa. The lower part of the profile is largely concretionary limestone. (The rule is marked at 10 cm. intervals).

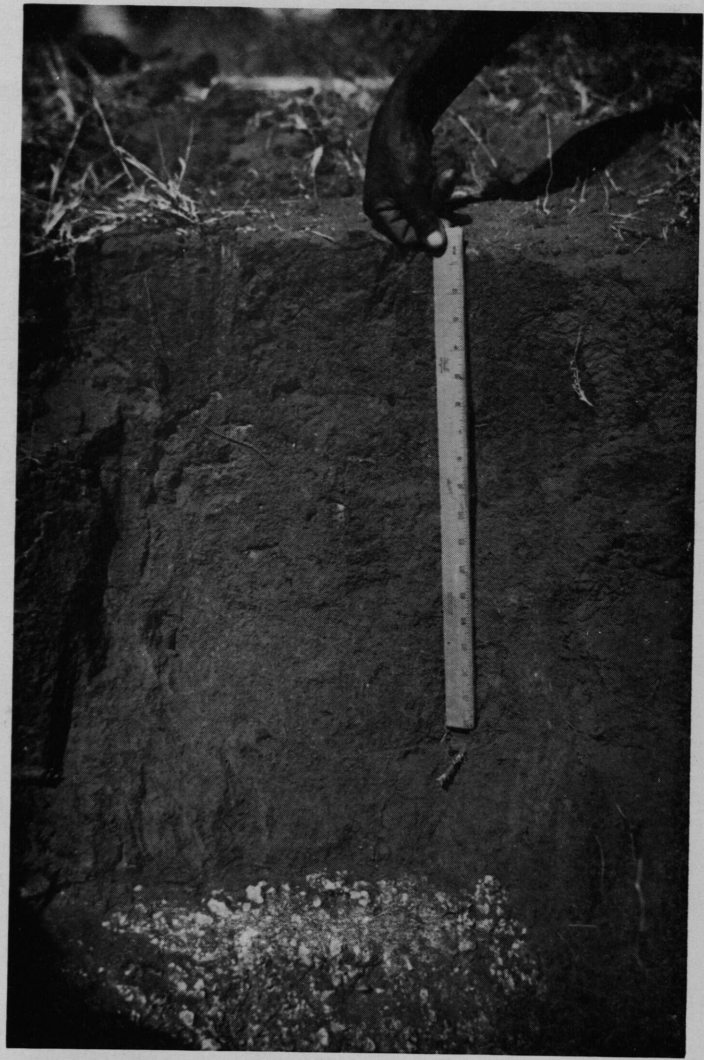

FIGURE 12. Profile pit in Lubiri soil (Profile 5). The concretionary limestone is visible in the lower part of the profile. The rule is 18 inches (46 cm.) long.

FIGURE 13. A sorghum crop on Chamaye Farm. Chamaye Hill is on the left.

FIGURE 14. Mamhumba mbuga, Kongwa, with scattered Acacias ; site of Profile 5.

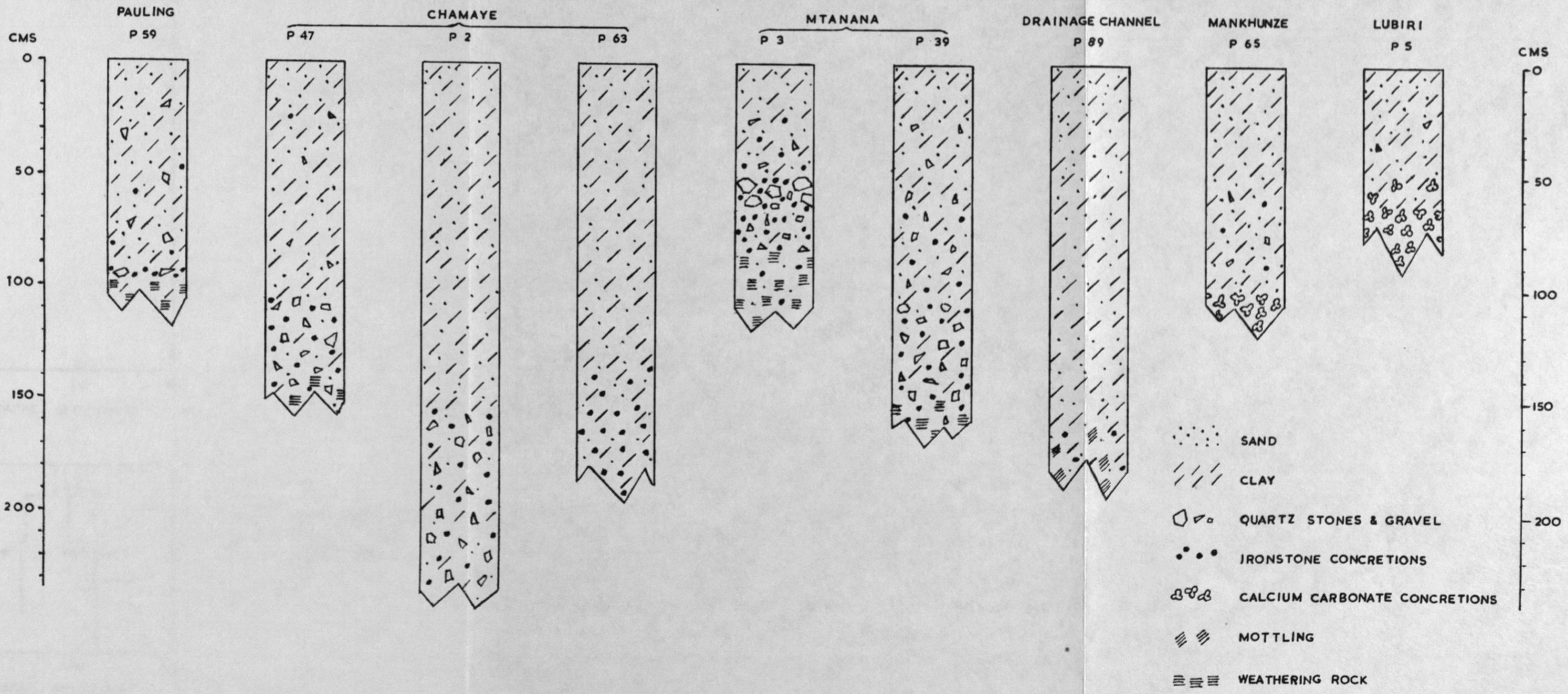

FIGURE 7. Profiles of the Kongwa soils, shown diagrammatically.

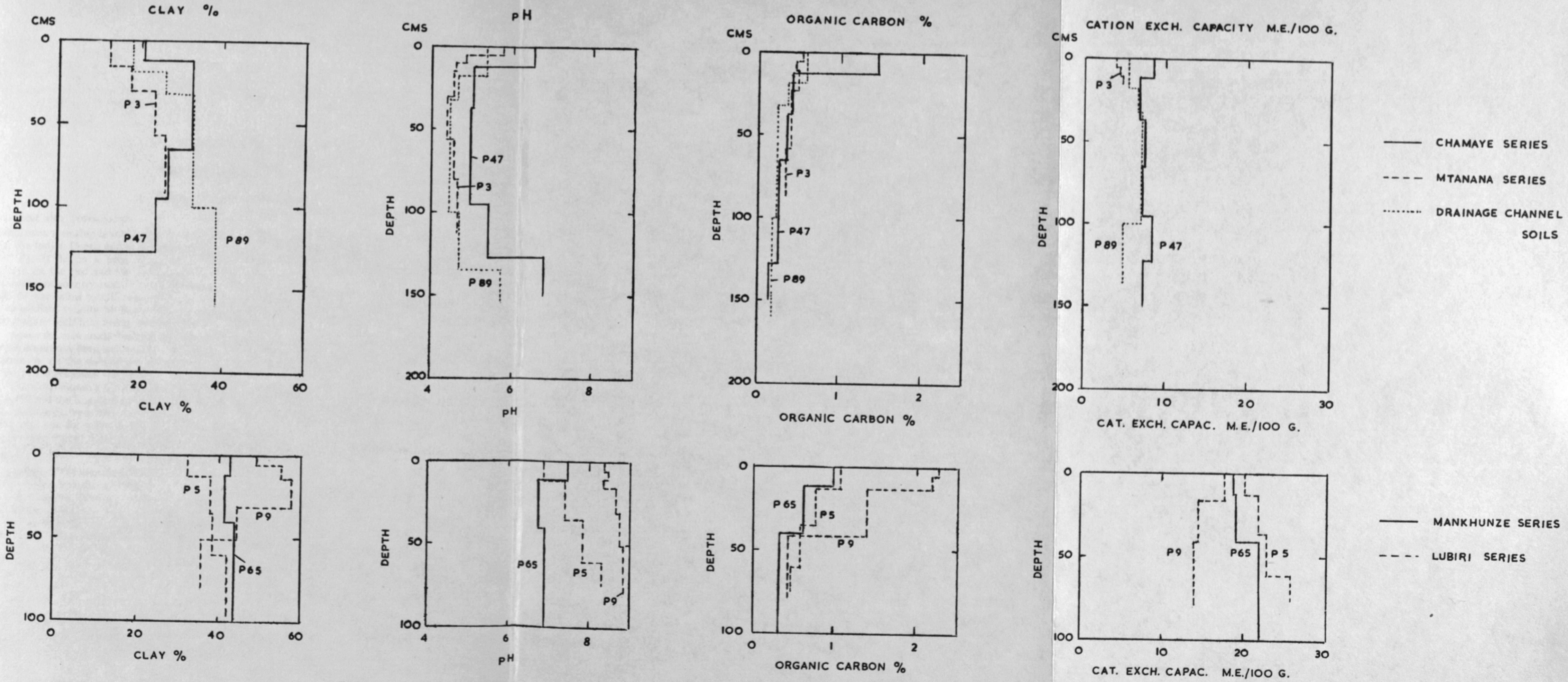

FIGURE 8. Variation with depth of percentage of clay, pH, percentage of organic carbon and cation exchange capacity for certain Kongwa profiles. The upper set of diagrams is for the acid soils and the lower set for the calcareous soils.

CHAPTER II

The Nachingwea Site

A General Features of the District

Situation and Topography

Nachingwea township is situated in the Southern Province of Tanganyika about 90 miles inland from the Indian Ocean and at a height above sea-level of 1,500 feet (latitude 10°20′S, longitude 38°45′E). It lies in a tract of gently undulating country between the Rondo and Makonde plateaux on the east and the Tunduru-Liwale escarpment on the west (Fig. 15). To the south this stretch of country extends to the Portugese East Africa border and to the north to the Rufiji river. It was called by Gillman (1943) the "inselberg corridor" but inselbergs are absent from the immediate vicinity of Nachingwea. To the north and east of Nachingwea there is some hilly country with hills rising to over 2,000 feet above sea-level.

Again the area studied is that farmed by the Tanganyika Agricultural Corporation. Three sample areas have been surveyed in detail and the soils are shown in Maps 2, 3 and 4. Additional information on the soils of the whole lease has been obtained from the study of a number of profile pits throughout the area.

The Corporation's lease lies across the watershed between the Mbemkuru river system to the north and the Lukuledi river system to the south. A number of small valleys run northwards and southwards from this watershed. These valleys contain ill-defined water-courses most of which only run for a few hours or a few days after heavy rain; none are permanent streams. Slopes rarely exceed 5 per cent, except in the hills to the north and east of Nachingwea.

Geology

The geology of the vicinity of Nachingwea has recently been described by Grantham and Pilson (1955). At present the underlying rock is everywhere gneiss of the Lower Basement Complex but it is probable that the Cretaceous sandstones of the Rondo and Makonde plateaux once overlaid this gneiss over the whole area. Pebbles of silicified sandstone belonging to this formation are occasionally discovered in the Nachingwea area but no evidence has been found that Cretaceous material has contributed significantly to the present soils.

The gneiss is mostly fairly fine-grained and varies considerably in composition. Granitic and hornblende gneisses are most common but strata of quartzite (e.g. Namanga Hill, Map 3) and of a dark non-stratified amphibolite also occur. Strata of crystalline limestone are found to the east of Nachingwea and there is an outcrop of this limestone to the immediate west of Namanga Hill. Pegmatite veins are common throughout the gneiss. The strike of the gneiss is approximately north-south and the dip is usually near vertical.

A number of rock specimens were examined for the writer by J. R. Harpum of the Department of Geological Survey, Tanganyika, and the following two descriptions are taken from his reports (Laboratory Reports X/3055/2 and X/3278).

*Acid Gneiss, sample H*1. Near Experimental Farm (Map 2)

A gneiss modified by cataclasis, composed of quartz, microcline, oligoclase, biotite and apatite. There is a little muscovite which is replacing the biotite in places, developing as small irregularly-oriented needles in the oligoclase, and traversing some of the quartz crystals as small disjointed veinlets. The microcline is lobing the oligoclase and appears to be replacing it. One small crystal of zircon was observed (uniaxial positive with a high birefringence). The rock seems to have suffered some potash metasomatism.

*Amphibolite, sample H*13. Near eastern edge of Map 3 (Chiumbati Farm)

A fairly fine-grained diopside-amphibolite consisting of hornblende, diopside, zoizite, scapolite and quartz.

Gillman (1943) has suggested that the southern portion of the "inselberg corridor" has been uplifted somewhat in geologically recent times. This suggestion is supported for the Nachingwea area by the convex shape of most of the slopes, indicating active cutting down by the streams.

Climate

There is an alternation of wet and dry seasons at Nachingwea, as at Kongwa, but the wet season is slightly longer at Nachingwea and the annual rainfall nearly twice that at Kongwa. Drought periods are liable to occur in the wet season but these rarely last for more than two weeks. Most of the rain falls in heavy thunderstorms. An intensity of 7 inches per hour lasting for 14 minutes has been measured; 7 inches of rain in 24 hours has also been recorded. The average annual rainfall over 7 years is 34·4 inches. The figures for each year are given in Table 10.

TABLE 10. *Annual Rainfall*, 1948 *to* 1955, *Nachingwea*

(Each year is measured from July of one year to June of the next)

Year	Rainfall Inches	Rainfall mm.	No. of gauges
1948/49	32·02	814	1
1949/50	39·07	1005	2
1950/51	32·22	818	14
1951/52	42·51	1080	10
1952/53	27·45	697	14
1953/54	28·93	735	20
1954/55	28·37	975	23

The monthly distribution of rain for a few typical years is given in Fig. 2.

Temperatures are slightly higher than at Kongwa. In 6 years recording the lowest screen temperature has been 48°F (May-June) and the highest 99°F (January). Mean monthly minima vary from 60°F in July to 71°F in January; mean maxima from 82°F in June to 92°F in November.

Some soil temperature measurements are given in Table 11. At 12 inches depth the soil temperature is rarely outside the range 25°-35°C (77°-95°F). At greater depths, e.g. the zone of rock weathering, it will vary little from 30°C throughout the year.

The two bottom lines of the table give the highest temperatures recorded at 2 inches (and the minima on the same day) with a bare surface and under the dry residues of a sorghum crop grown in the previous wet season. The shading effect is small. Under natural conditions there is little soil cover in the dry season owing to removal of grass by fire; the shading effect of the bare branches of the trees must be slight.

VEGETATION

The greater part of the land covered by these soil surveys carried, or had carried before clearing, an open deciduous woodland. This woodland was by no means uniform. A classification is attempted below in which the woodland is divided into several broad groups. By taking account of the species of the dominant trees many of these groups could be further sub-divided. On the whole, however, there did not appear to be any close or constant connection between the soil series, as determined by examination of profiles, and type of vegetation.

TABLE 11. *Soil Temperatures at Nachingwea at depths of 2 and 12 inches*

Period		Ground Cover	State of Ground	2 inches Min	2 inches Max	12 inches Min	12 inches Max
				°C	°C	°C	°C
Feb.17–29, 1952	..	Bare	Moist	23·7	39·3	27·5	30·1
July 1– 7, 1952	..	Bare	Dry	18·7	34·7	24·7	27·6
Dec. 1–31, 1952	..	Bare	Dry	27·4	47·0	32·4	36·4
Nov. 24, 1953	..	Bare	Dry	29·8	52·6	—	
Dec. 4, 1953	..	Stubble	Dry	29·2	48·4		—

At sites where there was a good correlation between vegetation and soil the decisive soil factor often proved to be clay content. This is almost certainly a moisture effect; the heavier the soil, the lower is the proportion of the rainfall which enters the profile and becomes available to the plant roots. The correlation is illustrated by the figures in Table 12 which were obtained by making a number of traverses across an area and noting the soil and the vegetation at 100 yard intervals.

TABLE 12. *Influence of soil texture on type of woodland for two areas near Nachingwea*

Soil textural class	No. of Observations	Percentage of each textural class occupied by: Miombo[1]	Pterocarpus-Combretum	Sclerocarya-bamboo
I. 5 miles west of Nachingwea:				
Loams and heavy loams	11	0	82	18
Sandy loams	24	46	42	12
Very sandy loams	9	56	44	0
Loamy sands	44	82	16	2
Sands	9	100	0	0
II. 2 miles south-west of Nachingwea:				
Loams	2	0	100	0
Sandy loams	17	18	29	53
Very sandy loams	3	100	0	0
Loamy sands	26	88	12	0
Sands	13	100	0	0

1. Miombo—deciduous woodland with dominance of species of *Brachystegia* and *Julbernardia*.

NOTE: Approximate clay percentages in texture classes:—

Loams . . . . . . over 25 per cent clay   Very sandy loams . . . . . . 10-12 per cent clay
Sandy loams . . 12-25 ,, ,,   Loamy sands . . . . 5-10 ,, ,,
Sands . . . . . . below 5 per cent clay

It will be seen that miombo woodland is predominant on the sandy soils, with clay contents up to about 20 per cent, while the other two communities occupy the heavier soils, with clay percentages of over 12 per cent. That there is a considerable overlap is not surprising, since the areas were not level and drier and wetter sites occurred within the textural classes.

The influence of texture is particularly noticeable in the two areas just described since in each case the soil texture was mainly controlled by the composition of the strata of the underlying gneiss and was therefore largely independent of the position of the site, i.e. whether on the crest of the ridge, upper slope, lower slope, etc. More often texture differences are due to the development of a catenary sequence, with the soil becoming progressively more sandy down the slope. The miombo woodland is again predominant on the sands of the lower slopes, usually with Pterocarpus-Combretum woodland on the sandy loams on top of the ridge, but the direct effect of texture is here obscured by the greater wetness of all lower slope soils.

In this survey the soil series were distinguished on profile characteristics such as colour, depth, presence of concretions, etc., and each soil series was allowed a fairly wide range of textures. It is therefore not to be expected that there should be a close correlation between soil series and vegetation. Vegetation boundaries frequently were found to coincide with soil boundaries and were therefore worth looking for. It was not usually possible to say just what soil series lay on either side of the boundary without examination with the soil auger. It follows that aerial photographs were not of any great help in the soil mapping.

An additional interfering factor in the correlation between soil and vegetation is the fact that much of the vegetation in the Nachingwea area has been affected by native shifting cultivation in the past 50 to 100 years and some of it much more recently. Vegetation boundaries are therefore sometimes cultivation boundaries and these rarely coincide with soil boundaries.

It might be argued that a survey whose purpose was to assess the agricultural possibilities of the land should have taken more notice of what was actually able to grow on a particular site than of colours and depths of profile horizons. Against this argument there is firstly the fact that the present vegetation has been considerably influenced by human activity in the past, as mentioned in the previous paragraph. And secondly there is the difference between the requirements of the tree species of the natural vegetation, with a life cycle of 50 years or more, and of annual crops. Reasons are given below for believing that the limits of some of the vegetation communities in the Nachingwea district are set by the water available to the roots in occasional drought years. For annual crops, however, an occasional failure or partial failure can be tolerated if in most years there is sufficient moisture. It seems likely that the soil profile will be little affected by extreme years and may well reflect average conditions better than the vegetation.

The following classification of the woodland communities in the vicinity of Nachingwea is a modified form of one worked out by P. E. Glover (unpublished report) of the East African Tsetse and Trypanosomiasis Research Organisation.

(1) *Upland Thicket communities.* On loams and sandy loams.
- (a) *Brachystegia microphylla* dominant (Fig. 16).
- (b) *Bombax rhodognaphalon* and *Cordyla africana* dominant.

(2) *Miombo woodland.* On sands and sandy loams (Figs. 17 and 18).
- (a) On well-drained to somewhat moist sites any of the following may be dominant:—
  Brachystegia bussei Harms.
  B. spiciformis Benth.
  B. utilis Hutch. and Burtt Davy.
  B. allenii Hutch. and Burtt Davy.

(b) On poor sands the dominant species is usually:—
Julbernardia globiflora (Benth.) Troupin..
(c) On sandy soil with impeded drainage (e.g. Naipingo series) the dominant species is usually:—
Brachystegia boehmii Taub.

(3) *Pterocarpus-Ostryoderris-Combretum woodland and variants.* On upland sites on loams and sandy loams (Fig. 19).

(a) One or both of the following species:—
Pterocarpus angolensis DC.
Ostryoderris stuhlmannii (Taub.) Dunn
together with one or more Combretum species:—
Combretum binderanum Kotschy.
C. apiculatum Sond. subsp. *boreale* Exell.
C. zeyheri Sond.
Bamboo (*Oxytenanthera abyssinica* Munro) may also be present but only to a minor extent (cf. type (5)).
(b) *Ricinodendron viticoides* Mildbr. with *Combretum* spp. Of only limited extent.
(c) The following are co-dominants in one variant:—
Erythrophleum africanum (Welw.) Harms.
Ostryoderris stuhlmannii (Taub.) Dunn.
Terminalia sericea Burch.
together with *Combretum* spp. as in (a).

(4) *Millettia-Markhamia* woodland. On upland sites on loams and sandy loams; chiefly to the east of Nachingwea and perhaps following the fairly recent clearing of upland thicket.
Millettia stuhlmannii Taub.
Markhamia obtusifolia (Baker) Sprague.

(5) *Sclerocarya-bamboo* Along the margins of valleys.
Sclerocarya caffra Sond.
Ostryoderris stuhlmannii (or *Pterocarpus angolensis*).
Combretum spp.
with dense bamboo (*Oxytenanthera abyssinica* Munro) (Fig. 21).

(6) *Combretum scrub.* An early stage in regeneration after native clearing of the bush on upland loams and sandy loams (Fig. 20).
Combretum spp. (as 3 (a)).
Terminalia sericea Burch.
often with thin bamboo.

(7) *Riverine communities.* Along seasonal water-courses.

(a) *Piliostigma-Thespasia*-bamboo scrub.
Piliostigma thonningii (Schum.) Milne-Redhead.
Thespasia garckeana F. Hoffm.
with bamboo and often *Kigelia aethiopica.*
(b) *Acacia usambarensis* Taub. scrub.
(c) Thicket dominated by:—
Sterculia appendiculata K. Schum.
often with lianes (Fig. 34).

The first two types are found on heavy soils in the wider valleys. The *Sterculia* thicket is usually on stonier soils associated with actively eroding gullies (Nandete series).

(8) *Mbuga Communities.* Tall grass with scattered small trees on seasonally water-logged soils.

(9) *Termite mound communities.* Commonly occurring trees are:—

Tamarindus indica L.
Acacia nigrescens Oliv.
Sterculia africana (Lour.) Fiori

The upland thicket communities contain a number of evergreen species. A.C. Hoyle (private communication) has suggested that this thicket is a survival from rain forest flourishing under a higher rainfall in the past. In the hills bordering the Kilombero valley (about 200 miles north-west of Nachingwea) at an altitude similar to that of Nachingwea rain forest exists at the present day under a rainfall of 40 to 50 inches.

Once the thicket has been cleared for native cultivation the annual grass fires prevent regeneration of the thicket when the cultivator moves on. The regenerating bush consists of Pterocarpus-Ostryoderris-Combretum woodland, or some similar open woodland, on the heavier soils or of miombo on the sandy soils. The evolution of the present vegetation on the land to the east of Nachingwea has thus been, according to the above theory:—

Rain forest
| diminution in rainfall
Upland thicket
| native clearing, then regeneration
(sands) | (loams)
Miombo | Pterocarpus-Combretum, etc.

It is possible that some of the land was cleared while the rainfall was still high enough to support rain forest. This would probably have come back as miombo, provided the population was high enough to have maintained annual grass fires. Miombo is the successor to cleared rain forest under such conditions in the Kilombero. When the rainfall declined to its present 35 inches the water available in the heavier soils would be insufficient for the *Brachystegia* and *Julbernardia* species and they would die out, leaving the *Pterocarpus*, *Ostryoderris*, *Combretum* and other species with a smaller water requirement. It was the late C. F. Charter (unpublished report) who pointed out that these latter species (*Pterocarpus*, etc.) exist as minor elements in the miombo and that removal of the *Brachystegia* and *Julbernardia* from the miombo and a thickening up of the remaining species would produce the *Pterocarpus-Ostryoderris-Combretum* woodland and its variants. In schematic form this alternative derivation of the present vegetation would be:—

Rain forest
| native clearing, then regeneration
Miombo
| diminution in rainfall
(sands) | (loams)
Miombo | Pterocarpus-Combretum, etc.

To the west of Nachingwea the upland thicket is rarely met with. It is impossible to say whether this is because it has all been cleared, according to the first scheme presented above, or whether a higher native population cleared all the rain forest before the rainfall diminished, as represented by the second scheme, so that the thicket never existed.

The above considerations apply to the better-drained soils. In the valleys, provided the soils are not too wet, there is at the present time miombo where the soils are sandy and some sort of riverine thicket where they are heavier. The heavier valley soils are the most fertile in the district and often appear to have been cleared and cultivated on a relatively short rotation. The *Sterculia* thicket (type 7 (c)) is perhaps a relic of the original rain forest and the scrub communities (7a and 7b) are probably early stages in the re-colonisation of abandoned cultivation which never develop further owing to renewed clearing.

This treatment of the vegetation at Nachingwea is at present not much more than a hypothesis and further study would be required to establish the suggested evolution of the present communities. The great sensitiveness of the vegetation to small differences in available moisture, as illustrated by the figures in Table 12, seem to support the idea that some of the communities are at the dry end of the range. This applies particularly to the miombo. In interpreting this in inches of actual rain it should be remembered that it is probably the occasional extreme year rather than the average which will limit a particular community. Although the lowest average rainfall for all gauges in the Nachingwea area (Table 10) is 27 inches, individual gauges have received less than 20 inches in a year. It appears that miombo can survive these occasional 20 inch years if practically all the rain enters the soil (as in the sands). But when, as in the heavier soils, an appreciable proportion of this 20 inches is lost by run-off, the miombo is replaced by a more drought-resistant woodland.

General Features of the soils of Nachingwea

The parent rock of the soils at Nachingwea is very similar to that of the Kongwa soils. The considerable differences between the soils of these two places can mostly be attributed to the higher rainfall at Nachingwea. A higher rate of natural erosion has tended to prevent the formation of a thick mantle of weathered material such as is formed at Kongwa, so that variations in the composition of the underlying gneiss are often reflected in the overlying soil. Sometimes, however, and particularly to the east of Nachingwea township, there is a mantle up to and exceeding four metres in thickness which obscures rock differences.

At Nachingwea there is a " textural catena," in contrast to Kongwa. On the tops of the ridges and on the upper slopes there is a loam or sandy loam. Lower down the slope this gives place to deep sands. Towards the foot of the slope a clay subsoil horizon appears below the sandy surface horizon. Near the heads of the valleys this shallow surface stretches right across the valley; in the lower reaches, particularly where the valley is wide, the sand thins out at the foot of the slope and the valley-bottom is occupied by a loam or clay loam. The development of this catena is obviously due to differential movement of the soil particles down the slope under the influence of surface run-off during rain and immediately afterwards; the sand particles remain on the slopes while the clay moves down into the valleys. That this process takes place at Nachingwea and not at Kongwa is probably due to a combination of more frequent rain at Nachingwea associated with a grass ground flora which checks the velocity of the run-off water sufficiently to allow deposition of sand on the slopes.

Again, associated with the higher rainfall at Nachingwea are frequent mottled clay horizons in the lower-lying soils and a relatively common occurrence of ironstone concretions and even massive sheets. This mottling and ironstone formation indicates temporary water-logging. There is, however, no permanent holdup of the drainage so that calcareous horizons are not normally found. In the few soils in which a little concretionary carbonate is found, e.g. the Nyati series, it is due to the combination of an impervious lower horizon in the profile combined with a seepage of water from higher up the slope continuing well into the dry season; as a result evaporation takes place for some months after the rains are over and calcium carbonate is deposited. The impervious subsoil prevents the leaching out of this carbonate during the succeeding rains.

Organic matter is, on the average, slightly higher in the Nachingwea soils than in those at Kongwa, due to the better growth of grass under the higher rainfall. As against the one to two per cent of organic matter in the Chamaye soils at Kongwa the analogous soils of the Nachingwea series at Nachingwea contain two to three per cent.

Another difference is the influence of parent rock on the Nachingwea soils, already mentioned. Thus the Chamaye series at Kongwa has two analogues at Nachingwea, one occurring on the resistant acid gneisses and the other on the more deeply weathered rocks.

B Classification and Description of the Soil Series

Sixteen soil series have so far been recognised. The more important of these series with their characteristics are listed in Table 13. The series form eight groups as follows:—

- I. Red Earths.
- II. Deep sands.
- III. Shallow sands overlying massive ironstone.
- IV. Pale mottled clays, often with a sandy horizon overlying the clay.
- V. Hardpan soils.
- VI. Dark loams and clays.
- VII. Alluvial soils.
- VIII. Immature soils on rock freshly exposed by erosion, and stony eroded soils.

The last group is of no agricultural importance and has not been examined as fully as the other groups. It has been mapped as the " Nandete " series.

Many of the soil series have been divided into sub-series. The subdivisions were based on what seemed to be the most important variable character of the series. In some cases this was the texture of the surface horizon, so that the subseries in such cases corresponds to the American " type." In other cases the subseries were based on sub-soil texture and in others again on sub-soil colour, as reflecting drainage conditions. These differences in drainage are often of considerable agricultural importance. Theoretically, these sub-series based on colour differences might have been given full series status but this would in many cases have obscured their pedological affinities. Also by greatly increasing the already large number of series occurring on a single farm, it would have made the maps more difficult to understand.

A number of profiles are shown diagrammatically in Fig. 23 and the variations with depth of certain analytical data are illustrated in Fig. 24.

I. RED EARTHS

In this group fall soils with red and with orange subsoils, as at Kongwa. At Nachingwea, however, separate series status has been given to the two forms since the orange soils seem much wetter than the red. The orange, or Nagaga, series has been divided into a " normal " form and a less-commonly occurring " low-lying " form in which leaching has been less severe and the orange colour of the subsoil is less intense (lower in value). All three above-mentioned forms have been further subdivided into loams (including sandy loams) and sands, based on the texture of the uppermost six to twelve inches; at greater depths the texture is always a sandy clay; the solum is always deep.

In the third Red Earth series—the Namatula series—the profile is usually shallow. Subsoil colours tend to be reddish-brown or yellowish-brown rather than red or orange. This series has been divided on the texture of the subsoil, which is a sand in one sub-series and a sandy

TABLE 13. Soil Series in Nachingwa

Series	Colour (subsoil)	Texture of surface	Texture of subsoil	Reaction	Drainage	Parent Material	Topographical position	Natural vegetation
RED EARTHS								
Nachingwea	red	sandy loam to loamy sand	sandy clay	acid to v. acid	good	basic gneiss	crests & upper slopes	deciduous woodland
Nagaga	orange	sandy loam to loamy sand	sandy clay	moderately to slightly acid	good to fair	do.	middle to lower slopes	do.
Namatula	brownish red to yellowish brown	loamy sand	clayey sand to sandy clay	slightly acid	impeded at depth	acid gneiss	crests, upper & middle slopes	do.
DEEP SANDS								
Nailala	orange to brown	sand	clayey sand	slightly to moderately acid	fair to poor	colluvium	middle to lower slopes	deciduous woodland
Nangoi	pale brown	sand	sand	do.	poor	do.	lower slopes	do.
Mitumbati	brown	sand	sand	slightly acid	poor	do.	do.	do.
SANDS OVERLYING MASSIVE IRONSTONE								
Chiumbati	brown	sand	sand	v. slightly acid	v. poor	colluvium	valley bottom	thin sands
MOTTLED CLAYS								
Naipingo	pale brown to yellow	sand to sandy loam	sandy clay to clayey sand	slightly acid	impeded	colluvium	lower slopes	deciduous woodland
Kihue	yellow	sandy loam	sandy clay	moderately acid	v. poor	do.	valley bottom	do.
Water-hole	yellow	sandy loam	sandy clay	do.	seasonally flooded	do.	do.	grass or sedges

TABLE 13 *continued*

HARDPAN SOILS								
Nyati	dark grey	sandy loam	sandy clay	slightly acid (subsoil alkaline)	v. poor	acid gneiss or colluvium	lower slopes	thin woodland or scrub
DARK COLOURED LOAMS								
Nkumba	dark brown to dark grey	loam	sandy clay	slightly acid to neutral	fair to poor	colluvium	valley margins to valley bottoms	deciduous woodland to riverine thicket
Nkumba swamp	dark grey	loam	sandy clay to clay	neutral	seasonally flooded	colluvium or alluvium	valley bottoms	grassland
Naunga	dark grey	loam	clay	neutral (subsoil alkaline)	poor	colluvium from basic gneiss	valley bottoms	grassland
ALLUVIAL								
Mandai	dark brown	loam to sandy loam	sand to sandy clay	neutral	good	alluvium	valley bottoms	grassland or scrub
ERODED SOILS								
Nandete	stony soils resulting from the removal of most of soil by erosion						broken country	thin woodland or riverine thicket

clay in the other. No account was taken of subsoil colour because of practical difficulties; redder and yellower tints follow one another in rapid succession and it would have been impracticable to map them on the scale of 1 in 10,000. Should further survey show the occurrence of larger uniform areas of one or the other tint it would be advisable to separate them. The character chosen to subdivide the series—texture of subsoil—does appear to correspond to marked differences in crop growth. The topsoil of Namatula profiles is always sandy so there is no subdivision on this feature.

Classification of the Red Earths

The complete list of Red Earth series and sub-series is given below.

Series	*Sub-series*
Nachingwea (red)	(1) Sandy loam (occasionally loam).
	(2) Sand.
Nagaga (orange)	(1) Normal form, sandy loam.
	(2) Normal form, sand.
	(3) Low-lying form, sandy loam (or loam).
	(4) Low-lying form, sand.
Namatula	(1) Sandy subsoil.
	(2) Sandy clay subsoil.

Note. The Munsell colour names, used in the profile descriptions, by avoiding the term " orange," tend to obscure the difference between the Nachingwea and Nagaga series. Roughly, 10R to 2·5YR hues have been classed as " red " and hues yellower than 2·5YR (from about 3YR up to 7·5YR) as " orange."

These Red Earths at Nachingwea, like those at Kongwa, belong to the Non-laterised Red Earths of Milne *et al.* (1936). The chief differences from the Kongwa soils are attributable to the higher rainfall at Nachingwea.

Both the Nachingwea series and the Namatula series are found on the higher ground. The distinction seems to be that on the one hand the Nachingwea series soils develop on deeply weathered rock or on deep colluvial " mantle " deposits; i.e. where the water table is always well below the solum. The Namatula series soils, on the other hand, develop over rock resistant to weathering, where a temporary perched water table sometimes rises into the lower horizons of the profile.

Nachingwea Sandy Loam or Loam (Figs. 22 and 25)

These soils usually have a dark reddish-brown surface horizon about 15 cm. thick. Typically there is about 20 per cent of clay in this horizon, with about 2 per cent of organic matter and a pH near 6. Under natural conditions there is a grass ground cover and this gives the soil a weak crumb structure.

Below this surface horizon there is usually about 2 metres of stoneless, red sandy clay. The depth is very variable; in isolated small areas it may be 50 cm. and in colluvial deposits on a long slope a depth of 5 metres has been recorded. The pH falls to a minimum of about 5 at about 50 cm. depth and rises slightly at greater depths. This minimum is probably due to the withdrawal of bases from this zone by plant roots and their return to the surface in the decaying vegetation. In the upper part of the profile the clay content increases with depth to 40 to 50 per cent at about 50 cm. depth. Below this it either remains constant, e.g. profile 17, or may decline, e.g. profile 95. This decline is believed to be due to the cementing of clay particles into larger aggregates in the lower horizons, as was seen in the Chamaye profile No. 47 (see p. 9).

At its lower boundary the red sandy clay passes into a relatively thin horizon (usually between 30 and 60 cm. thick) of subspherical ironstone pisolites and quartz gravel set in red sandy clay. There is often a stone-line of subangular quartz fragments, 5 to 10 cm. across, lying in this horizon.

Below this concretionary horizon lies weathered rock but the uppermost metre or more of this is usually completely weathered to a red sandy clay with only occasional shattered quartz veins to show that this part of the profile is still in its original position. There are not normally any pale mottles.

It is only occasionally in railway cuttings and in the banks of gullied water-courses that the next horizon, partly weathered rock, has been seen. In all cases it has proved to be one of the more basic gneisses, either a gneiss rich in hornblende or an amphibolite (Fig. 27). If bands of acid gneiss are also present they are relatively narrow. The essential requirement for the formation of this Nachingwea series is probably deep weathering of the underlying rock so that the profile is never water-logged for long, rather than the presence of hornblende, or other minerals of the more basic gneisses.

Fig. 22 shows a typical Nachingwea sandy loam profile on amphibolite. The concretionary horizon contains a quartz stone-line; the fragments of quartz making up the stone-line are derived from the occasional quartz vein in the amphibolite or sometimes from narrow strata of acid gneiss. In a similar, but rather shallower, profile the pH was 6·6 in the concretionary horizon and 6·9 in the weathered rock immediately below. The clay percentage in the concretionary horizon was 45 per cent of the fine earth fraction, about 10 per cent less than in the sandy clay just above.

Two typical profiles are described below. Analytical data are to be found in Tables 25 and 26*. Profile 17, under miombo woodland, has low exchangeable calcium values. Magnesium exceeds calcium at all levels. In most profiles, however, calcium slightly exceeds magnesium in the uppermost horizon even though magnesium predominates lower down. Profile 95 is more typical in this respect. This soil had been under bamboo and such soils usually show a rather higher organic carbon (2·3 per cent in one case) and base exchange status than those under normal miombo woodland.

*These Tables contain the analytical data for the sample profiles of all the series mapped at Nachingwea described in Chapter II. They are to be found in Appendix 3.

PROFILE 17

Nachingwea, Namanga Farm, Field 8. On a gently-sloping hillside (2 per cent slope). Altitude 1,600 feet.

0- 10 cm.	Dark red-brown loam (2·5YR 3/5), friable, with a fair number of fibrous roots. Weak crumb structure. Merging into:—
10- 22 cm.	Dark red loam (2·5YR 3/6) similar to above but fewer fibrous roots. Merging into:—
22-215 cm.	Dark red clay (10R 3/8). Massive, but with a few fibrous roots to 40 cm. depth. Larger roots to full depth of profile.
215-230 cm.(+)	Red sandy clay with concretionary ironstone (spherical, 1 cm. diam.) with MnO_2.

Drainage. Well-drained.

Vegetation. Well-grown miombo woodland with grass 4 to 5 feet high. Species observed included:—

Brachystegia spiciformis Benth.
Julbernardia globiflora (Benth.) Troupin.
Pterocarpus angolensis DC.
Strychnos innocua Del.
Albizzia harveyi Fourn.
Combretum apiculatum Sond. subsp-*boreale* Exell.

PROFILE 95

Nachingwea, western side of Experimental Farm. Level ground on the crest of a ridge. Altitude 1,500 feet.

0- 15 cm.	Dark red-brown sandy loam (5YR 3/3). Fair number of fibrous roots. Soil sets hard when dry. Sticky and plastic when wet.

15- 35 cm.	Transition zone (2·5YR 3/4). Very hard and compact when dry.
35-210 cm.(+)	Dark red sandy clay (10R 3/6), with a little quartz gravel (2 to 5 mm.) and subspherical ironstone. Massive structure. Very hard when dry, sticky and plastic when wet. Old tree roots to full depth of profile. Slight MnO_2 below 120 cm.

Drainage. Slow owing to absence of slope and to heavy subsoil but no permanent impedence.

Vegetation. Roadside verge at time of sampling but formerly under woodland scrub and bamboo, including:—

Pterocarpus angolensis DC.
Ostryoderris stuhlmannii (Taub.) Dunn ex Baker f.
Combretum sp.
Oxytenanthera abyssinica (A. Rich.) Munro.

Although the two profiles just described are typical of the series some considerably poorer soils seem to belong to the same series. Examples are given in Table 14.

In the first example, situated at the foot of Namanga Hill, in the north-west corner of field 1 (see Map 3) the poverty of the soil appears to be due to loss of the original topsoil by severe sheet erosion. The second example was also situated at the foot of a steep hill but here, judging by the lower clay percentage, the result has been severe leaching without appreciable erosion. The third example, from field 147, Chiumbati Farm, just north of the quarry (Map 4), was situated on a broad ridge and does not appear to have been eroded or excessively leached. There is probably a stratum of rock deficient in calcium, magnesium, etc., running northwards from the quarry. Similar very deficient strips of soil have been noted in several places to the east and south of Nachingwea township.

TABLE 14. *Examples of unusually poor Nachingwea soils*

Probable cause of poverty	Depth (cm.)	pH (water)	Clay %	Exch. cations m.e./100 g. soil			
				Ca	Mg	Mn	K
Truncation of profile . .	0- 20 90-105	4·55 5·05	33 41	not determined not determined			
Excessive leaching	0- 15 15- 30	5·20 4·85	18 36	0·6 0·1	1·0 0·3	0·2 0·1	0·3 0·2
Parent material deficient . .	0- 15	4·45	—	0·4	0·3	0·02	0·2

NACHINGWEA SAND

The Nachingwea sand differs from the loam and sandy loam only in the greater sandiness of its surface horizon. The clay content increases rapidly with depth and below about 30 cm. the soil is a red sandy clay indistinguishable from that of the sandy loam profile.

The sand is found lower down the slope than the sandy loam and the sandiness of the surface horizon is due to sheet erosion of the heavier soil higher up the slope. As the eroded material moves down the slope the sand particles move less quickly than the clay and, if conditions are suitable, the sand is deposited at the lower boundary of the series, forming the Nachingwea sand. The clay moves further down the slope and is eventually deposited in the valley bottom.

The total area of this sand is small, probably because the combination of conditions required for its formation is rarely achieved. Usually the sand is carried right off the soils of the Nachingwea series and comes to rest lower down the slope as a Nagaga, Nailala or Naipingo sand. No profile studies have been made. The clay content of the uppermost 10 to 15 cm. of the profile appears to range from about 5 to 12 per cent, anything higher than this being classed as a sandy loam.

NAGAGA SANDY LOAM, NORMAL FORM

This soil normally lies next down the slope to a Nachingwea sandy loam. It appears to have developed from the same parent material as the Nachingwea series and is similar in texture, depth, absence of stones in the upper part of the profile, etc. The chief differences are the orange subsoil colour of the Nagaga soil and the somewhat lesser acidity.

The surface horizon of a Nagaga sandy loam is dark brown in colour with a pH usually between 6 and 7. The clay content is 12 to 15 per cent, which is rather lower than an average Nachingwea sandy loam and the organic matter is 2 to 4 per cent. Calcium is the predominant cation in the surface horizon, though magnesium may exceed calcium in the lower horizons.

At a depth of about 30 cm. this dark surface horizon grades into an orange-coloured sandy clay. The pH declines to about 5 at a depth of about 50 cm. and then increases slightly at greater depths, much as it does in the Nachingwea series. The clay content is also similar (40 to 50 per cent). At a depth of one to two metres, or sometimes more, this horizon is succeeded by a horizon of subspherical ironstone concretions (Fig. 29) and quartz gravel. Below this is a zone of orange, yellow and grey mottles with soft earthy iron concretions. This is probably weathering rock in most profiles but may perhaps sometimes be " mantle " material. The mottling indicates periodic water logging due to the somewhat low-lying position of these soils combined with lateral seepage of water from soils higher up the slope.

In no Nagaga profile has any stone-line of large quartz fragments been seen. This may be merely chance; even in the definitely sedentary Nachingwea series there is often no such stone-line due to the absence of any quartz veins from the rock in the vicinity of the profile. On the other hand it suggests that many of the Nagaga soils are developed on deep colluvial mantle deposits.

Only one instance of a very acid Nagaga soil has been seen. The pH of the surface horizon was 4·6 and the clay content 36 per cent. This was probably a former lower horizon exposed as a result of sheet erosion. The soil was near the foot of a long slope and had been under native cultivation.

An example of a Nagaga sandy loam (profile 16) is described below. The whole profile is rather sandier than many Nagaga sandy loams. It is situated near an area of sandy Namatula soils derived from acid gneiss (Map 3, field 7) and it is probable that this particular profile has developed on colluvial material partly derived from this acid gneiss.

PROFILE 16

Nachingwea, Namanga Farm, field 7. Near the foot of a slope; gradient about 2 per cent. Altitude 1,550 feet.

0- 7 cm.	Dark brown sandy loam (7·5YR 4/2) with single grain structure. Many fibrous roots.
7- 17 cm.	Brown sandy loam (7·5YR 4/3). Similar to above. Merging into:—
17- 30 cm.	Reddish brown sandy clay (2·5YR 4/5). Harder than above, becoming massive. Fewer fibrous roots. Merging into:—
30- 90 cm.	Yellowish-red sandy clay (5YR 5/6). Massive; upper portion harder than lower, perhaps because drier. A few fibrous roots to 60 cm. depth. Merging into:—
90-150 cm.	Reddish-yellow clayey sand (5YR 6/8) with soft ferruginous concretions.
150-190 cm.	Orange sandy clay with reddish, yellow and white mottling. Some large roots.
190-200 cm.(+)	Red-brown, yellow and white mottled indurated sandy clay. Some earthy ironstone with MnO_2, decomposing feldspar and quartz gravel, i.e. weathering gneiss.

Drainage. Somewhat slow in upper horizons. Probably water-logged in lower horizons during wet spells.
Vegetation. Well-grown miombo woodland with grass 4 to 5 feet high. *Brachystegia boehmii* Taub. (an indicator of a badly-drained subsoil) dominant. Also present:—

Pterocarpus angolensis DC.
Ostryoderris stuhlmannii (Taub.) Dunn ex Bak. f.
Diplorhynchus mossambicensis Benth.
Combretum ap.

Nagaga sand, normal form

The Nagaga sand differs from the sandy loam in that the surface 15 cm. or so of the profile is much sandier—5 to 10 per cent of clay—and is usually somewhat more grey in hue. The organic matter is appreciably lower than in the sandy loam. At greater depths the clay content increases rapidly and the lower horizons of the profile are identical with those of the sandy loam.

Owing to its sandy nature and low organic matter content the surface horizon of these soils has little aggregate stability. It tends to slump during rain and dries out afterwards with a hard surface crust which can prevent emergence of seedlings.

A typical profile is described below.

Profile 112

Nachingwea, Namanga Farm, field 7, western side. A gently sloping, low-lying site (slope about 2%) in an area of ill-defined drainage. Altitude 1,550 feet.

0- 18 cm.	Dark brown very sandy loam (7·5YR 3/2). Loose on top from recent cultivation, hard, massive, and compact below. Few roots, merging into:—
18- 30 cm.	Red-brown sandy clay (5YR 4/4). Hard, massive and compact, with few roots. A little concretionary ironstone with slight MnO_2. Merging into:—
30-110 cm.	Red sandy clay (2·5YR 4/6 above, 2·5YR 5/8 below). Less hard than above, probably because moister. Massive, with few roots. A little concretionary ironstone, particularly in lower part of horizon. Merging into:—
110-140 cm.	Subspherical ironstone concretions (up to 10 mm. diam.) in friable red sandy clay (2·5YR 5/8). Quartz stone 30 mm. diam. near top of horizon. Merging into:—
140-200 cm.(+)	Coarsely mottled sandy clay, yellow, grey and orange mottles. Ironstone concretions up to 12 mm. diam. with MnO_2. Very few roots.

Drainage. Rather poor, owing to low-lying position and low degree of slope.
Vegetation. Under cultivation for the last three years. Formerly miombo woodland.

Nagaga sandy loam, low-lying form

This is a deep soil in which the upper horizons of the profile have affinities with the Nachingwea series while the rest of the profile is more like a Nagaga soil.

There is a dark reddish brown, or even black, surface horizon having the texture of a loam (25 per cent clay). There is about 3 per cent organic matter in this horizon but the dark colour is not entirely due to this. The pH value lies between 6 and 7.

In the normal form of the Nagaga series the orange-coloured subsoil commences at a depth of about 30 cm., but in this low-lying form the orange colour does not appear until a depth of 50 cm. or more has been reached. The clay content increases in this horizon, reaching a maximum at about 70 cm. and decreasing slightly below this. The pH value shows a minimum of about 5·5 at a similar depth. This is rather higher than in the " normal " profile and shows the lesser degree of leaching.

Two profiles have been studied. In one, No. 139 described below, no concretionary horizon had been met with at a depth of 155 cm. In the other, a concretionary horizon was reached at 160 cm. and the bottom of this horizon had not been reached at 195 cm., the bottom of the pit. In this concretionary horizon the percentage of material over 2 mm. was only 8·6; this was largely pisolitic ironstone but included some quartz gravel. Concretionary ironstone is not a prominent characteristic of this soil.

Except for one small patch on Mitumbati Farm (Map 3) this soil has been found only in the valley to the north-east and east of Chiumbati Farm. However this valley is at this point much wider than any other surveyed in the Nachingwea area and its head is some miles north of Chiumbati Farm. It may be that this " low-lying " sub-series is typical of the lower reaches of valleys, on well-drained parent material, while the " normal " sub-series is commoner in the upper reaches. Further survey will be necessary to decide this point.

Profile 139

Nachingwea, in valley to east of Chiumbati Farm. On a gentle slope (about 1·5 per cent) somwhat above the valley bottom. Altitude 1,300 feet.

0- 15 cm.	Black heavy loam (5YR 2/1). Fairly porous, with weak crumb structure. Moderate amount of fibrous root. Merging into:—
15- 30 cm.	Dark reddish brown sandy clay (5YR 3/3). Massive structure but with some pores. Fewer fibrous roots than above. Merging into:—
30- 60 cm.	Yellow-red sandy clay (5YR 4/6) becoming more orange with depth. Massive but with some pores. Cracking slightly (cracks up to 1 mm. wide) on drying. Very few fibrous roots. Merging into:—
60-100 cm.	Red sandy clay (2·5YR 4/8, near 3·5YR). Massive with few pores. Few roots. Cracking slightly. Merging into:—
100-155 cm.(+)	Yellow-red clay (5YR 5/8). Otherwise as preceding horizon.

Drainage. Probably sluggish but no evidence of prolonged water-logging.

Vegetation. Scrub and bamboo, with a few taller trees, including:—

Acacia nigrescens Oliv.
Albizzia harveyi Fourn.
Markhamia obtusifolia (Baker) Sprague.
Commiphora lindensis Engl.
Oxytenanthera abyssinica (A. Rich) Munro.

Probably intermediate between woodland and riverine communities.

Namatula series, sandy subsoil sub-series

The Namatula series consists of a group of shallow sandy soils derived from acid gneiss. The sub-series with a sandy subsoil shows the most striking difference from the Red Earths already described. The clayey subsoil sub-series, described below, has more points of similarity with the Nachingwea and Nagaga series.

In the sandy sub-series the whole profile down to the concretionary horizon is sandy; clay contents do not exceed 30 per cent and are often much lower. The surface horizon is a grey or grey-brown sand, low in organic matter. It has little structural stability; during rain it is liable to flow and afterwards it dries out with a compact crust. Below this surface horizon there is a pale red, pale brown or yellowish-brown clayey sand, often with a small amount of scattered quartz and feldspar gravel and small ironstone concretions. Typically this horizon is less acid than the corresponding horizon of a Nachingwea sandy loam although in the profile described (profile 105) there is a minimum pH value of 5·1 at 50 cm. depth. The pH values for the clayey subsoil profile (profile 117) are typical of the trend in many Namatula profiles of both sub-series.

This horizon gives place at a depth of 50 to 150 cm. to a thick concretionary ironstone horizon. This horizon is usually about 50 cm. thick and contains a stone-line of large quartz fragments and much quartz and feldspar gravel. The concretions are usually loose and sub-spherical but some cementing with iron oxides may have taken place. When freshly exposed these cemented horizons are soft; some hardening occurs on drying but the material does not become stone-like.

Below the concretionary horizon there is weathered acid gneiss, usually pale grey in colour with coarse red mottles. Red colours may predominate in the upper part but the proportion of grey increases with depth. The original structure of the rock is still visible but the material is soft and easily dug when freshly exposed. Like the cemented concretionary horizon, it hardens somewhat on drying but can be easily crumbled with the fingers.

Exposures in railway cuttings show that the concretionary horizon undulates greatly, according to the rate of weathering of the underlying rock. The depth below the surface is in general much less than that of the concretionary horizon of a Nachingwea soil. This lesser depth of weathering rock allows tree roots to penetrate to material with a relatively high content of calcium, etc., and explains the generally high pH values prevailing in Namatula profiles.

The mottling of the weathering rock zone indicates intermittent water-logging. The frequency and duration of periods of water-logging depends on the extent to which the underlying rock has weathered and varies greatly over short distances. For the same reason the colour of the horizon above the concretionary layer is also very variable. The soils both of the sandy and the clayey sub-series could be subdivided into those showing reddish colours, analagous to the Nachingwea series, and those showing yellowish-brown colours, analagous to the Nagaga series. In the areas of Namatula soil so far surveyed the subsoil colours were too variable for it to be practicable to separate the redder from the yellower subsoil colours on the scale of mapping used.

A sandy Namatula profile is described below.

PROFILE 105

Nachingwea, Paulingi Farm, field 7. Moderate slope (about 3 per cent) on a hillside. Granitic gneiss outcrops about 50 yards to the south, the strike of these rocks being in line with this profile pit. Altitude 1,400 feet.

0- 20 cm.	Brown and grey banded loamy sand (10YR 4/3 after mixing). Plough layer; little structure. A little angular quartz and feldspar (to 4 mm. across).
20- 35 cm.	Yellowish-red clayey sand (5YR 5/6). Massive and fairly hard when dry. Quartz and feldspar as above. Merging into:—
35-140 cm.	Red coarse sandy clay (2·5YR 5/6). Massive and fairly hard when dry. Quartz and feldspar as before but increasing markedly below 100 cm. and subspherical ironstone concretions appearing.
140-165 cm.	Red coarse sandy clay (2·5YR 5/6) with much quartz gravel (to 8 mm.), feldspar (to 4 mm.) and ironstone concretions. Some MnO_2. Several stones of acid gneiss (5 cm. diam.).
165-270 cm.(+)	Weathered acid gneiss. Soft throughout (moist) but original structure increasingly apparent with increase in depth. Upper part predominantly red, lower part predominantly grey. Water seeping in at bottom of pit.

Drainage. Free for upper horizons. Impeded below about 200 cm. by underlying impervious rock.
Vegetation. Maize, healthy in appearance.

NAMATULA SERIES, CLAYEY SUBSOIL SUB-SERIES (Fig. 26)

This soil has a higher percentage of clay in the lower horizons of the profile than has the sandy sub-series just described. Otherwise the two soils are similar.

The surface horizon is a sand, or sometimes a sandy loam, grey or grey-brown in colour. Like all sands in the Nachingwea district it has little aggregate stability and tends to form a crust on drying out after heavy rain. Below this surface horizon the clay increases considerably to about 40 per cent; there is usually also one or two per cent of quartz and feldspar gravel. The colour is usually a reddish brown or yellowish brown, i.e. lower in chroma than that of the Nachingwea and Nagaga soils. The pH values are also higher than in these other two series; in many profiles the pH does not fall below 6. Nevertheless, there is usually a minimum value at about 50 cm. depth.

The lower boundary of this horizon varies greatly in depth but is on the whole deeper than the corresponding boundary of the sandy subsoil sub-series. The concretionary horizon, which lies below, is very similar to that of the sandier soil. Below the concretionary horizon is the mottled weathering rock, soft when moist but still showing the original acid gneiss structure (Fig. 28.)

The differences between the two sub-series of the Namatula soil appear to arise from differences in the composition of the parent gneiss. The rocks with the higher proportion of quartz give rise to the sandy sub-series, and those with a higher proportion of clay-forming minerals to the clayey sub-series. The clayey sub-series also has affinities with deeper Red Earth series. The redder and heavier soils of the clayey sub-series grade into soils of the Nachingwea series, and the yellower into soils of the Nagaga series.

In the soil maps the redder and the yellower forms of this sub-series were not distinguished, for the same reason that the two forms of the sandy sub-series were also mapped together, viz. that they form a mosaic difficult to map on a scale of 1 in 10,000.

An example of a reddish form of the sub-series is described below.

PROFILE 117

Nachingwea, Namanga Farm, field 9, eastern boundary. Almost level ground on crest of a ridge. Altitude 1,500 feet. (Fig. 26).

0- 15 cm.	Very dark grey-brown sandy loam (10YR 3/2). Hard and massive, with few pores (dry). A few fibrous roots. A little angular quartz gravel; a few ironstone concretions, with slight MnO_2. Merging into:—
15- 30 cm.	Reddish-brown very clayey sand (5YR 4/3). Hard and massive (dry). Angular quartz and irregular ironstone (to 5 mm. diam.); slight MnO_2. Merging into:—
30- 65 cm.	Red sandy clay (2·5YR 4/6). Moist and fairly friable. A few fibrous roots. Increasing quartz gravel and ironstone; slight MnO_2; a few feldspar fragments in lower part of horizon. Merging into:—
65-120 cm.	Yellowish red sandy clay (5YR 4/6) with much quartz gravel (to 12 mm.), subspherical ironstone (to 8 mm.), feldspar and MnO_2. Stoneline of subangular quarts (to 10 cm. across) at top of horizon. Merging into:—
120-175 cm.	Greyer sandy clay, with coarse red mottling. Much quartz gravel; increased feldspar, but less ironstone than above; MnO_2 present. Some roots to 175 cm. The material shown in Fig. 28 is from this horizon.
175-205 cm. (+)	Rotted rock; roughly horizontal white and rust-coloured bands showing original structure of the acid gneiss. Slight MnO_2.

Drainage. The presence of *Brachystegia boehmii* indicates impeded drainage.

Vegetation. Thin miombo woodland, including:—

Brachystegia boehmii Taub.
Brachystegia bussei Harms.
Combretum binderanum Kotschy.

VEGETATION OF THE RED EARTHS

There is no close association between any of the Red Earth soil series and any particular type of vegetation. The influence of soil texture over-rides that of other factors, as described in the section on vegetation (p. 33). The Nachingwea and Nagaga loams and sandy loams tend to carry Upland Thicket, *Pterocarpus-Ostryoderris-Combretum* woodland and its variants, *Millettia-Markhamia* woodland or *Combretum* scrub. The very sandy loams and sands belonging to these two series tend to carry miombo. There is, however, a considerable middle range in texture in which any of the above mentioned communities can occur. The miombo woodland on Nachingwea and Nagaga soils is usually well-grown and dense and dominated by one of the following species:

Brachystegia spiciformis.
B. bussei.

Sclerocarya-Combretum woodland, with bamboo, is often found on the wetter Nagaga sandy loams of both the " normal " and " low-lying " sub-series.

The Namatula series, which usually have a very sandy surface texture, tend to carry miombo woodland. On better-drained sites *Brachystegia allenii* is frequently dominant. On level areas, liable to suffer temporarily from a high perched water-table the woodland is usually thin and contains many non-*Brachystegia* species, e.g. *Diospyros* and *Terminalia.* The chief *Brachystegia* in such situations is usually *B. boehmii.*

Bamboo is liable to occur on any of the Red Earths and in any vegetation community except the Upland Thicket. It does not grow thickly except in the *Sclerocarya-Combretum* woodland or occasionally the *Pterocarpus-Ostryoderris-Combretum* and *Millettia-Markhamia* woodlands. The factors which determine its distribution are unknown.

FERTILITY OF THE RED EARTHS

Most field experiments with fertilisers have been on the Nachingwea sandy loam. Non-leguminous crops, maize in particular, suffer from nitrogen deficiency and top-dressing with sulphate of ammonia gives very considerable increases in crop. The nitrogen deficiency is especially marked in years of higher than normal rainfall.

Phosphates usually increase the yields of both legumes and non-legumes but the response depends on the particular site. Reasonable yields can be obtained without additional phosphate but a dressing of 1 cwt. per acre of single superphosphate appears to be worth while for maize and groundnuts. Dressings of 2 to 3 cwts. usually give higher yields but only in occasional experiments has such a dressing been shown to give an economic return. With non-legumes there is little response to phosphate fertiliser unless nitrogen is also applied. Several experiments have shown residual effects of phosphate in the second crop after the application of the fertiliser.

The above remarks apply primarily to soils of the Nachingwea series. There have been few experiments on the Nagaga soils but those which have been carried out show a similar trend However, yields without fertiliser tend to be somewhat higher than on the Nachingwea soils and responses to fertilisers rather lower. The usefulness of the Nagaga sands for arable cropping is limited by their liability to erosion.

There have also been few experiments on the Namatula soils. The sub-series with a clayey subsoil appears to behave similarly to the Nachingwea soils although somewhat more liable to erode. The sandy subsoil sub-series has on the whole given poor results. Crops are usually stunted and chlorotic. It is possible that these sandy soils suffer from temporary waterlogging during periods of heavy rain and from lack of moisture during dry periods.

There is some evidence of calcium deficiency in some of the Red Earths, chiefly affecting groundnut yields. (Anderson, 1955). An exchangeable calcium figure of 2 m.e./100g. soil appears to be about the critical level. On some of the highly acid and calcium-deficient patches of Nachingwea soil, referred to on p. 43, some recent liming experiments have shown an appreciable response to the application of 1 ton of burnt lime to the acre. Increased yields were obtained with groundnuts, soya bean and maize.

There appears to be no deficiency of potassium. Applications of potash fertilisers have depressed yields in several experiments, particularly on soils low in calcium.

The extractable phosphorus figures given in Table 26 are of doubtful value for deducing phosphorus deficiency. Although citric acid extracts rather more phosphorus than O.3N hydrochloric acid the amount extracted is still extremely low in comparison with that from soils of temperate regions. Nevertheless these Red Earth soils are not acutely deficient in available phosphorus since they give fair yields without fertiliser, as noted above. The extractable phosphorus figures for these mature soils should be compared with those for immature Red Earths, given on p. 70.

MINERALS OF THE CLAY AND SAND FRACTIONS

Muir *et al.* (1957) have examined the clay fraction of a typical profile of each of the three Red Earths found at Nachingwea by X-ray Diffraction and Differential Thermal Analysis. In every case the clay fraction was mainly kaolinite. Haematite and goethite were present in amounts of the order of 10 per cent. No gibbsite or boehmite were detected.

The sand fraction is mainly quartz. A separation in bromoform (S.G.2.9) of the fine sand fraction of a Nachingwea sandy loam gave the following results:—

Horizon	0-15 cm.	50-100 cm.
Heavy minerals (per cent of fine sand)	7·8	6·0

Muir *et al.* reported appreciable amounts of feldspar in the fine sand fraction of several Nachingwea sandy loams. One profile contained some sillimanite. Hornblende and ilmenite are frequently present in small amounts, as is shown in Appendix I, where the approximate composition is given for the fine sand fraction of a number of Nachingwea, Nagaga and Namatula series profiles.

Other Red Earths in the vicinity of Nachingwea

Two Red Earth profiles from Matekwe, 50 miles to the west of Nachingwea, have been examined. The rock here is a coarse-grained granitic gneiss belonging to the Masasi series (geological series).

One soil was similar in colour to the Nachingwea series (2·5YR 4/6 below 25 cm. depth) but in most other properties it resembled the Namatula soils. The pH value was between 6·0 and 6·5 for all horizons and the clay content less than 20 per cent.

In the upper 45 cm. of the profile there was 2 per cent or so of quartz and feldspar gravel. Below this was a horizon of loose ironstone concretions with considerably more gravel than above. This continued to 120 cm. which was the bottom of the pit.

The other soil examined was yellower in colour (5YR 5/6 to 5/8 below 40 cm.) and had affinities with both the Nagaga and Namatula series but chiefly with the latter. The pH values, for example, were about 6·2 in all horizons and there was always a few per cent of gravel. The clay content rose from 10 per cent at the surface to 30 per cent at 50 cm. depth.

These soils, derived from a different geological formation than those around Nachingwea, will probably not fit into the soil series erected for the Nachingwea soils and will require their own series when they come to be mapped.

II. DEEP SANDS

A number of soils whose chief characteristic is the sandiness of their profiles have been grouped together as " Deep Sands." The surface horizon usually contains only 5 to 10 per cent of clay and although the clay content rises in the lower horizons it is usually less than 15 per cent at 50 cm. depth and not more than 30 per cent at greater depths. At a depth of 1 to 2 metres there is a concretionary ironstone horizon although in one series, the Mitumbati sands, the concretionary horizon lies somewhat nearer the surface, typically at 60 to 80 cm. depth.

These Deep Sands are found on middle and lower slopes. The degree of slope is usually less than 5 per cent. At this small angle of slope lateral movement of water in the lower horizons of the profile is slow. Since water enters freely into the surface horizons of these sandy soils, water-logging of the lower horizons of the profile is probably frequent during the wet season. The concretionary horizon indicates the usual upper limit of water-logging.

The parent material of these soils is colluvium derived from Red Earths higher up the slope and carried down the slope by run-off after rain. The sandiness of the colluvium is due to sorting during transport. The sand is deposited on the middle and lower slopes while much of the clay originally associated with the sand is carried on into the valley-bottoms, or even right out of the area.

Classification of the Deep Sands

These soils have been divided into three series; the Nailala series being subdivided into two sub-series.

Series	*Sub-series*
Nailala	(i) Orange subsoil
	(ii) Brown subsoil
Nangoi	
Mitumbati	

The Nailala sands develop on deep colluvium and are thus related to the Nachingwea and Nagaga series formed on the deeper-weathering rock or on the heavier colluvial deposits. The different subsoil colours reflect differing incidences of water-logging in the upper part of the profile. The distinction between the two sub-series in the field was based on the soil colour at a depth of 40 to 50 cm.

The Nangoi series is an extreme case of the Nailala series. The profile consists of 1 to 2 metres of almost pure quartz sand. The Mitumbati sands are rather shallower than the Nailala sands, which they generally resemble. Where observed in depth, they overlie acid gneiss and therefore have affinities with the Namatula soils.

NAILALA SERIES

As briefly stated above, these soils develop on sandy colluvium derived from Red Earths lying higher up the slope.

The surface horizon is very sandy, with 5 to 10 per cent of clay and 2 to 3 per cent of silt. The sand is somewhat darkened by organic matter but this amounts to only about 1 per cent. The reaction is near neutral and presumably the return of bases in leaf fall and in ash is sufficient nearly to saturate the small amount of soil colloids.

The clay content increases with depth to about 25 per cent at 50 to 100 cm. and remains fairly constant below this. The pH falls with increasing depth, sometimes to below 5. In the better-drained orange sub-series the fall is usually more marked than in the poorly-drained brown sub-series. The organic matter decreases rapidly in the lower horizons. The exchangeable base content of the subsoil horizons is low; it may fall to 1 m.e. per 100 g. in the more acid subsoils.

At a depth of 1 to 2 metres a horizon of hard ironstone concretion is reached. These are usually irregular in shape but sometimes a proportion of them are spherical (pea-iron, see Fig. 29). Associated with these hard concretions are a number of soft irregularly-shaped earthy concretions. There is not usually any accumulation of quartz gravel on the concretionary horizon. Only one profile pit passed through the concretionary layer and in this pit there was a horizon of red, white and yellow mottled material below. This may have been decomposing rock but was more likely, from the similarity of its clay content to that above the concretionary horizon, to have been further colluvial material with local precipitation of ferric oxide. Continuing precipitation appears to produce the soft, earthy concretions of the ironstone horizon. The two sub-series of the Nailala sands are described below.

NAILALA SAND, SUB-SERIES WITH ORANGE SUBSOIL

This sub-series occurs on the better-drained sites. Consequently the profile is subject to leaching and the subsoil pH may fall below 5. The colour of the surface horizon is a dark grey or dark grey-brown. The subsoil colour, at a depth of about 50 cm., is typically 5YR 4/6 to 5/6.

This soil usually occupies mid-slopes, coming next below soils of the Nagaga series. This can be seen in the Experiment Farm area (Map 2). Occasionally a soil, apparently of this sub-series, lies at the crest of a ridge, e.g. on Mitumbati Farm, in the south-west corner of Map 3. Of the two profiles examined here P21 had about one metre of sand overlying a prominent quartz stone-line while P142 had 2½ metres of sand above a gravel and concretionary ironstone horizon. The mode of formation of this soil is probably different from that of Nailala sands on slopes. The existence of patches of Namatula and Mitumbati soils in the vicinity of P21 and P142 suggest the influence of granitic gneiss.

An example of the normal, mid-slope form of the sub-series is described below.

PROFILE 94

Nachingwea, Malawandu Farm, south of field 20N. Very gentle slope (ca. 1 per cent) in area of ill-defined drainage. Altitude 1,500 feet.

0- 15 cm.	Dark grey loamy sand (2·5Y 4/1). Loose. Moderate amount of fibrous roots. A few ironstone concretions (to 4 mm. diam.) with slight MnO_2. Merging into:—
15- 35 cm.	Brown loamy sand (7·5YR 4/2). Becoming massive. Fewer roots. Ironstone as above. Merging into:—

35- 90 cm.	Reddish-brown clayey sand (5YR 4/4). Massive structure. Increasing subspherical and irregular ironstone concretions (to 8 mm. diam.) with MnO_2. Merging into:—
90-170 cm.	Reddish-yellow sandy clay (7·5YR 6/6) with much earthy concretionary ironstone. A little MnO_2. Many tree roots to about 170 cm.
170-185 cm. (+)	Increasing amount of irregular earthy ironstone, with MnO_2. Massive and harder than horizon above. Few roots.

Drainage. Surface drainage poor. Upper horizons porous but probably a temporary water-table at about 100 cm. after heavy rain.

Vegetation. Well-grown miombo woodland, with candelabra *Euphorbia* (*Euphorbia bilocularis* N.E.Br.) on termite mounds. Other species include:—

Julbernardia globiflora (Benth.) Troupin (Dominant).
Brachystegia boehmii Taub.
Ostryoderris stuhlmannii (Taub.) Dunn ex Baker f.
Diplorhynchus mossambicensis Benth.
Pseudolachnostylis bussei Pax ex Hutch.

Nailala Sand, sub-series with brown subsoil

These soils occur lower down the slope than the orange sub-series and are correspondingly more liable to periodic water-logging. To this their brown colour is due. These soils are less leached than the orange sub-series and so have a higher pH in the lower horizons. The surface is grey or dark grey in colour and the subsoil, at a depth of 50 cm., is about 7·5YR 5/4, or 10YR 4/3.

The division between the two sub-series is not very clear-cut and intermediate forms are frequently found.

A profile of the brown sub-series is described below.

Profile 93

Nachingwea, Experimental Farm, southern boundary. Bottom of slope (slope ca. 1 per cent) at head of a drainage line. Altitude 1,500 feet.

0- 15 cm.	Dark grey sand (10YR 4/1). Loose, single-grain structure. Moderate amount of fibrous roots. Merging into:—
15- 35 cm.	Dark grey-brown sand (10YR 4/2). Single-grain structure, becoming slightly compact. Fewer fibrous roots. Merging into:—
35- 60 cm.	Brown clayey sand (7·5YR 5/4). Massive structure. Merging into:—
60-140 cm.	Light brown clayey sand (7·5YR 6/4) becoming yellower with depth (10YR 6/4). Massive. Slight coarse mottling in lowest 10 cm. of horizon. A little "shot" ironstone. Merging into:—
140-200 cm. (+)	Coarsely mottled clayey sand, red, white and yellow mottles, with much "pea" ironstone. Massive. Some tree roots to full depth of pit.

Drainage. Poor. Profile porous, but subject to temporary high water-table.

Vegetation. Miombo woodland of moderate density with grass about 4 feet high. *Julbernardia globiflora* dominant. Other species include:—

Pterocarpus angolensis DC.
Ostryoderris stuhlmannii (Taub.) Dunn ex Baker f.
Diplorhynchus mossambicensis Benth.
Pseudolachnostylis bussei Pax ex Hutch.

Nangoi Sand (Fig. 31)

The Nangoi profile consists largely of quartz sand, and most of this is coarse sand. Down to a depth of 1 to 2 metres the silt content is only 1 to 2 per cent and the clay below 10 per cent. The soil occurs in belts running along the foot of slopes or in "cups" surrounding the heads of small valleys, e.g. east of field 22C, Map 2. The parent material of the soil is probably deposited from sheets of storm water flowing down the slope when its velocity is checked at the foot of the slope.

The surface of the profile is usually dark grey in colour. It is about neutral in reaction and has an organic carbon content of less than 1 per cent, sometimes even less than a half per cent.

The lower horizons may be orange, brown or almost white in colour. As in the Nailala sands, the subsoil colour is largely controlled by the degree of aeration of the subsoil. Most of the Nangoi sands, because of their position at the foot of the slope, are water-logged for considerable periods in the wet season. Brown to very pale brown colours are therefore common. In the profile described below the pH is near 7 in all horizons but in some profiles considerably lower values are found at a depth of 50 cm. or more.

The sandy horizons of the Nangoi profile usually rest on a stratum of heavy clay, which contributes to the poor drainage of these soils. This clay is probably the original soil of the valley floor which has become buried by the sand washed down the slope. There may, however, have been some illuviation with clay from the overlying deposit.

The combination of low exchange capacity and frequent water-logging makes the soil very infertile. Tree growth is poor and the ground cover of grass and sedges is sparse, with much exposed bare ground.

A Nangoi profile is described below.

PROFILE 133

Nachingwea, on Ruponda road, east of Namanga Farm. Near the bottom of slope (slope ca. 4 per cent). Altitude 1,500 feet.

0- 12 cm.	Very dark grey coarse sand (10YR 3/1). Loose, single grain. Many fibrous roots. Merging into:—
12- 30 cm.	Dark grey-brown coarse sand (10YR 4/2). Massive; slightly hard consistence. Fewer fibrous roots. Merging into:—
30- 60 cm.	Brown coarse sand (10YR 5/3). Massive; rather harder than above. Fewer fibrous roots. Merging into:—
60-150 cm.	Pale orange slightly clayey coarse sand (5YR 6/6). Massive and hard; compact. Few fibrous roots. Merging into:—
150-200 cm. (+)	Similar to above (colour 7·5YR 6/6). A few angular quartz stones (to 5 cm. across) were present near 200 cm. depth.

Drainage. Apparently well-drained within the profile but the vegetation suggests poor drainage. Probably temporarily water-logged after rain, due to the large volume of water flowing from the hillside above.

Vegetation. Thin miombo woodland. Species include:—

Julbernardia globiflora (Benth.) Troupin.
Terminalia sericea Burch.
Diplorhynchus mossambicensis Benth.
Combretum sp.

MITUMBATI SERIES

Soils of the Mitumbati series are similar to the Nailala sands but the concretionary horizon is nearer the surface and is much more strongly developed. This horizon consists of hard rounded concretions and there is often a fair degree of cementation into a massive ironstone horizon. Quartz gravel occurs throughout the profile indicating derivation from acid gneiss and there is often a stoneline of quartz fragments. The series is to be distinguished from the Chiumbati series in which there is only a shallow horizon of sand over the concretionary layer and in which the concretionary layer is always cemented and slag-like.

The surface horizon of a Mitumbati soil is a grey to dark grey sand, with about 5 per cent of clay and a nearly neutral reaction. The organic carbon content is less than one per cent. Below the surface horizon the colour is usually brown but may be reddish-brown (e.g. 5YR 4/4). Normally the pH in these lower horizons is slightly below 7 but values below 5 have been noted. The texture continues sandy down to about 75 cm., at which depth the concretionary horizon is met with.

The concretionary horizon is 50 to 100 cm. thick, contains numerous hard iron concretions and is frequently somewhat cemented with iron oxides. Where there is a stoneline this may lie in the loose upper part of the horizon or may be cemented into the middle. Deposits of MnO_2 are fairly frequent.

Only one profile pit penetrated through the concretionary horizon to the underlying material. This proved to be a coarsely mottled sandy clay (perhaps weathered rock in situ) with a lower content of gravel than the upper horizons. This horizon seemed unconnected with the rest of the profile, which probably originated from granitic gneiss further up the slope.

Most Mitumbati profiles appear to have developed on colluvial material derived from Namatula soils. Profile 114 (Map 3, Namanga Farm, field 7) is such a soil. However, Profile 141 (west side of Map 3) does not lie in such a situation. This profile is near the anomalous Nailala profiles (21 and 142) already noted as lying on the crest of a ridge. Possibly the rock forming this ridge weathers to a particularly sandy material; where drainage is free a Nailala profile will develop but where it is impeded, perhaps by shallow weathering of the rock, a Mitumbati soil will form. This would make such Mitumbati sands special cases of Namatula sands. Whether this explanation of P141 is the true one or not, there is little doubt that most Mitumbati soils have developed on somewhat gravelly colluvium derived from Namatula soils.

The Mitumbati sands are usually poorly drained though rather better drainage is indicated by the reddish subsoil colours of a few profiles. The profile described below is typical of the poorer-drained soils. The subsoil colour was yellowish brown and there was a perched water-table occupying the lower part of the concretionary horizon when the pit was dug, some weeks after the end of the rains. This profile had a quartz stone-line cemented into the concretionary horizon.

Profile 116

Nachingwea, Namanga Farm, between fields 9 and 10. Almost level ground on the crest of a ridge. Altitude 1,500 feet.

0- 10 cm.	Dark grey loamy sand (10YR 4/1). Top 2 or 3 cms. loose, single-grain structure; fairly hard and massive below. Some pores, many fibrous roots. A little quartz gravel and irregular ironstone pisolites (to 4 mm.). Slight MnO_2. Merging into:—
10- 35 cm.	Brown slightly clayey sand (10YR 5/3). Fairly hard and massive at top, becoming moister and more friable below. Moderate amount of fibrous roots. Quartz and ironstone as above. Slight MnO_2. Merging into:—
35- 70 cm.	Yellow-brown slightly clayey sand (10YR 5/4). Moist and friable. Some fibrous roots. Increasing quartz gravel (to 3 mm.) subspherical and irregular ironstone (to 8 mm.) and more MnO_2. Fairly clearly defined from:—
70-145 cm.	Rust-coloured and black concretions in brown sandy clay (7·5YR 5/6), cemented. Ironstone concretions to 12 mm. diam., quartz gravel to 5 mm., and much MnO_2. At 110-130 cm. there is a horizon of subangular quartz stones, up to 10 cm. across. Water-table at 140 cm. (end of May).

Drainage. External drainage good. Freely drained in upper horizons, probably impeded in concretionary horizon. High water-table during, and shortly after, the rains.

Vegetation. Thin miombo woodland, with many species typical of wet soils.

Brachystegia boehmii Taub.
Diplorhynchus mossambicensis Benth.
Bauhinia petersiana C. Bolle.
Pavetta crassipes K. Schum.

Natural Vegetation of the Deep Sands

The Deep Sands usually carry miombo woodland. The association of miombo woodland with sandy surface textures is general in the Nachingwea district and has already been described. The dominant tree on the Deep Sands is usually *Julbernardia globiflora* but is sometimes *Brachystegia allenii.* Where drainage is poor *Brachystegia boehmii* comes in and is usually dominant where drainage is particularly sluggish. *Bauhinia petersiana* is a common shrub in the wetter sites

Bamboo is sometimes present but is never dense. Grass growth is usually good, a tall *Digitaria* sp. being common. However, on the Nangoi series the grass is usually poor.

Tree growth is good on the better-drained sands. *B. allenii* grows up to 50 feet tall and *J. globiflora* nearly as tall. But on the Nangoi sands the trees are smaller and widely-spaced; *J. globiflora* is the usual dominant on these sands.

Large termite mounds are common on these soils and these have their own vegetation community. *Tamarindus indica*, *Euphorbia bilocularis* and *Sterculia africana* are common dominants.

FERTILITY

Provided the drainage is satisfactory, the Deep Sands will produce good yields but it is likely that their reserve of fertility will be lower than that of the Red Earths with their higher organic matter and clay contents. In years of low rainfall the sands often give better yields than the red sandy loams owing to the better entry of water into the sands and the greater availability of the water within the profile. This is illustrated by the results in Table 15 from two field experiments on the Experimental Farm in 1953, a dry year. One experiment was planted on a Nachingwea sandy loam and the other on a Nailala sand.

TABLE 15

Response of maize to phosphorus fertiliser on a Nachingwea sandy loam and a Nailala sand

Fertiliser dressing lb./acre of P.	Yield of maize lb./acre of grain	
	Nachingwea sandy loam	Nailala sand
Nil	1843	2377
9lb.	1732	2840
18lb.	1858	2850
Sig. diff. 1 per cent	345	343

A practical difficulty in the utilisation of the Nailala sands for arable cropping is their great liability to erode.

MINERALS OF THE CLAY AND SAND FRACTION

There have been no determinations of clay minerals from the Deep Sands. It is unlikely that the clay is appreciably different from that of the red soils, i.e. kaolinite.

The commoner minerals in the fine sand fraction of three profiles are listed in the Appendix I. Zircon and ilmenite were the commonest minerals after quartz. Hornblende, which is of frequent occurrence in the red soils, is rare in the Deep Sands.

III. SHALLOW SANDS OVERLYING MASSIVE IRONSTONE — CHIUMBATI SERIES

These soils appear to be an extreme form of the Mitumbati sands. The very sandy upper horizon had less than 5 per cent of clay and a thickness of 15 to 50 cm. in the profiles examined. At its lower boundary this sand passes abruptly into a cemented and slag-like layer of concretionary ironstone. This is difficult to penetrate with a pick-axe even when moist. Inclusions of quartz and feldspar are often present in this concretionary horizon.

In no profile was this concretionary horizon completely penetrated so it is not known what lies underneath. However, blocks of similar material are occasionally found on the surface in valley bottoms (Fig. 33). They appear to have been left stranded by the stream cutting down its bed as a consequence of the rejuvenation of the drainage mentioned on p. 32. There seems little doubt that these blocks were originally formed below the surface at about the level of the wet season water-table and that they are analogous to the ironstone horizons described in the preceding paragraph. These residual blocks are usually about 30 cm. thick and lie immediately upon acid gneiss showing little sign of weathering. It is a reasonable assumption that acid gneiss always underlies the ironstone horizon of these shallow sands, particularly as these soils are always associated with Namatula and Mitumbati soils which develop from acid gneiss.

The soils have a high water-table in the rains or are even subject to short duration flooding. The ironstone has many sand-filled pores and channels and is probably quite pervious to water, so that the drainage is more likely to be impeded by the underlying little-weathered rock.

Only one series of these soils has been distinguished—the Chiumbati series. A profile is described below.

These soils are of little or no agricultural value. No information has been obtained on the minerals of either the sand or clay fractions.

PROFILE 118

Nachingwea, Namanga Farm, field 9, southern end. In an incipient drainage line, in a slight slope (1½ per cent). Altitude 1,500 feet.

0- 12 cm.	Dark grey sand (10YR 4/1). Friable, easily breaking down to single grains. A few fibrous roots. A few irregular ironstone pisolites (to 15 mm. across), angular quartz (to 3 mm.). Moderate MnO_2. Merging into:—
12- 30 cm.	Brown sand (7·5YR 5/3). Friable. Fewer roots. Quartz and ironstone as above; very slight MnO_2. Has been disc-ploughed to this depth but soil not completely overturned.
30- 52 cm.	Pale brown sand (10YR 6/3). Moist and friable (May). Few roots. Irregular ironstone (to 20 mm.), quartz (to 4 mm.), slight MnO_2.
52 cm.(+)	Massive cemented concretionary ironstone (Fig. 30). Nodules black, with rust-coloured coating. Some sand in interstices. Horizon difficult to penetrate with pick or crowbar, although moist.

Drainage. Frequently water-logged during the rains. Concretionary horizon is pervious to water.
Vegetation. Cleared from bush three years previously but no longer cultivated. Now carrying an incomplete cover of grass, chiefly *Pennisetum polystachyon* Schult.

VEGETATION OF THE SHALLOW SANDS OVERLYING IRONSTONE

The natural vegetation of these soils is grass and sedges with scattered small trees and shrubs. At one site (Profile 102, Map 2) the following tree species were noted:—

Diplorhynchus mossambicenis Benth.
Pseudolachnostylis bussei Pax.
Pteliopsis myrtifolia Engl. and Diels.
Vitex sp.

IV. SOILS WITH MOTTLED CLAY SUBSOIL

These mottled clays are somewhat leached soils occurring in low-lying situations. They are subject to temporary water-logging, which gives them a yellowish or pale brownish subsoil, with rusty mottling at depth and iron concretions. The water-logging is due to the heavy texture of the subsoil which hinders downward movement of water. The soils lie on slight slopes so that the water in the profile eventually drains away laterally and removes a proportion of the bases and other plant nutrients.

Although these soils have a heavy subsoil, the surface horizons may be sandy. In the Naipingo series the surface may be a shallow sand, a sandy loam, or a deep sand with mottling indicating bad drainage conditions. Three sub-series of the Naipingo soils have been recognised, corresponding to these three grades of surface texture.

In the Kihue series the soil is a heavy clay to within a few inches of the surface. In one sub-series there is a shallow surface layer of sand; in the other the texture of the surface is a loam or clay loam.

Finally there are the "water-hole soils," soils occurring in small depressions within one of the other two series and which are under water for periods varying from a few weeks to several months each year.

The complete list of series and sub-series is, therefore:—

Series	*Sub-series*
Naipingo	(1) Sand (less than 50 cm. deep)
	(2) Sandy loam
	(3) Mottled sand (over 50 cm. deep)
Kihue	(1) Thin sand over clay
	(2) Clay loam
Water-hole soils	

A fuller description of these soils follows.

Naipingo Sand

This is the commonest sub-series of the Naipingo soils. The profile consists of a dark grey loamy sand at the surface, with 5 to 10 per cent of clay, a pH just below 7 and an organic matter content of 1 to 1·5 per cent. Below this is a brown clayey sand with similar pH and clay content but less organic matter. From a depth of 20 or 30 cm. the clay content increases with depth and the colour of the soil becomes yellow or pale brown. The pH decreases with depth to a minimum of about 5 at 1 to 2 metres depth.

Rusty mottles and concretionary ironstone make their appearance at a depth of about 1 metre (70-150 cm. in various profiles). The ironstone is often of the "pea ironstone" variety but irregular earthy concretions also occur. The absence of mottling or concretions from the upper 70 cm. of the profile distinguish soils of the Naipingo series from Kihue soils.

The Naipingo sands develop on deep colluvial deposits and no profile pits reached recognisable weathered rock. The soils are distinguished from the Nagaga sands, which they resemble in some respects, by the yellower or browner colour of the subsoil (7·5 to 10YR) and from the Nailala sands with brown subsoil by the rapid increase in clay content between 20 and 50 cm. depth in the Naipingo sands.

A typical profile is described below.

Profile 127

Nachingwea, Namanga Farm, field 7, western boundary. Area of ill-defined drainage. A low-lying, almost level site. Altitude 1,600 feet.

0- 10 cm.	Very dark grey loamy sand (10YR 3/1). Structure massive but weak; porous, with many fibrous roots. Merging into:—
10- 25 cm.	Very dark brown clayey sand (10YR 2/2). Massive, porous, fewer fibrous roots. Merging into:—
25- 50 cm.	Dark brown clayey sand (10YR 4/3). Massive, very hard, cracking slightly (irregular vertical cracks) on drying. Few fibrous roots. Merging into:—
50-140 cm.	Yellow sandy clay (10YR 7/6). Dry, massive and hard above 80 cm., moist and friable below. Few fibrous roots. Merging into:—
140-190 cm.	Light yellow-brown sandy clay (10YR 6/4). Slight coarse rusty mottling. Some subspherical ironstone (to 5 mm. diam.) with slight MnO_2. Very moist, friable.
190-210 cm.(+)	Very pale brown sandy clay (10YR 8/4). Much earthy ironstone (to 10 mm. diam.) and hard pisolites (to 5 mm.), with MnO_2. Water seeping in (October).

Drainage. External drainage poor; internal drainage slow. The water-table may have been kept up artificially by seepage from a recently constructed dam nearby but the water level in the dam had been low and the high water-table is probably natural.

Vegetation. Miombo woodland felled 3 years previously. Now grass and regenerating bush. *Tamarindus indica* on termite mounds.

Naipingo sandy loam

The sandy loam is very similar to the sand just described. It differs chiefly in having a higher percentage of clay throughout the profile. The surface horizon contains 10 to 20 per cent of clay. In the two profiles of this sub-series examined the mottling appeared at a shallower depth (about 50 cm.) than is usual in the sand. The minimum pH was also at about 50 cm. depth. These differences from the sand are to be expected in the heavier and less permeable soil.

A Naipingo sandy loam is described below. In this profile many of the concretions were in the form of " shot ironstone," i.e. hard spheres of diameter 2 to 3 mm.

Profile 125

Nachingwea, Namanga Farm, east of dam. Area of ill-defined drainage; slope slight (about 1 per cent). Altitude 1,600 feet.

0- 12 cm.	Black sandy loam (10YR 2/1). Massive, but fairly soft. Moderate amount of fibrous roots.
12- 25 cm.	Similar, becoming browner (10YR 4/2). Fewer fibrous roots but fairly porous. Merging into:—
25- 50 cm.	Yellow-brown sandy clay (10YR 5/4). Massive and hard. A few irregular, narrow vertical cracks. Few fibrous roots but fairly porous. Merging into:—
50- 75 cm.	Similar, but very hard (dry). Coarse rusty mottles in lower part of horizon. A few fibrous roots.
75- 95 cm.	Similar (10YR 6/6, brownish yellow) with coarse rusty mottling throughout. Merging into:—
95-125 cm.	Pale brownish yellow sandy clay (10YR 7/5) becoming greyer with depth. Earthy ironstone concretions (to 10 mm.); a little " shot " ironstone; slight MnO_2. Moist and fairly friable. (October).
125-190 cm.(+)	Very pale brown sandy clay (10YR 8/3) with orange coarse mottles (5YR 5/6) 1 to 2 cm. across. " Shot " ironstone and subspherical concretions (to 5 mm.); slight MnO_2. Very few roots. Moist and friable.

Drainage. External drainage poor. Internal drainage slow.

Vegetation. Cleared from miombo 3 years previously. Now grass verge to road.

Naipingo Mottled Sand

This not very common sub-series is distinguished from the normal Naipingo sand, described above, by the greater depth of its sandy surface horizon. However, only soils in which periodic water-logging occurs within the upper 50 cm. of the profile (indicated by mottling of the sand) are included in this sub-series. Soils of similar textural horizons but without this indication of water-logging so near the surface are classed at Nailala sands.

No mottled sand profile has been fully analysed. The following profile was seen in a road-side borrow-pit to the west of the Experimental Farm. The available analytical data are included in the description.

0- 10 cm.	Dark grey sand (10YR 4/1). Fairly hard and massive. pH (water) 6·5, clay 9 per cent. Merging into:—
10- 28 cm.	Brown clayey sand (10YR 5/3), with coarse rusty mottling. Some hard pisolites (3 per cent); pH 5·7, clay 10 per cent. Merging into:—
28- 75 cm.	White and yellow mottled very clayey sand (10YR 6/4 after mixing). Massive, fairly hard; slight irregular vertical cracking on drying. pH 5·0, clay 20 per cent.
75-105 cm.(+)	White sandy clay, with coarse rusty mottling and hard pisolites (19 per cent); pH 5·2, clay 23 per cent.

The pit did not extend beyond 105 cm. but there was presumably a heavier horizon at greater depth to produce the water-logging. Auger bores in patches of this soil on Namanga Farm showed a high water-table during the rains.

Kihue Series

The soils of the Kihue series have a higher clay content than the Naipingo soils and consequently an even greater impedence in the drainage. Rusty staining along root channels is visible in the surface horizon and coarse rusty mottles and iron concretions at a somewhat greater depth.

The series is not of common occurrence in the areas surveyed. Apparently the rather lighter-textured parent material which gives rise to the Naipingo soils is more abundant in the situations in which these series form. This parent material is probably colluvial since no quartz gravel horizon or stone-line was reached in the 6 foot profile pits in any of the mottled clays.

The Kihue sub-series with thin sand overlying clay consists of a surface horizon 15 to 20 cm. thick of dark grey sand. Below this the colour fades to yellow and the clay content increases rapidly. The lower part of the profile is similar to that of the " clay " sub-series described below. The profile is probably a composite one produced by colluvial sand becoming deposited upon a former Kihue clay profile.

Only one profile of the heavier, Kihue clay loam sub-series has been fully examined; this is No. 126, described below. The soil resembles the Naipingo soils in the low organic matter content (about 1·5 per cent) and the neutral pH of the surface horizon and in the increased acidity, pale colour, mottling and concretions of the lower horizons. The chief differences are the rusty staining along roots in the surface horizons of the Kihue soil and the higher clay content of all horizons. In the profile examined there was 11 per cent of " stones and gravel " (almost entirely concretionary ironstone) in the 40-75 cm. horizon and 29 per cent in the 75-120 cm. horizon. This is higher than the usual for Naipingo soils but it is not known if there is an invariable feature of the Kihue profile. The sandier members of the Kihue series grade into the Naipingo sandy loams.

Profile 126

Nachingwea, Namanga Farm, below dam. Almost level ground in a minor valley. Altitude 1,600 feet.

0- 8 cm.	Very dark grey-brown loam (10YR 3/2). Moderate crumb structure. Fair number of fibrous roots. Fine rusty staining along root channels. Merging into:—
8- 18 cm.	Yellow sandy clay (10YR 7/6). Weak crumb structure. A few hard, dark red ironstone pisolites (5 to 10 mm. diam.) with slight MnO_2. Fair number of fibrous roots. Fine rusty staining along root channels. Merging into:—
18- 40 cm.	Yellow sandy clay (10YR 7/6). Weak clod structure. More numerous pisolites than above. Fewer fibrous roots. A little rusty staining along root channels. Moist (October). Merging into:—
40- 75 cm.	Yellow sandy clay (10YR 7/6). Massive structure. Pisolites increasing (some from this horizon are shown in Fig. 29). Rusty mottles (1 cm. diam.), increasing with depth. Moist. Merging into:—
75-120 cm.	Sandy clay, coarsely mottled strong brown and very pale brown (10YR 8/4). Many hard pisolites (2 to 10 mm. diam.) with MnO_2. A few roots. Moist. Merging into:—
120-175 cm.(+)	Sandy clay, coarsely mottled strong brown (7·5YR 5/6) and white (10YR 8/1). Fewer pisolites. Very few roots. Moist.

Drainage. Very poor. Seasonally water-logged in the lower horizons. Seasonal water-holes (natural) in the vicinity.

Vegetation. Miombo woodland felled 3 years previously. Now grass and regenerating bush, including:—

Brachystegia boehmii Taub.
Bauhinia petersiana C. Bolle.
Acacia sp.

Water-hole Soils

These soils only occur in local depressions in Naipingo soils (possibly Kihue soils also) and therefore occupy only a small total area. In general features they resemble the Naipingo and Kihue soils but as a result of prolonged water-logging of the whole profile ironstone concretions occur in all horizons.

These concretions are usually of the " pea ironstone " type. In two profiles studied they comprised 2 to 3 per cent of the upper horizons and increased in quantity in the lower horizons. However, the amount of concretionary ironstone depends on drainage conditions at each particular site and some water-hole soils appear to have much more than 2 or 3 per cent in the surface horizon. The analyses do not show the rise in pH at the surface which is shown by the Naipingo and Kihue soils. This is not due to lack of vegetation for grass growth is usually satisfactory, as is shown by the organic matter figures. The higher surface pH values of the Naipingo and Kihue soils is probably due largely to plant ash left by the annual grass fires. In the water-holes the grass tends to remain green longer after the end of the rains and so often fails to get burnt, which may have some bearing on the pH value of the surface soil.

The profile described below is under water for a week or two at a time in an average season, during periods of heavy rain. The clay content is fairly high ranging from 28 per cent in the surface to more than 40 per cent below 12 cm., but another similar profile showed only 15 per cent clay in the surface horizon and 28 per cent at 50 cm.

PROFILE 51

Nachingwea, Namanga Farm, east of field 6. In a valley-bottom. Altitude 1,500 feet.

0- 12 cm. Very dark grey-brown sandy loam (10YR 3/2) with some pea ironstone (to 4 mm.).

12- 72 cm. Brownish yellow sandy clay (10YR 6/6) with increased amount of pea ironstone and a little quartz gravel.

72-186 cm. Pale brown sandy clay (10YR 6/3) with coarse rusty mottling (cemented by iron oxides) and pea ironstone, the latter decreasing with depth.

Drainage. The profile is situated in a local depression in the valley, and is under water periodically during the rains.

Vegetation. Thin miombo woodland, with tall grass. *Brachystegia boehmii* Taub. dominant.

NATURAL VEGETATION OF THE MOTTLED CLAYS

The surface horizon of the mottled clays is usually fairly sandy so that water penetration is good. The heavier soils, the Kihue clay loams, are low-lying and liable to temporary flooding. There is therefore no shortage of water in these profiles. Correspondingly, the natural vegetation of all these soils is miombo woodland. *Brachystegia boehmii* is the usual dominant. Frequently there is a fair variety of other species, including *Pteliopsis myrtifolia*, *Julbernardia globiflora*, etc., but elsewhere, particularly on Napingo sands, there is an almost pure stand of *B. boehmii.*

FERTILITY

These soils are too wet for most arable crops. An area on Namanga Farm was cleared and cropping was attempted but the land was soon allowed to revert to grass and is now used for grazing. The local grasses do not provide good pasture but some improvement is no doubt possible.

When the higher land is farmed and graded soil conservation terraces are constructed, the lower ground often has to carry large volumes of storm water discharged by the terraces. This is an additional reason for a grass cover on the mottled clays.

MINERALS IN THE CLAY AND SAND FRACTIONS

The clay mineral is probably kaolinite, judged by the low cation exchange capacity. No mineral identification in the fine sand fraction has been made.

V. HARDPAN CLAYS — NYATI SERIES

These clays with a hard and impervious subsurface pan have been mapped as the Nyati series. They are black or dark grey loams or clay loams with grey or brown rusty mottled subsoils. The impermeability of the lower horizons is associated with an appreciable proportion of sodium in the exchange complex and perhaps also with some illuviation of clay.

Two profiles have been examined. Both were on a slight slope and the wetness of the upper part of the profile—indicated by mottling—was due in part to seepage of water from higher up the slope and in part to the impermeable subsoil preventing vertical drainage. Both profiles were slightly calcareous in their lower horizons due to evaporation of the seepage water during the dry season and the absence of any appreciable downward water movement during the wet season. There was also a slight accumulation of salts in the lower horizons.

The surface soil is a black or very dark grey loam or clay loam with 2 to 3 per cent of organic matter. The pH was 6 or slightly below and calcium and magnesium were the predominant cations. Below the surface horizon the soil becomes grey or brown, with fine rusty mottling. At greater depths (about 50 cm.) the mottles become larger and concretionary ironstone appears.

At about metre depth the pH rises above 7 and the exchangeable sodium becomes appreciable in the hardpan horizon; a rise in conductivity indicates a slight accumulation of soluble salts. The profile described below possessed a stone-line at about 1·5 metres depth; the other profile examined had no stone-line. In both profiles weathered acid gneiss was recognisable at 2 metres depth.

The second profile was in general similar to that described below but had a rather heavier surface horizon (24 per cent clay). The horizons immediately below the surface were brown in colour. Below 90 cm. depth the exchangeable sodium rose to 4 m.e. per 100 g. soil (34 per cent of the total exchangeable bases). This portion of the profile was very impermeable. Water was seeping into the pit in the zone 60-90 cm. but below this the soil was dry. The clay content was 40 per cent in the 60-90 cm. horizon but only 36 per cent. in this impermeable horizon. There was less carbonate than in profile 151 but the pH rose to above 8.

In the early stages of mapping, particularly on the Experimental Farm, all heavy black soils with mottled grey or brown subsoils were put in the Nyati series. Not all these soils had the impervious hardpan layer of the profiles analysed and it now seems probable that some of them should therefore have been put in another series, perhaps the Kihue series. This applies, for example, to the long strip of soil occupying a valley bottom at the east boundary of the Experimental Farm map. The mottling of this soil is probably due to a high water-table during the wet season. The soil carries thick bamboo; in this it differs from the Kihue soils of Namanga, which supported miombo. The true Nyati soils, with subsurface hardpan, always seem to be associated with acid gneiss.

Occasionally, where a Nyati soil lies on a moderate slope, the upper black horizon is missing and there is a brown impermeable horizon exposed at the surface. This is the case in some of the occurrences of this soil on Chiumbati Farm. The absence of the uppermost horizon of the normal profile is almost certainly due to accelerated erosion.

TABLE 16. *Soluble salts in a Nyati sandy loam. Profile* 151

Horizon (cm.)	Total souble salts, %	Chloride %	Sulphate %
100-135	0·07	0·001	0·002
135-150	0·09	0·002	0·002
150-180	0·09	0·003	0·003

Profile 151 is described below. Analyses are given in Tables 25 and 26. Extraction of the lower horizons with water removed about 0·1 per cent of soluble salts but these appear to have been largely bicarbonates since the other likely anions, chloride and sulphate, were low (Tabe 16).

PROFILE 151

Nachingwea, Paulingi Farm, north of field 5. Gently sloping ground (slope 3 to 4 per cent) on the edge of a valley.

0- 10 cm.	Very dark grey sandy loam (10YR 3/1). Weak crumb structure, massive, slightly porous. Fairly friable when moist; hard and cracking slightly on drying. Moderate amount of fibrous root. Merging into:—
10- 25 cm.	Dark grey sandy clay (5YR 4/1). Massive, hard (fairly dry) and compact with cracks 2-3 mm. wide. Slight fine rusty mottling (5YR 4/8), and slight quartz gravel. Merging into:—
25- 50 cm.	Dark grey clay (5YR 4/1) massive, very hard (fairly dry), compact. Increasing fine rusty mottling. Slight quartz gravel and small ironstone. A few fine roots. Merging into:—
50-100 cm.	Similar (10YR 4/1). Rusty mottles in upper part, changing to soft concretionary ironstone. Very few roots. Merging into:—
100-135 cm.	Similar (4/0). More friable than above, and with small calcareous concretions.
135-150 cm.	(but undulating). Sparse stone-line of quartz and decomposing feldspar in dark grey-brown clay (10YR 6/2). Hard, massive, compact, cracking slightly. A few small ironstone concretions.
150-180 cm.	Pale grey sandy clay (10YR 6/1) with quartz gravel and small ironstone. Fine rusty mottling and specks of carbonate. Very few roots.
180 cm.(+)	Decomposing acid gneiss, light grey (2·5Y 7/2) with white and strong brown mottles.

Drainage. Very poor. Site receives seepage water from above and drainage within the profile is very slow. Although about 5 inches of rain had fallen in the month before digging the pit, there was little penetration of moisture below 10 cm. depth.

Vegetation. Very open woodland, with clumps of bamboo and scattered *Sclerocarya caffra, Combretum* spp. and *Acacia* spp.

NATURAL VEGETATION AND FERTILITY OF THE NYATI SERIES

The poor drainage conditions in these soils discourage tree growth. The natural vegetation is open woodland, open scrub, or grassland. Trees observed include *Sclerocarya caffra, Terminalia sericea*, and *Combretum* spp., all of which are tolerant of wet conditions.

No attempts have been made to cultivate these soils and it does not appear likely that they would be suitable for arable cropping.

MINERAL FRACTIONS

No work has been done on the minerals of the clay or sand fractions.

VI. DARK-COLOURED LOAMS AND CLAYS

These are dark-coloured and fairly heavy soils formed on lower slopes and in valley bottoms. Except perhaps for the Nkumba brown sub-series, they develop on colluvial or alluvial material. The Nkumba brown sandy loam occurs in the better-drained sites and appears to develop on weathered material which has not moved much, if at all, since it was formed from the underlying rock. This soil has affinities with the soils of the Nagaga series.

The dark soils differ from the mottled clays, which occupy a similar topographic position, in that in no horizon is the pH much below 7, whereas in the mottled clays the subsoil is strongly acid. Also, the dark soils do not have a prominent concretionary horizon. The Nkumba brown soil is not quite typical since it has a moderately acid subsoil and a concretionary horizon.

The reason for this difference between the two soil groups is probably a matter of drainage. For example, on the east side of Namanga Farm (Map 3) there is a minor valley with mottled soils of the Naipingo and Kihue series in its upper stretches and Nkumba soils lower down. Where the mottled soils develop the longitudinal fall of the valley is 1 to 1·5 feet in 100, while in the lower part with Nkumba soils the fall is less than 1 in 100. It seems likely that there is some lateral subsurface drainage at the steeper gradient, leading to loss of calcium and other nutrients, although the flow is not rapid enough to prevent periodic water-logging. The Nkumba soils in the flatter reaches of the valley not only receive dissolved bases from the mottled soils but retain much of the water which enters the profile. The net loss of bases from the Nkumba soils is therefore small. Nkumba soils also prevail in the wide and gently-graded valley to the east of Chiumbati Farm, which is further evidence of the development of the series in situations not subject to much leaching.

The absence of concretions is presumably related to the absence of acid horizons in the profile. However, movement of iron is not directly a result of an acid environment since much of the dissolved iron in soils having a concretionary horizon seems to be mobilised in the almost neutral weathering rock zone below the concretionary horizon. It may be that there is some mobilisation of iron in the dark loams but that its reprecipitation is diffuse, throughout the profile, and not concentrated in one horizon.

It is perhaps worth noting that the iron mobilised in the mottled clays is reprecipitated in the same soils and is not carried down the valley to any appreciable extent to form concretions in the Nkumba soils below. The dark clays have a relatively high organic matter content of 2 to 4 per cent and fairly high level of available phosphorus (acid-soluble) in their surface horizons.

Two series of dark loams have been recognised. The commoner one, the Nkumba series, is subdivided into three sub-series.

Series	*Sub-series*
Nkumba	(i) Brown sandy loam
	(ii) Black loam or sandy loam
	(iii) Black swamp soil
Naunga	—

The Nkumba swamp soil differs considerably from the other two sub-series and might perhaps merit full series status.

NKUMBA BROWN SUB-SERIES

The soil is intermediate between the Nagaga low-lying sandy loam and Nkumba black loam. The following catena occurs repeatedly in the north-east corner of Map 4:—

Nachingwea sandy loam
Nagaga sandy loam (normal form)
Nagaga low-lying sandy loam
Nkumba brown sandy loam
Nkumba black loam

The surface horizon of the Nkumba brown soil is a black to very dark grey loam or sandy loam. It possesses a noticeable crumb structure. This horizon is followed by a dark brown sandy clay—5YR 4/4 or 4/6 to 7·5YR 3/4 in various profiles. In the profile described below (P140) small amounts of concretionary ironstone were present from a depth of 50 cm. down to 155 cm. (and probably beyond). In another profile there was a definite concretionary horizon with 15 per cent " stones and gravel " (mostly concretions) at 118-130 cm. depth. However, this soil lay on a fair slope (4 per cent) and there is some doubt as to whether the portion of the profile below 118 cm. belonged to the upper portion.

Profile 140 has a low surface pH which is perhaps due to flow of flood water over the soil; flooding occurs in this valley after heavy rain. The other profile, mentioned in the previous paragraph, is above flood level and the pH of the surface horizon (6·85 in water) is higher than that in the lower horizons.

Large raised termite mounds are common on this soil. These large mounds, which occur on most of the lower-lying soils, are probably associated with a high water-table. On the well-drained Nachingwea series soils the termitaria are largely below surface level.

A description of profile 140 is given below.

PROFILE 140

Nachingwea, north-east of field 151, Chiumbati Farm. Nearly level ground (slope about 1½ per cent) in a valley. Altitude 1,300 feet.

0- 12 cm.	Black loam (5YR 2/1) with weak crumb structure. Fairly porous. Medium number of fibrous roots. Merging into:—
12- 30 cm.	Dark brown sandy clay (7·5YR 3/2). Massive, with some pores. Fine irregular vertical cracks on drying (½ mm. wide). Fewer fibrous roots. A few hard pisolites (to 3 mm. diam.) with slight MnO_2. Merging into:—
30- 60 cm.	Dark red-brown sandy clay (5YR 3/4). Massive, with a few pores (termite tunnels?). Slight cracking on drying. Very few fibrous roots, some hard pisolites (to 3 mm. diam.) with slight MnO_2. Merging into:—
60-100 cm.	Yellowish-red sandy clay (5YR 4/6). Similar, but with more and larger (to 8 mm.) pisolites with moderate MnO_2. One quartz stone (10 cm. diam.) at 90 cm. depth. Merging into:—
100-155 cm.(+)	Brown sandy clay (7·5YR 4/4), similar to above.

Drainage. External drainage poor; ground low-lying and hummocky. Internal drainage slow but probably rarely water-logged.

Vegetation. Deciduous woodland and scrub. Species include:—

Albizzia harveyi Fourn.
Combretum sp.
Acacia usambarensis Taub.
Oxytenanthera abyssinica (A. Rich) Munro.
Adansonia digitata L. (baobab).

NKUMBA BLACK SUB-SERIES

The Nkumba brown soil, which has just been described, lies on the lower slopes bordering the wider and more gently-graded valleys. The actual valley floor is usualy occupied by a Nkumba black loam. The soil may be flooded for a day or two when the rain is heavy but prolonged flooding leads to the development of the " swamp " sub-series.

The surface horizon of the Nkumba black loam, like that of the brown sub-series, is black, neutral in reaction, has a fairly high organic content and has a noticeable crumb structure. In texture it is usually a loam, i.e. rather heavier than the brown soil. The lower horizons appear black when wet but are very dark grey or very dark brown (10YR 2/2 to 10YR 3/3) when dry. Below a depth of about 50 cm. (35-65 cm.) there is an increasing amount of yellowish or reddish-brown mottling. There is usually a very small amount of concretionary ironstone and quartz gravel but this was probably in the parent material from the beginning. The pH remains above 6 at all depths and the cation exchange capacity is relatively high. Calcium is the predominant cation but magnesium is almost as high in the lower horizons of the two profiles analysed. Sodium is only present in traces and there is no accumulation of salts.

The surface horizon is sandier than the lower horizons. Below 30 to 40 cm. the texture is fairly uniform. It seems likely that the parent material is alluvium. The variation in the proportions of fine and coarse sand in successive horizons of profile 138 (Table 25) support this derivation. The " stones and gravel " in this profile were largely quartz.

PROFILE 138

North-east of field 151, Chiumbati Farm. Level ground (slope less than 1 per cent) in valley bottom. Altitude 1,300 feet.

0- 15 cm.	Black sandy clay (10YR 2/1), with weak crumb structure. Slight irregular vertical cracking on drying. Many fibrous roots. Merging into:—
15- 30 cm.	Very dark brown sandy clay (10YR 2/2). Weak cloddy structure, hard. Slight cracking as above. Fewer fibrous roots. Merging into:—
30- 65 cm.	Dark brown clay (10YR 3/3). Massive, with tendency to cloddy structure. Slight cracking as above. Fewer fibrous roots. Some small pisolites, with much MnO_2. Merging into:—
65-165 cm.(+)	Dark grey brown clay (10YR 3/2) with reddish-brown coarse mottling (5YR 4/4). Massive and hard. Some quartz gravel (to 6 mm.) and hard pisolites (to 4 mm.) with much MnO_2. Very slight cracking. No fibrous roots. (Horizon below 140 cm. sampled with auger).

Drainage. External drainage poor. Internal drainage slow.
Vegetation. *Sclerocarya caffra* woodland scrub, with bamboo. Other species include:—
Acacia usambarensis Taub.
Steganotaenia araliacea Hochst.
Piliostigma thonningii (Schum.) Milne-Redhead.
Cassia sp.

NKUMBA SWAMP SUB-SERIES

This soil is found in depressions in areas of the black sub-series where prolonged flooding can occur in the rains. The valley in which profile 134 (described below) was dug is flooded for several months on end in wetter years but not at all or only temporarily in dry years.

The surface horizon is a black loam or clay which cracks on drying. In profile 134 the pH was low at the surface but in another profile it was 6·4 (in water) at the surface, diminishing to 5·5 between 50 and 100 cm. and then rising to over 7 below 150 cm. The low pH at the surface of profile 134 may be due to flow of flood water over the water-logged soil. There is often rusty staining along root channels in the upper horizons.

The lower horizons consist of a dark grey clay or sandy clay with brown mottling, increasing in amount with depth. Irregular vertical cracks appear on drying. There is little change in clay content with depth, neither in profile 134 nor in the other profile analysed, in which the range of clay was only from 33·3 per cent in the sandiest horizon to 34·1 per cent in the heaviest. Small amounts of quartz gravel and concretionary ironstone probably belong to the parent material, as they appear to do in the previous sub-series.

Conductivities (1:5 suspension in water) are slightly higher in the swamp soils than in the other Nkumba soils but do not indicate serious salinity. The highest figure in profile 134 was 0·091 millimhos while in the other, sandier, profile it reached 0·123 millimhos at 150 cm. depth. This latter figure corresponded to 0·08 per cent salts extractable by water. Associated with these salts was a trace of carbonate and an exchangeable sodium figure of 1·4 m.e./100 g. soil, which is considerably higher than the exchangeable potassium but represents only 12 per cent of the total exchangeable bases. In profile 134, as will be seen in Table 26, the highest sodium value was only 4 per cent of the total exchangeable bases.

There is little doubt that the parent material of profile 134 is alluvium. The uniformity of texture is somewhat unusual for alluvium (cf. the Mandai soils) but is perhaps due to the long-continued activities of the soil fauna. These include frogs and crabs. In addition the soil is far enough away from hills and steep slopes to escape the washes of sand and gravel seen in the Mandai soils. In the sandier profile the proportions of sand, silt and clay are so close to those in a Nachingwea sandy loam higher up the slope that the parent material must have been transported bodily without resorting i.e. it is colluvial.

The clay profile, No. 134, is described below.

PROFILE 134

Nachingwea, Nkumba mbuga. Level ground, seasonally flooded. Altitude 1,350 feet.

0- 20 cm.	Dark grey clay (10YR 4/1) with pronounced rusty staining along roots. Slightly hard consistence when dry. Cracking widely on drying. Disturbed by ploughing.
20- 40 cm.	Dark grey clay (10YR 4/1) (dark blue-grey when wet). Less staining than horizon above. Angular blocky structure, very hard, wide cracks and burrows (? crabs). Merging into:—
60-100 cm.	Dark grey clay, with coarse mottling, brown and rust-coloured, increasing with depth. Blocky structure, very hard. A little irregular earthy ironstone and hard pisolites (to 8 mm.) with slight MnO_2. Merging into:—
100-200 cm.(+)	Brown (10YR 4/3) and grey (6/0) coarsely mottled clay. A few hard pisolites (to 6 mm.) with slight MnO_2. Moist and plastic. Water-table at 150 cm. (end of October).

Drainage. Seasonally flooded, except in years of abnormally low rainfall. In some years the water does not subside until July or August. Lower horizons waterlogged for most of the year.
Vegetation. Natural grassland.

NAUNGA SERIES

Only one small area of this series has been discovered. It lies to the south of the main road at the eastern edge of the Chiumbati soil map.

The following description is based on one profile pit in this patch of soil.

The surface horizon is a black sandy clay with 30 per cent of clay and nearly 4 per cent of organic matter. This, and the succeeding, horizons crack widely on drying (Fig. 32). The pH at the surface is just below 7.

In the lower horizons the clay rises to 60 per cent at 100 cm. depth and the pH increases to over 8. In the lowest horizons there is concretionary carbonate and appreciable salinity. The conductivity of 0·716 millimhos in the horizon 140-210 cm. corresponded to 0·15 per cent water soluble salts. The exchangeable sodium is appreciable but only forms 5 per cent of the total exchangeable cations. Calcium is the predominant cation; potassium appears to be on the low side. The cation exchange capacity is higher than in any other soil so far examined in the Nachingwea district; it rises to nearly 50 m.e. per 100 g. soil in the lowest horizon of the profile. This high exchange capacity is due to the montmorillonitic clay in this soil (see below).

The Naunga soils have poor internal drainage, due to their heavy texture, but are not subject to prolonged flooding.

The parent material of the soil appears to be alluvial or colluvial, probably a mixture of the two. It will be seen from the map that the main source of parent material is the Nachingwea sandy loams lying to the east and south. A short distance to the east there are a number of outcrops of basic rock. These were fine-grained amphibolites; a specimen has been described above. (H.13, p. 32).

The Naunga soils are distinguished from the other soils in the district, or at least from others so far discovered, by the wide cracking on drying and the high exchange capacity, both characters arising from the montmorillonitic clay.

PROFILE 137

Nachingwea, east of Chiumbati Farm; west of field 152. Gently sloping land (slope ca. 1½ per cent) at the junction of two valleys. Altitude 1,300 feet.

0- 15 cm.	Black sandy clay (2/0), with weak angular blocky structure. Wide cracks (up to 4 mm.) on drying. Many fibrous roots. Merging into:—
15- 30 cm.	Black sandy clay (5YR 2/1). Similar to above but fewer fibrous roots. Merging into:—
30- 65 cm.	Dark grey clay (4/0) with brown mottling. Weak angular blocky structure. Cracking widely on drying. A few fibrous roots. Merging into:—
65-140 cm.	Dark grey clay (4/0), hard and massive. Cracking on drying. A few roots. Occasional carbonate concretions, a little concretionary ironstone (to 3 mm.) with MnO_2. Sharply defined, over most of profile face, by a slightly undulating layer of flattened petrified tree roots, from:—
140-210 cm.	Grey clay (3/0), cloddy. Irregular vertical and horizontal cracks spaced at about 10 cm. interval. A few carbonate concretions.

Drainage. External drainage fairly good, as a result of the slope, but the area receives water discharged by the two valleys (carrying water after storms). Drainage within the profile very slow, and probably seasonally waterlogged in lower horizons.

Vegetation. Natural grass, coarse, about 1 metre high, with scattered trees and shrubs, including:—

Albizzia harveyi Fourn.
Acacia usambarensis Taub.
Combretum sp.

NOTE.—The petrified roots at 140 cm. depth were flattened and straplike, about 3 cm. wide. They appeared to be mostly iron oxide but retained the outward form of roots. They occupied a layer extending most of the way round the profile pit. They were probably the roots of a tree formerly standing on the site and had spread out horizontally because of adverse soil conditions in the horizon below.

Natural Vegetation of the Dark Clays

These dark loams and clays appear to be too wet for miombo or for *Pterocarpus* woodland. The better drained Nkumba brown and black loams usually carry *Sclerocarya caffra* woodland with thick bamboo or else a riverine thicket community. The latter include the *Piliostigma-Thespasia*-bamboo scrub and the *Acacia usambarensis* scrub of the classification given earlier.

The Nkumba swamp soil and the Naunga clay are wetter, during the rains, and support grassland with scattered trees. Tree species include *Sclerocarya caffra*, *Terminalia sericea*, *Acacia usambarensis* and *Albizzia harveyi*. The longer the period of flooding each year the sparser is the tree growth. One of the trees most tolerant to flooding is *Kigelia aethiopica*.

Fertility

There has been no large-scale cultivation on these soils. Small areas of Nkumba brown and black loams have been used for vegetable growing, for fruit trees, for plant breeding and multiplication, etc., usually with watering in the dry season. The appearance of such crops suggests that these Nkumba loams are very fertile soils, probably the best in the vicinity of Nachingwea. The analytical figures for pH, exchangeable bases and phosphorus support this claim.

Unfortunately most of these soils are subject to flooding and cultivation of the land would necessitate some measure of flood control. It is not easy to see how this could be done at any reasonable cost. Alternatively, the water might be retained and rice grown but in many years it would be difficult to provide water for any but the lowest-lying of the soils.

The Nkumba swamp soils will grow rice successfully, except perhaps in the driest years, but their area is small. The Naunga soil might also be utilised for rice but its area is even smaller.

Minerals of the Clay and Sand Fractions

The clay fraction of the Naunga soil is a mixture of montmorillonite and kaolinite. (Muir *et al.*, 1957.) This applies to both the clay of the surface horizon and that from a depth of 200 cm. The presence of the montmorillonite accounts for the high cation exchange capacity of these soils. Whereas in most other soils the trend of the exchange capacity with increasing depth follows the organic matter rather than the clay content (Fig. 23), in the Naunga profile the exchange capacity is controlled by the clay content.

The fine sand fraction of the Naunga profile contained, besides quartz, some hornblende, sillimanite, staurolite, kyanite, rutile, garnet, tourmaline, zircon and epidote.

No similar examination of Nkumba soils has been made but it seems likely that they also contain some clay more active than kaolinite. In Table 17 some values of cation exchange

TABLE 17

Cation exchange capacity per 100g. of clay (less than 2μ) and of organic carbon for various soil series

Soil series (and profile)		Cation exchange capacity, m.e./100 g.	
		Clay	Organic carbon
Nachingwea	(P17)	12	450
Nagaga	(P90)	11	395
Nkumba brown	(P140)	13	860
Nkumba black	(P138)	35	540
Nkumba swamp	(P134)	32	250
Naunga	(P137)	65	370

capacity of the clay have been calculated from the percentages of organic carbon and clay and the total exchange capacity for two or more horizons of a profile. The assumption in such calculations is that the exchange capacity of a gram of clay or of organic matter does not change from one horizon to another. Only the upper horizons of a profile were used since this assumption is less likely to hold in the lower horizons. The method can only give rough results because of the limited accuracy of the Walkley-Black organic carbon determinations.

VII. ALLUVIAL SOILS — MANDAI SERIES

It is probable that some of the Nkumba soils have formed on alluvial deposits but in those soils there has been appreciable subsequent development of the profile. The Mandai soils, on the other hand, are found on young alluvial deposits in which the original stratification is still prominent. These young alluvial soils occur in narrow valleys in broken country to the west and north-west of Namanga Hill (Map 3) and in valleys leading away from the ranges of hills to the east of Chiumbati Farm (Map 4).

The Mandai soils are brownish in colour and vary from fairly light to moderately heavy in texture. There are usually strata of sand and gravel at intervals in the profile. These represent occasional violent floods and perhaps periodic expansion of native cultivation on to too steeply sloping ground in the catchment area.

One profile is described below. The soil is slightly acid in all horizons. The cation exchange capacity is high, being similar to that of the Nkumba soils, and the citric-soluble phosphorus is very high for soils of the district. There is also a fairly high organic matter content, due to good growth of grasses and herbs on these soils favourably supplied with both nutrients and moisture.

These soils will obviously vary greatly from place to place, depending on the source of the deposited material, the velocity of the floods, and so on. Another profile analysed was more acid in the lower horizons, had a lower cation exchange capacity and a lower phosphorus figure. In these respects it approached one of the sedentary soils, e.g. the Nachingwea series. Either it was an older soil or the alluvial material had originated in the erosion of older soils higher up in the catchment area.

PROFILE 150

Nachingwea, north of Mitumbati Farm. In an incised valley about 50 metres wide, near centre of the valley. Practically level. Altitude 1,600 feet.

0- 10 cm.	Dark brown loam (7·5YR 3/2), with weak crumb structure. Friable, fairly porous, with a moderate amount of fibrous root. Cracking slightly on drying. Some angular quartz and quartz-feldspar (to 20 mm.), also irregular ironstone concretions (to 4 mm.) with slight MnO_2. Merging into:—
10- 50 cm.	Very dark grey-brown sandy clay (10YR 3/2), with cloddy to weak crumb structure. Hard, somewhat less porous than above; moderate amount of fibrous root. Cracking in irregular vertical cracks (5 to 10 cm. between cracks). Less quartz, etc., than above. Clearly defined from:—
50- 64 cm.	Dark grey-brown clayey sand with much gravel (to 20 mm.) quartz, feldspar, pea ironstone, slight MnO_2. Loose, but fairly compact. Separated by a horizontal crack from:—
64-153 cm.	Dark brown sandy clay (7·5YR 4/2). Massive and compact; very few roots. Slight irregular vertical cracking. Scattered quartz and feldspar gravel (to 20 mm.) including a definite gravel horizon at 90 to 95 cm. A little irregular ironstone (to 3 mm.) with MnO_2. Clearly defined from:—
153-164 cm.	Dark brown clayey sand with much gravel (to 15 mm.) quartz, feldspar, irregular ironstone with moderate MnO_2. Loose, but less so than upper gravel horizon. Clearly defined from:—
164-200 cm.(+)	Dark brown clayey sand (7·5YR 4/3). Massive and compact layers alternating with looser, coarse sandy and gravelly layers. Quartz and feldspar to 5 mm. Irregular ironstone concretions with MnO_2.

Drainage. Apparently well-drained. Water was reached in a nearby pit in an earlier year but at a greater depth than 2 metres, and probably earlier in the dry season. This older pit was dry at the date of sampling (September) to its full depth of 3 to 4 metres.

Vegetation. Tall grass and shrubs, with occasional trees. Species include:—

Hyparrhenia sp.
Vernonia glabra Vtke. (a tall herb).
Bauhinia sp. (a small tree).
Acacia usambarensis Taub.
Kigelia aethiopica Decne.

Natural Vegetation and Fertility

Several different vegetation communities are found on these soils. Usually conditions appear to be too wet for close woodland and commonly tall grasses or bamboo predominate; associated with the grasses are scattered trees, particularly *Kigelia aethiopica* but also *Combretum* and other species. Other trees occupy the steep banks of the valleys in which these soils occur and send their roots down into the water which accumulates in the lower horizons of these soils.

Several attempts have been made to use the soils for fruit or vegetables. In most cases the crop has eventually been swept away by floods or covered with sand. Some of these valleys have now been dammed to provide water for the nearby farms. Provided the dam is large enough to absorb the occasional floods and provided some control of the catchment area is exercised, to prevent silting-up of the dams, this practice will enable these Mandai soils to be utilised. The dam will allow a certain amount of irrigation during the dry season. The total area of these soils made available in this way will inevitably be small.

Minerals of the clay and sand fraction

No examination of the clay mineral of these soils has been made. Visual examination of the soils shows a fair proportion of mica and other unweathered minerals. This fact, taken with the high cation exchange capacity, suggests that some micaceous mineral forms part, at least, of the clay fraction.

VIII. ERODED AND IMMATURE SOILS

The stony Nandete soils are produced by severe sheet erosion of one of the mature soils already described. Usually it is a Nachingwea soil which is eroded since these cover the greatest area and, from their position on the higher ground, are susceptible to erosion. Typically, erosion has removed all the soil above the gravel or concretionary horizon so that quartz stones and gravel and concretionary ironstone are exposed at the surface. In extreme cases even this material is removed and the under-lying rock may be visible.

An example of a Nandete soil with exposed stones is illustrated in Fig. 34. No analyses have been done.

Where the underlying rock has been exposed by past erosion a subsequent alteration in conditions may allow the development of a fresh profile on the exposed rock surface. These immature profiles are only found in pockets of a few square feet in area and on the soil map it was not possible to separate them from the Nandete soils in which they occur.

Two of these immature soils have been examined. One of them (profile 152) had developed amongst quartz rubble lying between large quartzite outcrops on Namanga Hill. The chief points to notice are, firstly, the large amount of stones and gravel (88 per cent below 2 cm. depth) and, secondly, the high percentage of organic matter in the fine earth fraction; in the top 2 cm. the organic carbon was 18 per cent of the fine earth. There was a layer of leaf litter, about ½ cm. thick, lying on the surface. It appears that termites are not active at this site, perhaps because of the frequent dessication of these shallow stony soils. This may be the cause of the high organic matter content of this soil.

The other immature soil (profile 153) has developed on weathered basic gneiss in a gully to the west of Namanga Hill. The soil proper is confined to the top 7 cm. of the profile. The stratification below this is inherited from the parent material.

A characteristic of both these young soils is their high available phosphorus, as estimated by extraction with 1 per cent citric acid. The value for the surface horizon of profile 153 was 11 mg. phosphorus per 100 g. soil, which is ten to twenty times the value obtained in the mature Nachingwea series soils derived from similar parent material.

" Total phosphorus " values for these soils were obtained by boiling for one hour with 6N hydrochloric acid. Table 18 gives the values obtained for the upper horizons of the two immature soils and, for comparison, mean values for the uppermost horizon of several of the mature soils.

TABLE 18. *Total phosphorus in the top horizon of immature and mature soils at Nachingwea*

Age	Soil	Total P (mg./100 g. soil)
Immature	Profile 152, 0- 2 cm.	49
	Profile 152, 2-10 cm.	53
	Profile 153, 0- 3 cm.	35
	Profile 153, 3- 7 cm.	27
Mature	Nachingwea series (mean of 6 samples) ..	14
	Nagaga series (mean of 3 samples) ..	9
	Namatula series, clay subsoil (1 sample) ..	9

The total phosphorus is higher in the immature soils than in the mature but only by a factor of about three, compared with the ten to twenty for the citric-soluble phosphorus. The development of the mature profile therefore appears to involve the loss by leaching of about two-thirds of the total phosphorus and the fixation against extraction with citric acid of most of the remaining phosphorus.

Descriptions of these two immature profiles are given below.

PROFILE ON QUARTZ RUBBLE. (PROFILE 152)

Nachingwea, on the crest of a quartz ridge (Namanga Hill). Slope 2 to 3 per cent at site but increasing rapidly to the east and west. Altitude 1,750 feet.

About ½ cm. thickness of slighly decomposed leaf litter, dark grey-brown. Sharply defined from:—

0-2 cm. Dark red-brown loamy sand (5YR 2/2), with much quartz gravel and carbon particles. Loose and porous, with slight crumb structure and a moderate amount of fibrous root. Clearly defined from:—

2-25 cm. Dark red-brown gravelly sandy loam (5YR 3/3), with quartz stones and boulders. Loose and porous, with a moderate amount of fibrous root. Abrupt transition to:—

at 25 cm. Massive quartzite.

Drainage. Very free.

Vegetation. Open woodland, with shrubs and short grass. The trees include:—

Commiphora lindensis Engl.
Combretum binderanum Kotschy.
Brachystegia boehmii Taub.
Markhamia obtusifolia (Bak.) Sprague.

PROFILE ON BASIC GNEISS. (PROFILE 153)

North of Mitumbati Farm, in broken, gullied country. Slope about 10 per cent. Altitude 1,500 feet.

0-7 cm. Dark red-brown friable sandy loam (5YR 3/4), stoneless. Fairly porous, with weak crumb structure and moderate amount of fibrous root. Sharply defined from:—

7-12 cm. Weathered hornblende gneiss, in situ. Speckled 5YR 4/8 to 5Y 2/2. Sharply defined from:—

12-14 cm. (inclined to horizontal.) Iron-stained quartz gravel up to 2 cm. diameter (2·5YR 5/8). A former quartz vein.

14-17 cm. Similar to 7-12 cm. horizon but less weathered.

17-19 cm. Dark red-brown sandy clay (5YR 3/4) with grains of hornblende, feldspar, etc. Of limited horizontal extent, possibly an old root channel.

19-30 cms.(+) Decomposing gneiss, less weathered than upper horizons. Roots to 20 cm. at least.

Drainage. Rapid.

Vegetation. Thin miombo woodland, with an incomplete ground cover of short grass. Trees include:—

Brachystegia boehmii Taub.
B. bussei Harms.
Diplorhynchus mossambicensis Benth.

FIGURE 15. Namanga Farm from Namanga Hill.

FIGURE 16. Brachystegia microphylla (the flat-topped trees) with thicket, north of Chiumbati Farm. The thicket has been cleared from the foreground.

FIGURE 17. Miombo woodland on Nailala sand on site of Nachingwea Experimental Farm. Wet season aspect. Site of Profile 91.

FIGURE 18. Chain-felling miombo woodland, Nachingwea.

FIGURE 19. Pterocarpus-Combretum woodland at Nachingwea after the dry season grass fire.

FIGURE 20. Combretum scrub on site of former African cultivation. After dry season grass fire at Nachingwea.

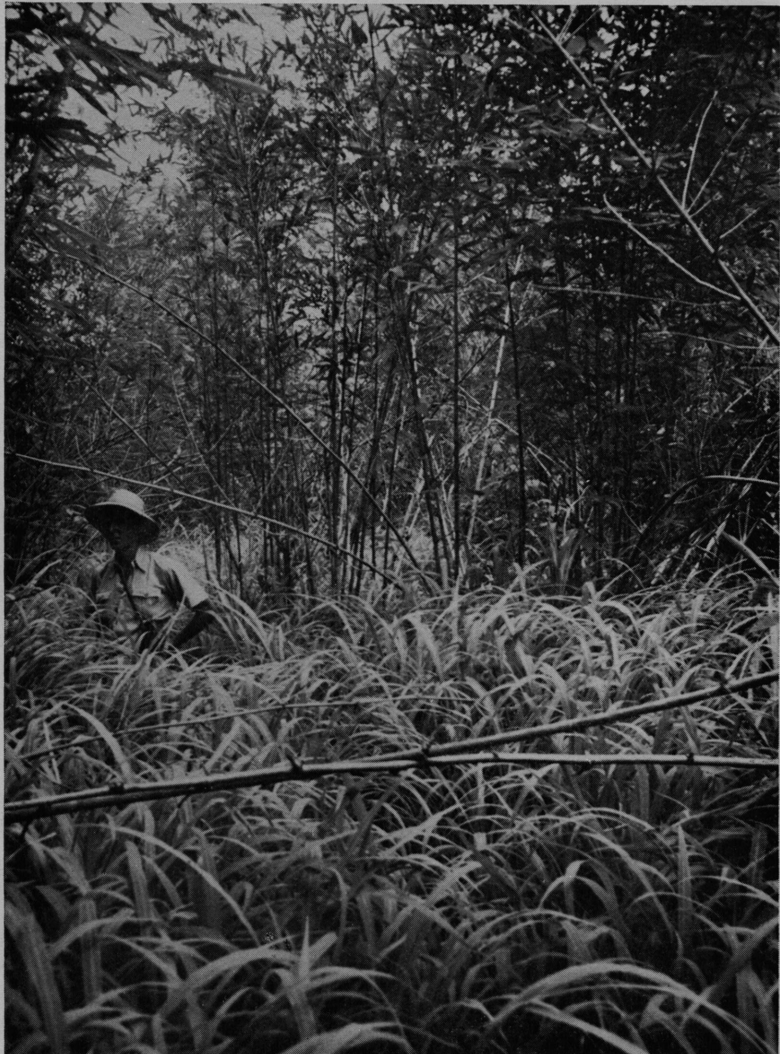

FIGURE 21. Bamboo and grass at Nachingwea.

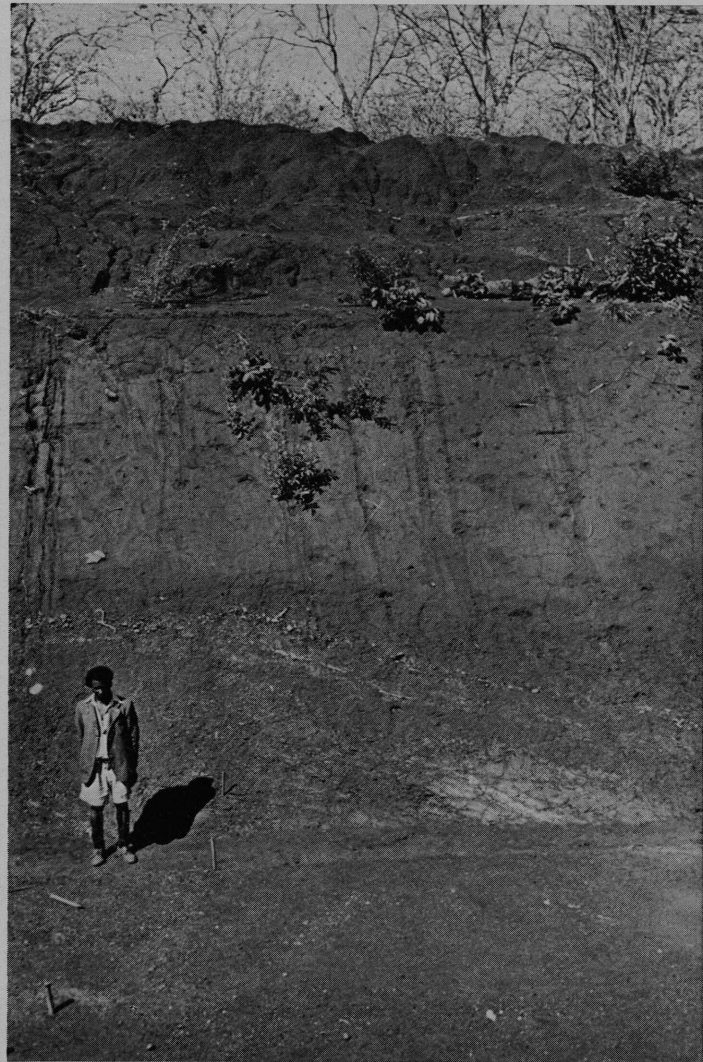

FIGURE 22. A Nachingwea series sandy loam exposed in a railway cutting near Nachingwea. The undulating stone-line lies just above the man's head on the left side of the picture and dips to the right. The rock (distinguishable on the right) is an amphibolite with narrow quartz veins. One such vein lies just below the stone-line in the centre of the picture. The darkening just above the stone-line is due to concretionary ironstone. (The hummocky material at the top is spoil from the cutting ; the original surface is the straight line below this).

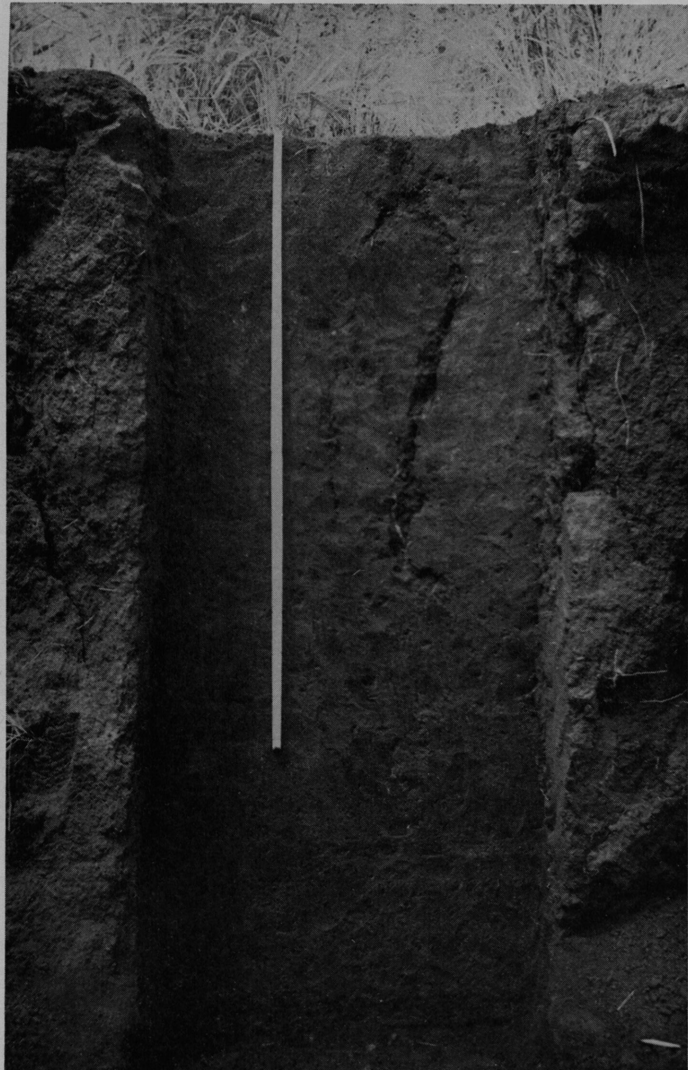

FIGURE 25. A Nachingwea series soil near the Experimental Farm, Nachingwea. The gradual darkening below the bottom of the rule is due to greater moisture. The narrow dark band at the extreme bottom of the profile is the upper part of the concretionary ironstone horizon. The rule is 5 feet (152 cm.) long.

FIGURE 26. Profile pit in a Namatula soil (Profile 117). The stoneline occurs at a depth of about 75 cm.; the white specks visible at a depth of 110—130 cm. are mainly feldspar fragments. The mottled weathered and grass can be seen below the bottom of the rule. (The rule is marked at 10 cm. intervals).

FIGURE 27. Fragments of weathering fine-grained amphibolite from the lower horizons of a soil of the Nachingwea series.

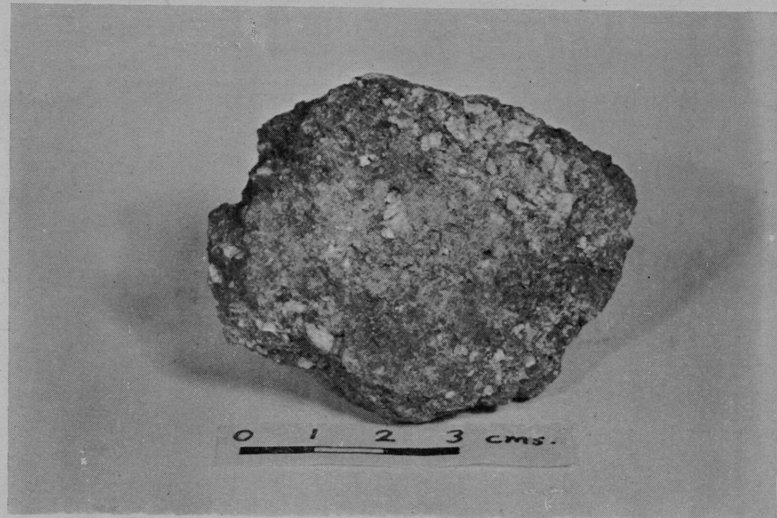

FIGURE 28. Fragment of weathering acid gneiss from the lower horizons (about 150 cm. depth) of a Namatula series soil (Profile 117—see fig. 26). The light-coloured mineral is feldspar.

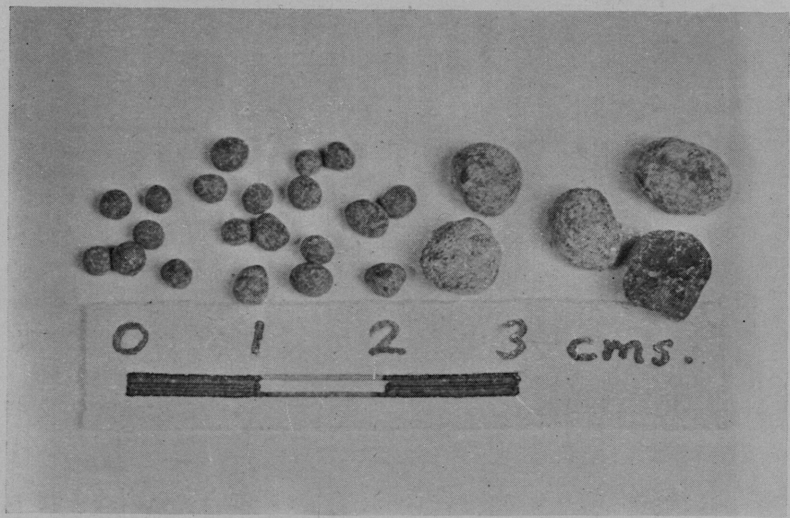

FIGURE 29. Left: "Shot" ironstone from a Nagaga sandy loam. (Profile 113).
Right: "Pea" ironstone from Profile 126 (Kihue series). The dark concretion on the right is seen in section.

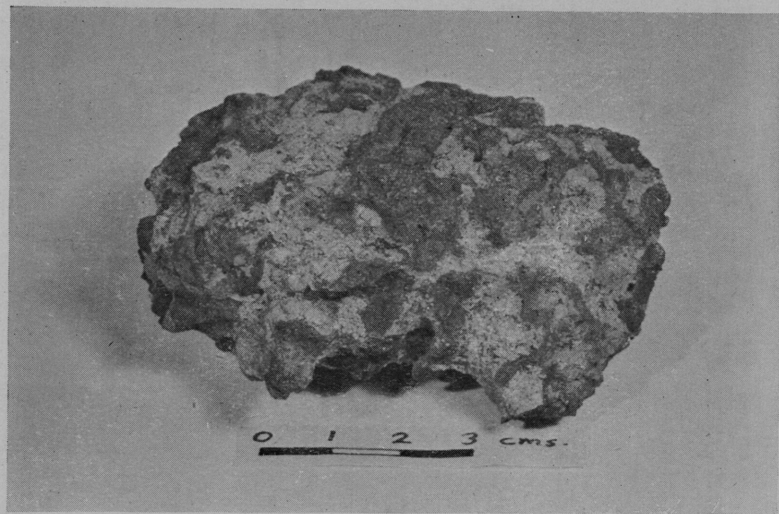

FIGURE 30. A fragment from a massive ironstone sheet—Chiumbati series, Profile 118. The dark areas are hard iron-rich material while the intervening light areas are less firmly cemented clayey sand.

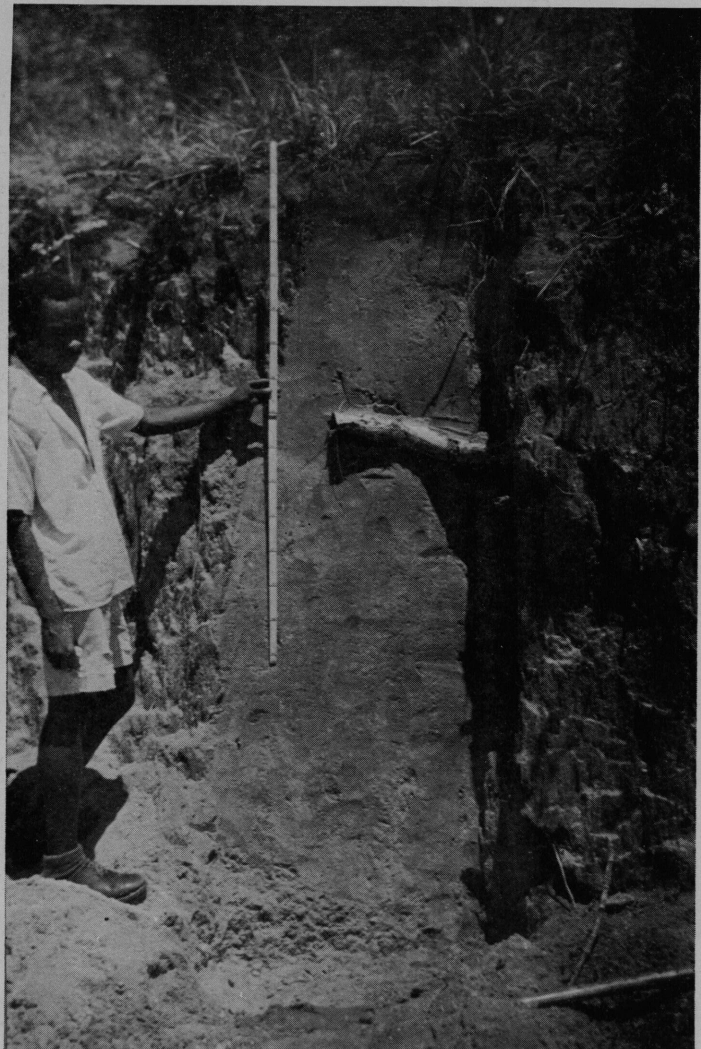

FIGURE 31. A Nangoi sand profile at Nachingwea. The concretionary ironstone horizon, with an undulating upper surface, can be seen to the right of the assistant's foot. The rule is 5 feet (152 cm.) long.

FIGURE 32. Cracking of ~~Namanga~~ [Naunga] clay during the dry season. The rule is about 3 cm. wide.

FIGURE 33. Massive concretionary ironstone exposed on the surface as the result of the natural deepening of a valley near Nachingwea Experimental Farm. Note inclusions of quartz and feldspar from the underlying arid gneiss. The rule is marked at 10 cm. intervals.

FIGURE 34. The eroded side of a gully to the south-west of Namanga Hill. Earth pillars are left where the soil is shielded from direct impact of raindrops.

CHAPTER III

Description of the Soil Maps

KONGWA. MAP 1

The bush clearing at Kongwa was done in mile squares. The clearing was complete except for occasional large trees and for clumps of bush on broken ground. The soil map 1 is the result of a survey of a portion of this cleared land.

Surveying was done in the dry season when the ground was bare or only carried annual grasses. At this time of the year the soil carries the least amount of cover and soil colour, stones, etc., can easily be seen. A great disadvantage is that it is impossible to drill holes with the soil auger in the sun-dried soil. This disadvantage is less serious than it might be in that during the dry season the numerous ant colonies (true ants) deposit heaps of subsoil at the entrance to their nests. These heaps reveal the subsoil colour and the presence or absence of carbonate. Profile pits were dug to determine the normal depth of the profiles of the different series and to provide samples for analysis. Soil mapping was possible under those conditions at Kongwa because there is a considerable degree of uniformity in the texture of the subsoils so that no soil groups were based on subsoil texture. It would be impossible at Nachingwea where a sandy surface horizon can overlie a variety of subsoils.

The ground was covered by making parallel traverses 350 yards apart, with diversions where necessary to clear up doubtful points. As already stated the land surveyed had all been cleared of bush. Survey in standing *Commiphora* thicket would require the cutting of traces at about 200 yards interval (since the lateral visibility would be nil).

A contoured map of the ground was not available. The soil conservation banks have therefore been shown on the soil map. These banks where theoretically on the contour and spaced at 9 feet vertical intervals. Some irregularities exist in the siting of these banks but their position gives a sufficiently accurate idea of the topography. The high ground is to the east.

The water-courses are depressions 2 to 3 yards wide and 2 to 4 feet deep. They only carry water for short periods after heavy rain.

The strike of the Basement Complex is east-west in the neighbourhood of Kongwa. A distinction has been made between " outcrops ", apparently continuous with the country rock, and " boulders ", which may have been transported.

The northern part of the map consists of a basin in the bottom of which lies the former Mankhunze mbuga, a fairly level area of Mankhunze soil. The basin is enclosed by inselbergs to the north and north-east and by high ground to the east and south. To the west a ridge runs southward along trace 8 but there is a gap in the south-west corner of field E8 through which the basin drains into the Kinyasungwe river. It will be seen that remnants of lake-bed travertine are to be found both at the bottom of the Mankhunze basin and on the top of the ridge traversed by trace E, 80 feet higher. If these remnants are all of the same age there would appear to have been considerable warping of the land subsequent to the formation of the travertine.

The southern portion of the map contains a westward running valley, also draining into

Kinyasungwe. No signs of lake-bed travertine were found in this area. Where there is calcium carbonate it is in the form of small nodular concretions, a few centimetres in diameter, and this has every appearance of having formed recently, within the existing soils. Its existence in the lower horizons of the typically acid Chamaye and other series is an indication of a diminution in rainfall in fairly recent times.

The " water-holes " which are shown on the map are man-made excavations, often 10 yards or so in diameter and several feet deep. They are now overgrown but they point to a much larger human population, and a much larger grazing area, in the past. This was perhaps when the rainfall was higher than at present.

The soil map shows a catenary sequence of soils. Fig. 35 is a section across the Mankhunze mbuga and helps to bring out this sequence. The catena sequence from high ground to low is:—

Pauling red sandy loam
Pauling orange sandy loam
Chamaye red sandy loam
Chamaye orange sandy loam (with or without limestone)
Mankhunze loam
Lubiri loam

Variation in detail occur. The Pauling orange sub-series is often missing; the Chamaye orange sub-series also may be missing, so that the Chamaye red soil passes straight into the Mankhunze loam, or may be replaced by the calcareous sub-series of the Chamaye red sandy loam. The Lubiri series is absent from the section and only occurs in a small area in field G6. In the minor valleys, such as that cut by the right-hand end of the section, the Mankhunze soil also is absent and the lowest member of the catena is a Chamaye orange soil.

The dotted line in the section indicates the depth of soil above the concretionary horizon and stone-line. Its position is based on the depth of soil as seen in the profile pits on or near the line of the section.

The Pauling orange sub-series indicates somewhat moist conditions. These may occur in flattish areas on top of a rise, as in the northern part of field E7, or in incipient drainage lines within the Pauling red soil, as in the southern part of field E7. When the soil occupies a drainage line it is usually succeeded by a Chamaye orange soil, indicating continuation of the moist conditions down the slope. Sometimes, however, the Pauling orange soil is succeeded by a Chamaye red soil suggesting either that the moisture is insufficient to influence the lower soil or that it drains away through fissures in the underlying rock. Examples can be seen in field E9.

The section in Fig. 35 does not intersect either of the Pallid soils. The Mtanana soils occupy a position on the ridges similar to the Pauling soils, with a tendency to run down the slope towards the valleys. The conditions for the formation of these soils are discussed in greater detail later.

The Drainage Channel soils occupy minor valleys, lying below Chamaye orange soils. A north to south transect from fields F5 to E5 shows the following sequence:—

Pauling red sandy loam
Chamaye red sandy loam
Chamaye orange sandy loam
Drainage Channel soil

Passing westward from this last soil, this catenary sequence continues with:—

Chamaye series with secondary limestone (red or orange sub-series)
Mankhunze loam

The Drainage Channel soils, then, fall within the Chamaye series in the catena. The conditions for the formation of the Drainage Channel soils appear to be an extensive leaching of the exchangeable bases, giving a low pH value, and a sufficiency of water to provide a wet and

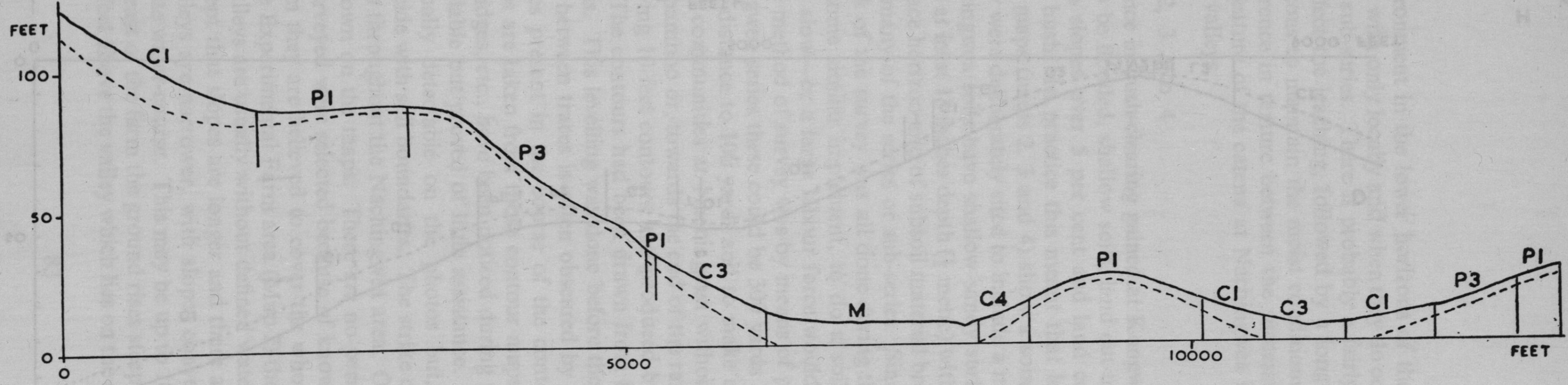

FIGURE 35. North - south section across the Mankhunze mbuga (fields G7, F7, and E7) showing the relation of soil to topography. The broken line is the boundary between the mixed upper horizons and the undisturbed rock below. For explanation of the symbols see the soil map. Vertical exaggeration × 25.

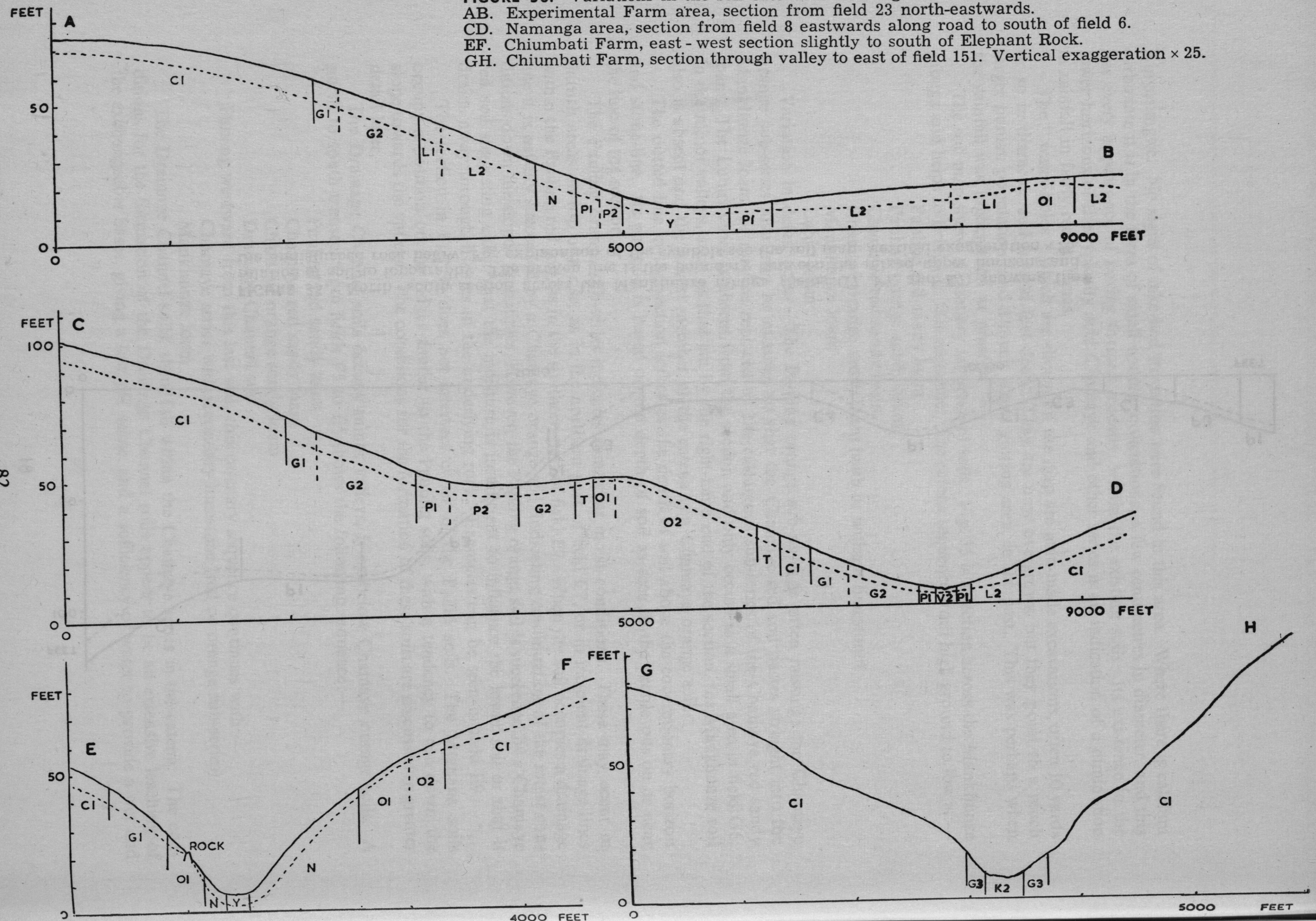

FIGURE 36. Variations in the soil catena at Nachingwea.
AB. Experimental Farm area, section from field 23 north-eastwards.
CD. Namanga area, section from field 8 eastwards along road to south of field 6.
EF. Chiumbati Farm, east - west section slightly to south of Elephant Rock.
GH. Chiumbati Farm, section through valley to east of field 151. Vertical exaggeration × 25.

possibly anaerobic environment in the lower horizons of the soil for at least part of the year. Such conditions are met with only locally and when they do occur it is within an area of Chamaye soil, usually the orange sub-series. There is probably a fairly strong vertical and lateral flow of water during rain, to effect the leaching, followed by a long-continued lateral seepage of water through the lower horizons to maintain the moist conditions and to mobilise the iron.

There is little difference in texture between the successive soils of the catena at Kongwa. In contrast, a marked feature of the catena at Nachingwea is the development of sands on the slopes and clays in the valleys.

NACHINGWEA. MAPS 2, 3 AND 4

At Nachingwea experience in bush-clearing gained at Kongwa was acted upon and clearing was selective. Soils liable to be flooded, shallow soils, land cut up by water-courses, areas with outcropping rock, land on slopes over 5 per cent and land considered unsuitable for any other reason were left under bush. In practice this meant that less than half the total acreage was cleared. The three soil maps (maps 2, 3 and 4) show a somewhat higher percentage utilisation because areas for survey were deliberately sited to include a maximum amount of cultivated land.

Many of the Nachingwea soils have shallow sandy surface horizons. To distinguish them it is necessary to drill to at least 18 inches depth ($\frac{1}{2}$ metre) with the auger. In contrast to Kongwa, examination of the surface horizon and of subsoil material brought up by soil fauna is insufficient to distinguish between many of the series or sub-series. Since it is not possible to use an auger in dry soil the field work of the survey was all done during the wet season. It would be possible, using a soil chisel or some similar implement, to do a soil survey during the dry season but progress would be very slow—or a large labour force would be required.

As at Kongwa, the method of survey was by means of parallel traverses. On fairly uniform stretches of the Nachingwea series these could be 300 yards apart but in the valleys it was often necessary to reduce the distance to 100 yards and to make occasional cross-links. It is possible to traverse all the bush communities at Nachingwea without trace cutting though the going is often arduous in thick bamboo or, towards the end of the rains, in long grass 6 to 8 feet high.

Contour maps, giving 10 feet contours and produced by the Corporation's Survey Department, were available. The contours had been drawn from levels run along east-west traces cut at quarter mile intervals. This levelling was done before the felling of the bush and under these conditions the ground between traces is often obscured by shrubs and tall grass. Slight errors are therefore sometimes present in the course of the contours between traces. The contours shown on the soil maps are taken from those contour maps with occasional adjustments where minor drainage lines, ridges, etc., have been noticed during the course of the soil survey. Aerial photographs were available but proved of little assistance. The boundaries between vegetation communities were usually detectable on the photos but, as already mentioned, vegetation boundaries rarely coincide with soil boundaries. The strike of the Basement Complex is approximately north and south throughout the Nachingwea area. Outcrops are not common; all known outcrops have been shown on the maps. There are no permanent streams.

The three areas surveyed were selected because of known differences in topography, or soil, or both. Between them they are believed to cover the whole range of soils present in the Corporation's lease. In the Experimental Farm area (Map 2) there are no long rises, the lower slopes are concave and the valleys are usually without defined water-courses. The Namanga Farm area (Map 3) is similar except that slopes are longer and there are two rocky hills. Near Chiumbati Farm (Map 4) the valleys are narrower, with slopes convex almost to the valley bottom, and there is usually a definite water-course. This may be up to 10 feet wide and from 2 to 5 feet deep. To the east and south-east of the farm the ground rises steeply to hills a little over 2,000 feet high, i.e. a rise of about 800 feet above the valley which lies on the east side of the map. Typical sections from the three maps are shown in Fig. 36. The Experimental Farm appears to be an area of mature topography while Chiumbati Farm is more juvenile. Namanga Farm is intermediate.

The words " sandy " or " heavy " on the maps indicate a soil texture, in the top few inches, noticeably different from the average. When used in connection with the Nachingwea sandy loam, the term " sandy " implies about 12 per cent of clay while the term " heavy " 25 per cent or over. " Shallow " implies that there is less than 18 inches of soil above rock or a prominent stone-line.

EXPERIMENTAL FARM. MAP 2

The ground covered by this map lies across the watershed between the Mbemkuru drainage system, which drains a small area in the north-west of the map, and the Lukuledi system, which drains the rest. As already stated, there are no hills or steep slopes. The valleys are bounded by concave slopes, showing an advanced state of peneplanation. A section is shown in Fig. 36.

There is a large outcrop of acid-gneiss just south of field 7 at the southern edge of the map. This is associated with Namatula soils in field 7. Further areas of these soils occur at the bottom of field 5 and in field 4, on the western edge of the map. Since Namatula soils are always associated with acid-gneiss and since the strike of the rock is almost due north-south, there is a strong suggestion of successive east-west faults, with the northern side of the fault shifted to the west. There are further occurrences of Namatula soils in the eastern part of the map. On the whole, however, the soils are of the Nachingwea, Nagaga and other series derived from the deeper weathered gneisses. Variations in the texture of the Nachingwea soil probably reflect differences in the proportions of quartz in the parent rock. The Nachingwea soil on the western side of the Experimental Farm is particularly heavy. The profile 95, described in a previous section, is an example. On the eastern side of the Experimental Farm and in the adjoining portion of field 23 the soil is sandier.

The section (Fig. 36, AB) shows the succession of soils across the valley in the eastern portion of the map. It runs from field 23 eastwards to just north of field 20S. Apart from a small patch of Namatula soil near its east end, the section shows the catenary sequence of soils developed from the more deeply weathered gneisses.

The succession is:—

Nachingwea sandy loam
Nagaga sandy loam
Nagaga sand
Nailala sand, orange subsoil
Nailala sand, brown subsoil
Nangoi sand
Naipingo sand
Naipingo sandy loam
" Nyati loam "

The Nangoi sand is not a constant member of the catena and is usually limited to the heads of valleys and drainage lines. Also, as explained earlier, the soil here described as " Nyati loam " does not appear to possess the impervious subsoil now recognised as typical of the series and is probably better classified with the Kihue series. A feature of this mature catena is the considerable development of sands. The five middle soils are all sands.

The acid gneiss is nowhere extensive enough to produce a complete catena of derived soils. The nearest approach is to the north of field 5 where the succession is:—

Namatula, clay subsoil sub-series
Mitumbati sand
Nyati loam

NAMANGA FARM. MAP 3

The northern end of Namanga Farm, covered by map 3, is hillier than the vicinity of the Experimental Farm. The two hills, Namanga and Nangoi, rise sharply above the surrounding undulating country. Apart from the slopes of these hills, however, gradients are mostly less than 5 per cent. There is an area dissected by steep-sided gullies in the north-west. Fig. 15 gives a general view of the country from the top of Namanga Hill.

This area, like the previous one, lies across the Mbemkuru-Lukuledi watershed. The gullied area in the north-west drains into the Mbemkuru; the rest of the map lies within the Lukuledi drainage area. The erosion in the north-west appears to be entirely natural and not to be due to any human interference; the Mbemkuru tributaries are cutting back into the ridge dividing the two river systems. The other valleys, belonging to the Lukuledi system, are wide and shallow without defined water-courses. Seasonal water-holes occur and one of the larger ones has been converted into permanent pool by excavation and the building of an earth well.

The chief rock outcrops are of quartzite. One forms the summit of Nangoi Hill and the other a north-south spine along the whole length of Namanga Hill. Rock is also exposed at many places in the gullies in the north-west. North of field 4, Mitumbati Farm, there is a considerable exposure of amphibolite, with narrow bands of more acid gneiss. Nearer Namanga Hill there are exposures of acid gneiss and quartzite. Immediately to the west of Namanga Hill, and a few hundred feet outside the surveyed area, there is a large exposure of crystalline limestone.

The soil series are the same as those of the Experimental Farm map, with the addition of the Kihue and Nandete series, the former a valley clay and the latter a lithosol of the eroded gullies. At Namanga, however, the Nagaga sandy loam becomes more extensive, while the Nailala sands are relatively unimportant. The Nangoi sand occurs at the head of drainage lines and also in a belt at the foot of the steep slope to the west of Nangoi Hill. The various divisions of the Naipingo series are extensively developed in the eastern half of the mapped area.

The influence of the acid gneiss stratum stretching slightly east of south from Namanga Hill can be seen in the succession of patches of Namatula and Mitumbati soils. The effect of the acid gneiss is only apparent on the higher ground. In the valleys the colluvial Nailala and Naipingo sands obscure any effects of the acid strata. Just south of Namanga Hill the Nachingwea sandy loam forms a continuous cover over the acid gneiss, except for an isolated patch of Namatula sand. This points to the existence of some movement of the Nachingwea soils down the slope.

In the western part of the map there is another, though less definite, north-south succession of Namatula and Mitumbati soils along the crest of a slight ridge. The Nailala sands accompanying these soils do not lie in their normal position on the slope below a Nachingwea or Nagaga soil. The Nailala sands in this area are probably developed on sandy parent material resulting from the mixture of the weathering products of adjacent strata of acid and basic gneisses.

Similarly the Nagaga sand in fields 6 and 7 of Namanga Farm and the Nachingwea sand at the bottom of field 10 are probably the result of addition of sand from nearby acid gneiss strata rather than of the removal of clay during colluvial movement down the slope.

The section C-D (Fig. 36) shows the sequence of soils occurring on a line running due east from field 8. From the west the sequence is:—

Nachingwea sandy loam
Nagaga sandy loam
Nagaga sand
Naipingo sand
Naipingo sandy loam
Kihue clay

The sequence is interrupted after the Naipingo sandy loam by the stratum of acid gneiss running southward from Namanga hill. This gives rise to Namatula and Mitumbati soils. To the east of these there is a repetition of the catena given above, this time ending in the Kihue clay though omitting the Naipingo sandy loam.

This catena differs from that at the Experimental Farm in omitting the Nailala and Nangoi sands. These sands do occur elsewhere on this Namanga Farm map, but the Nailala sands in particular are much less common here than they are near the Experimental Farm.

The Kihue soils are the lowest member of the catena in the northern and western parts of the map, i.e. nearest to the heads of the valleys in which they lie. In the south-east the Kihue soil is replaced by the Nkumba black loam. This is probably a matter of the gradient of the valley affecting the degree of leaching, as explained on p. 62.

CHIUMBATI FARM. MAP 4

To the east of Chiumbati Farm several hills rise to a height of 2,000 feet, i.e. 700 to 800 feet above the valley floors within the farm. Slopes are steep on the upper parts of these hills but lower down, and including the area of the soil map, gradients of over 5 per cent are uncommon. Slopes a mile long, with little variation in gradient, are to be seen on Chiumbati Farm and longer slopes occur a few miles further east.

The valley in the eastern portion of the map tends to be flat-bottomed, with a wandering, slightly incised water-course. This water-course often runs for several months during the wet season. After heavy rain the whole valley-bottom may be flooded. This valley originates on the Mbemkuru-Lukuledi watershed and on Chiumbati Farm it is about 10 miles from its source, which probably explains some of the differences between the soils of this valley and those of the valleys shown on the Experimental Farm and Namanga Farm maps.

The steep-sided gully running down the centre of Chiumbati Farm is about 50 feet deep in its upper portion, near the farm buildings. This depth suggests some weakness in the underlying rock since the catchment area of the gully is extremely small. The rock exposures in this gully are mostly acid gneiss but amphibolite and limestone were also noted.

The valley on the western edge of the map rises just off the map in the north-west corner and is immature in form, with relatively steep-sloping sides. There is a well-defined water-course which runs during wet periods. This water-course is cutting down into colluvial and alluvial sediments and nowhere reaches rock, suggesting fairly recent rejuvenation of the drainage.

Elephant Rock, in the north-west corner of the sheet, is a large whale-backed outcrop of acid gneiss with a north-south strike. There is a smaller outcrop of the same rock a short distance to the south-west. The frequent occurrences of Namatula soils to the south of these outcrops, together with the exposure of massive ironstone on the road in the south-west indicate the continuation southwards of the Elephant Rock acid gneiss. Further outcrops of acid gneiss were noted in the quarry in field 147, in field 150, near the farm buildings and elsewhere in this central valley and in the south-east corner of the sheet.

Amphibolite was seen at several points on the small hill to the east of field 147 and at one point about half a mile south of the farm buildings. There are also a number of outcrops just off the map to the east of field 152. A specimen from this area was described on p. 32.

Grantham and Pilson (1955) found serpentine on the hill to the east of field 147.

Over the greater part of the Chiumbati sheet the soil belongs to the Nachingwea and associated series derived from the more basic gneisses. In the eastern part of the map, where there is no interference from acid gneiss outcrops, the Nailala and Naipingo sands only occur to a very limited extent. The Kihue soils are also missing and the catena is reduced to:—

Nachingwea sandy loam
Nagaga sand loam, normal profile
Nagaga sand loam, low-lying form
Nkumba brown loam
Nkumba black loam

Between field 151 and 155 (Fig. 36, GH) it is still further reduced to:—

Nachingwea sandy loam
Nagaga sandy loam, low-lying form
Nkumba black loam

If the sections AB, CD and GH of Fig. 36 are compared, it will be seen that there is a progressive increase in slope and a corresponding reduction in the proportion of sands in the catena. Presumably on the steeper slopes the movement downhill of soil particles washed off the higher ground is so rapid that there is no separation into sand on the lower slopes and clay in the valley bottoms. Much of this material is probably carried out of the area in the stream-bed, since the Nkumba loam in the valley bottom contains a lower percentage of sand than the Nachingwea sandy loam from which the material is derived.

On the western boundary of the map the picture is complicated by outcrops of acid gneiss. The soils of the section EF (Fig. 36) just south of Elephant Rock, are mostly derived from acid gneiss. The sequence here is:—

Namatula sand, clayey subsoil
Namatula sand, sandy subsoil
Nangoi sand
Nyati loam

The degree of slope at this point is similar to that in the section GH but near Elephant Rock there has evidently been some separation of the soil fractions into sand on the lower slopes and clay in the valley. The reason for this difference from the catena further east is not apparent. It may be that surface run-off is less severe from the sandy soils in the vicinity of Elephant Rock than from the Nachingwea sandy loams on the eastern side of Chiumbati Farm.

CHAPTER IV

Development of the Soils of Kongwa and Nachingwea and their relation to other tropical soils

I Development

(i) *Red Earths*

Both the acid gneiss and the basic gneiss give rise to Red Earths. Due to the relatively high temperatures existing in the zone of weathering rock in tropical regions, chemical weathering greatly exceeds physical weathering; this contrasts with conditions in colder climates where physical agents such as frost and glaciation are important. In the Red Earths, as in most tropical soils, the parent rock is almost entirely decomposed into quartz sand, clay and iron oxide before there is any development of a profile.

The two Red Earth series from Kongwa and the Nachingwea and Nagaga series from Nachingwea do not show any mottling in the weathering zone. This indicates that water-logging, and attendant anaerobic conditions, rarely occur. The iron liberated by decomposition of the hornblende, for example, is deposited very close to its point of formation as ferric oxide. There is therefore little or no formation of concretions. The presence of a few concretions in some of the profiles indicates occasional reduction and solution of the iron and its redeposition in concretionary zones.

As a result of erosion, natural or accelerated, the ground level is slowly lowered and correspondingly the fully weathered parent material is gradually incorporated into the upper horizons of the profile. The larger quartz fragments and any concretions remain in a well-defined layer at a depth varying from about 70 cm. in the Pauling soils to 2 metres or more in the Chamaye, Nachingwea and Nagaga soils. This is due to the action of soil fauna, chiefly termites, as described in chapter I. In the shallower soils a few stones and gravel fragments are brought to the surface by burrowing mammals (chiefly ant-bears) and perhaps by the roots of falling trees. In the deeper profiles the stones are usually beyond the reach of such agencies.

Profile development, then, takes effect on fully weathered material in which particles over about 3 mm. in diameter are rare. The main agents producing differentiation in the profile are:—

- (i) Addition of organic matter.
- (ii) Loss of clay from the surface in run-off water.
- (iii) Perhaps, also, vertical illuviation of clay.
- (iv) Circulation of exchangeable bases through downward leaching and return to the surface in leaf-fall.
- (v) Similar movements of nitrogen, phosphate, sulphate, etc., including conversion of phosphate into relatively insoluble compounds.
- (vi) Loss of cations and anions in surface run-off and perhaps also in lateral subsoil flow.
- (vii) Replacement of cations and anions (excluding nitrate) in new material incorporated into lower horizons by the sinking of the stone-line.

Profile development involves no appreciable decomposition of the quartz sand, the clay or the ferric oxide.

In the Namatula series the underlying resistant acid gneiss hinders drainage and causes temporary reducing conditions in the weathering rock zone, as is indicated by the pale mottling. Under these conditions the iron liberated by the decomposition of the rock goes into solution to some extent. The surface of the perched water-table fluctuates with alternating wet and dry periods. Each time it falls some of the dissolved iron is oxidised and precipitated. The iron tends to preceipitate for preference on existing ferric oxide and in this way a horizon of concretions is built up. Once the concretions have reached a diameter over about 3 mm. they join the quartz stones and gravel and remain at a constant depth below the surface. The finer material which becomes incorporated in the part of the profile above the stone-line is acted upon by the agents already listed which bring about development of the profile. As with the deeper soils, the profile above the stone-line consists almost entirely of quartz sand, clay and ferric oxide. However, as the Namatula soils are often fairly shallow, the upper horizons usually contain a small percentage of larger quartz fragments and concretions. There are often, also, some feldspar fragments which have survived weathering in the zone below the stone-line.

In all these Red Earths there is probably a slow movement down the slope of the upper part of the profile. This certainly occurs on steep slopes in the Kiboriani block (Fig. 9). The evidence for its occurring on slopes with less than 5 per cent slope is that a uniform red sandy clay is produced from markedly stratified parent rock. Also, the quartz stones are spread fairly uniformly in the stone-line whereas they originate in widely separated quartz veins. The mechanism of the movement is probably the collapse of insect burrow and root channels and the closing of cracks; the tendency will be for the upper side to collapse on to the lower rather than vice versa.

The foregoing account of the formation of the Red Earths is to some extent conjectural but it appears to fit the facts.

Milne (1947) has claimed that the present rainfall in the semi-arid parts of Tanganyika such as Kongwa is insufficient to moisten the soil to a depth of 2 metres. He therefore considers the red soils, having a depth of 2 metres or more, to be " fossil relics " of a wetter period in the past.

To obtain information on rainfall penetration a line of pits was dug in *Commiphora* thicket to the south of the Experimental Farm. The three upper pits reached rock, partly weathered but still fairly hard, at depths of 2 metres or less; the material immediately above had moisture contents of 8·5 to 9·6 per cent. The next two pits down the slope had moisture contents of 11·2 and 9·9, respectively, at 2 metres depth; they did not reach rock. The lowest pit, in Chamaye orange soil in a slight drainage line, contained 12·5 per cent moisture at 2½ metres depth; again rock was not reached. These figures were obtained in July, when transpiration would have reduced the moisture level to wilting point. Higher figures probably occur during the wet season.

The foregoing figures show that the present rainfall at Kongwa can produce weathering at a depth of 2 metres, and probably more. The much higher rainfall at Nachingwea is adequate to produce weathering at well over 2 metres depth.

A few pits in Chamaye and Nachingwea series have shown depths of 4 to 5 metres of uniform red sandy clay without any signs of rock structure in the weathered material. This great thickness of sandy clay is not a soil in the strict sense of the word but rather a mantle in whose upper horizons the soil profile has developed. These mantles always lie on the lower slopes and are probably produced by successive depositions of soil eroded from the higher ground. Where the upper slopes are fairly steep and soil creep is appreciable they may be produced by the piling up at the foot of the slope of the moving sheet of soil but this is perhaps a less common phenomenon than the first. Probably all soils in which there is more than about 2 metres of earth above the stone-line are " mantle soils." It might have been expected that such soils would differ appreciably from the shallower soils higher up the slope formed from the weathered rock directly or with only slight lateral movement. As far as can be seen the differences are, in fact, slight or non-existent, probably because of the inert nature of the soil components—the quartz sand, kaolinitic clay and ferric oxide. The process of profile development in the upper position, followed by washing-down to the lower position and the development of a fresh profile there has had no appreciable effect on these materials.

Development of Orange Subsoil Colours

The Nagaga series at Nachingwea, with an orange instead of a red subsoil, and the orange subsoil sub-series of the Pauling and Chamaye soils have been included with the Red Earths because they differ so little from the true Red Earths. The orange soils lie below the red soils on slopes or occupy local depressions in areas of red soil. It is clear that they are rather more favourably supplied with water than the red soils. Probably the orange colour is due to the greater hydration of the ferric oxide coating the sand and clay particles but the precise mechanics of the process are not clear. The orange colour develops in the weathering rock zone and is usually associated with yellow and grey mottling. When this material becomes incorporated in the profile above the weathering zone it takes on a uniform orange colour. It is not at all obvious why development should proceed thus in the series mentioned at the beginning of this paragraph, i.e. soils on deeply-weathered material, while in the shallow Namatula series red colours should be developed under still wetter conditions. There is often a temporary water-table submerging the weathering rock in this latter series and furthermore, as was pointed out when the Namatula profile was described, the subsoil colour in this series can be either red or orange.

Red Earths with Calcareous Horizons

Although reasons have already been given for supposing that Red Earths are still forming at Kongwa under the present rainfall it is unlikely that the formation of a Red Earth can proceed simultaneously with the precipitation of calcium carbonate. In the case of Red Earths with calcareous subsoils the Red Earth must have formed first and the carbonate must have come in later, as a result of a change in the conditions. These soils occur in drainage lines; the secondary precipitation of carbonate shows that water draining into these low-lying areas formerly passed on to the lower reaches of the valley but no longer does so. The most likely explanation is a diminution in the rainfall.

Formation of Sandy Surface Horizons

In all the Red Earths there is a tendency for the upper 10 to 20 cm. of the profile to be sandier than the remainder. This is particularly marked in the Nachingwea and Nagaga " sand " sub-series. It is also a feature of the soils lying lower down the slope from these two series, e.g. the Nailala and Naipingo sands.

It is possible that the loss of clay from the upper layers has been by vertical transport into the lower horizons but this process is probably of relatively small importance, if it occurs at all. Far more important is the preferential transport of clay in surface run-off after heavy rain. The clay in the top few millimetres of the soil is dispersed by rain-drop impact. In most storms there is some surface run-off and this water is always turbid. The run-off is slow-moving on the prevailing gentle slopes and does not usually carry much sand. There is therefore a preferential removal of clay, and the residual soil at the top of the slope becomes sandier.

The process would only affect the top few millimetres of the profile were it not for the continual mixing of the soil horizons by the soil fauna. Termites are particularly effective in bringing up clay since they build their runs over dead vegetation on the surface and often for considerable distances up tree trunks. The material for these runs appears to be obtained from sub-surface horizons and is richer in clay than the surface horizon, as is shown on Table 19.

These runs are eventually washed out and the clay particles will be carried away preferentially. The result is a depletion of the clay to the depth from which the termites obtain their building material.

TABLE 19. *Comparison of termite run material with soil horizons for a Nachingwea sandy loam*

Horizon (cm.)	Gravel (> 2 mm.)	Analysis of fine earth (< 2 mm.)					
		pH	Coarse sand	Fine sand	Silt	Clay	Organic carbon
	%		%	%	%	%	%
Termite run	0·2	6·35	24·9	25·3	6·7	36·8	1·30
0- 15 ..	0·7	5·90	43·5	28·3	4·8	21·3	0·99
15- 30 ..	0·6	5·42	37·8	18·2	4·5	38·0	1·04
90-100 ..	1·8	6·30	20·3	9·6	8·1	57·3	0·34

(2) PALLID SOILS

(i) *Mtanana Series*

The pallid Mtanana soils are only developed to a small extent in the Kongwa area covered by Map 1 and where they do occur they do not show the extreme paleness and acidity which is typical of the series. The " typical " form is illustrated by profile 39, described earlier, and is found where the series occurs in wide, continuous stretches. Such a stretch is that which occupies most of the broad Mtanana ridge in the eastern portion of Unit 2 and the western portion of Unit 3.

The mode of formation of these soils is still obscure but the following points seem relevant:—

(a) In the western and central parts of Unit 1 Red Earths predominate. This area is part of the Kinyasungwe drainage basin, which is an area of active erosion. Pallid soils predominate on the eastern boundary of Unit 1 and on Units 2 and 3. These areas were originally drained by valleys occupying the sites of the present Mamhumba and Lubiri mbugas. These valleys have now silted up and erosion in their former drainage basins is presumably greatly diminished.

(b) In the only Mtanana profile in which the clay minerals have been identified (profile 3) there is some montmorillonite in the horizon immediately above the rock, indicating impeded drainage. However, the rock profile 3 is a pegmatite, which is almost certainly not typical of the series as a whole.

If, as in profile 3, an impervious rock layer is the reason for the development of an Mtanana soil, this imperviousness might be due either to particularly resistant rock or perhaps to the rock strata lying horizontally. (Usually the angle of dip is high.) In either case there should be a tendency for patches of Mtanana soil to be elongated in an east-west direction following the run of the rock strata. There is little evidence of this to be seen in the soil map, though extensive soil creep might obscure the pattern.

In general the processes leading to the formation of a Mtanana profile are similar to those of a red earth. The pronounced concretionary ironstone horizon suggests affinities with the Namatula series. In the weathering zone the rock is decomposed into quartz sand and gravel, clay and iron oxides. A considerable proportion of the iron goes into solution and is reprecipitated as concretions. The reason for this solution and reprecipitation of iron is not yet apparent.

If further work shows that impeded drainage is universal in the Mtanana soils then the mobilisation of the iron is explainable as due to periodic anaerobic conditions. But if the drainage is not invariably impeded then perhaps the slower rate of development due to the lowered rate of erosion may explain the soils. Given a long enough period of time the iron may move even in a reasonably well-aerated environment.

(ii) *Drainage Channel Soils*

These soils usually develop in mantle deposits, though development in shallower material is probably not impossible. The pale colours shown at all levels in the profile indicate removal of iron oxide. This soil occurs in areas of Chamaye soil. Its parent material, at any rate when the profile forms on a mantle deposit, must originally have formed part of a Chamaye soil, since the mantles are produced by the accumulation of material moving down the slope from such a soil. It appears that solution of the iron oxide present in the original Chamaye soil material must proceed at all levels in these Drainage Soil profiles. If for instance, iron oxide were only dissolved in the lower horizon of the profile, as in the Mtanana series, the upper horizons of the profile would retain the red or orange colour of a Chamaye soil.

These soils occupy drainage lines but the upper part of the profile is by no means permanently water-logged, even during the wet season. Possibly the water draining through these soils contains organic matter extracts capable of dissolving ferric oxide even under aerobic conditions, in the manner described by Bloomfield (1953-1955) for several coniferous and broad-leaved leaf extracts.

The reprecipitation of the iron in the lower horizons probably takes place when the profile dries out in the dry season.

(3) Calcareous Valley Soils at Kongwa

In many places these soils, certainly of the Lubiri series and probably of the Mankhunze series, develop on a calcareous parent material. This is particularly true of the soils of the Mamhumba and Lumbiri mbugas. In the area mapped, however, the soils are apparently formed on non-calcareous mantle deposits.

Where the soils develop on non-calcareous material the calcium carbonate is brought in as dissolved bicarbonate in water draining from the higher ground. In the northern portion of the soil map some of the calcium may have been dissolved from the scattered travertine deposits which exist in this area. In the southern portion there is, apparently, no travertine and the calcium must have been leached from Chamaye, Pauling, etc., soils higher up the slope. Even on the mbugas the concretionary limestone may be largely derived from drainage water from the surrounding upland areas. The concretionary horizon contains two or three times as much calcium carbonate as the parent deposits and it seems unlikely that the water-table in these mbugas is ever raised sufficiently to supply calcium-rich water for evaporation in the concretionary horizon. The concretionary carbonate is more likely to be derived from dissolved calcium in surface drainage water which penetrates to a depth of a metre or two and from there is transpired by plant roots.

A calcareous black clay, considered as a zonal soil, is typical of a drier climate than an acid Red Earth. Yet in Kongwa the calcareous black clays are better supplied with moisture than the Red Earths. This apparent anomaly can only be explained on the basis of a catenary relation with the higher-lying soils, such as has been suggested in the preceding paragraph.

(4) Hillside sands and mottled clays at Nachingwea

The fullest development of these soils is in the vicinity of the Experimental Farm (Map 2); a list is given on p. 84. The formation of the Nachingwea and Nagaga soils at the top of the catena has already been dealt with. The lower soils, from the Nailala sand downwards, are formed on colluvial material derived from the upper two soils.

Nailala series. The development of sandy surface horizons in the Red Earths, by preferential removal of the clay particles, has already been described. The residual surface sand, although it is less easily moved than the clay, is not entirely static but tends to move down the slope at a slower rate than the clay. Where the slope is not too steep and where the process has continued for a sufficiently long period the result is the formation of a belt of sandy soil, the Nailala series, situated just below Nagaga soils. In these soils there is at least 50 cm. depth of sandy material with less than 10 per cent of clay; more clay is present in the horizons underlying this sandy material but usually it remains less than that found in the Red Earths at a similar depth.

In these sandy soils there may be some removal of clay by lateral flow of water in the lower part of the profile. On one occasion, after heavy rain, water was observed issuing with some velocity from a rat-hole at the foot of a slope. This indicated appreciable lateral subsoil flow and the velocity was sufficient to carry clay in suspension. Also, water collecting in the valleys after rain often shows a white turbidity; it seems probable that this turbidity is due to kaolin removed from the subsoil since wash from surface soils is always red or brown. Nevertheless, it is believed that the surface sorting of soil particles described in the previous paragraph is the more important process in the development of these sands.

It should be noted that the Nailala sands only develop on the more gentle slopes, such as are found in the Experimental Farm area. On Chiumbati Farm, where slopes are usually steeper (see Fig. 36), these soils are not found. Probably the slopes are too steep for the sand to accumulate.

Nangoi series. These soils are a special case of the Nailala sands in which the separation of the clay particles from the sand has been particularly complete. The Nangoi sands are usually limited to areas round the head of drainage lines and the foot of the steeper slopes (about 5 per cent gradient). This suggests that it is only at such sites that there are found the precise conditions of slope, run-off velocity, etc., necessary for such complete separation of sand and clay.

Naipingo series. Next in the catena below the Nailala and Nangoi sands come the Naipingo series. In this series the clayey subsoil, present in the upper soils of the catena (Nachingwea and Nagaga series), makes a reappearance. The soil occurs at the foot of the slope, where the gradient begins to flatten out and where the velocity of run-off water is checked. The suspended clay will therefore tend to be deposited. The process will be accentuated by the denser grass growth in these moister soils which will slow down water movement and encourage deposition of suspended particles.

The common form of Naipingo series is the Naipingo sand, to which there is up to 50 cm. of relatively sandy material overlying the clayey subsoil. The reason for this increase in clay with depth is not clear. If the colluvial deposits on which these soils form are still building up then it would appear that the increase of the clay with depth is due to illuvial deposition of clay within sandier material. This illuviation could be either vertical, from the surface, or lateral, from higher up the slope. In some cases the profile may be a composite one, i.e. the heavier subsoil may originally have been a surface soil and have become buried by more sandy material. This could have come about by changes in climate or vegetation or perhaps by increasing pene-planation of the higher ground. There is, however, no evidence for such a process and it seems more likely that the soil is produced by current conditions.

Water-logging, with attendant anaerobic conditions, appears to be of fairly frequent occurrence in the Naipingo soils. This, together with the somewhat acid reaction, results in solution of the iron and its partial removal from the upper part of the profile. During the dry season the soil dries out and iron is reprecipitated as concretions in the lower part of the profile. The iron that is precipitated may have come from higher up the slope and not necessarily from the material immediately overlying the concretionary horizon.

The colluvium on which all these soils form is derived from the upper horizons of the Red Earth profiles at the top of the slope. There are therefore very few primary minerals, and these only the most resistant to weathering. Quartz is the main constituent and the clay mineral is almost certainly kaolin. The minerals present in the fine sand fraction of some Nailala and Nangoi profiles are shown in Table 21. (Appendix I).

Kihue series. The Kihue loams and clays are the usual lowest member of the catena. These rather heavy soils are formed on the clay-rich colluvium which collects at the lowest points in the valleys.

In these soils mottling is present right up to the surface, indicating a high water-table at least occasionally. The acidity of the lower horizons of the profile shows that leaching takes place and it seems probable that there is slow lateral movement of the water. This suggestion is supported by the fact, already noted, that Kihue clays form in valleys when the longitudinal gradient is one per cent or more. Where the gradient is less than this, the soil is normally a dark-coloured clay.

The concretionary horizon, with 30 per cent of gravel-sized concretions in the profile analysed, is probably more porous than the horizons above and will assist the lateral flow of water. The reason that the concretions form at any particular level is probably that at such a level there is the most frequent alternation of oxidising and reducing conditions. There is no permanent water-table at this level. In wet periods free water can be found at a few centimetres depth, though this may be slowly moving downwards, and in the dry season the water-table if present at all, lies below 2 metres depth.

The water-hole soils have a similar origin to the Kihue clays but are submerged for relatively long periods—from a few days to several months at a time. The clustered depressions in which the water-holes lie, and the hummocky nature of the intervening ground, may perhaps be a form of " gilgai " relief.

(5) Sands with concretionary ironstone

Mitumbati sands. The Mitumbati sands have a similar origin to the deeper Nailala and Nangoi sands, i.e. they develop on sandy colluvium on slopes. The appreciable amounts of quartz gravel and of iron concretions found in the upper horizons of Mitumbati sands were probably originally present in the parent colluvium. This colluvial material, in the case of these sands, is derived from soils of the Namatula series in which such gravel fragments normally occur.

The thicker concretionary horizons of the Mitumbati sands are perhaps partly accumulated from the higher Namatula soils. Since this coarser material sinks in the profile, under the influence of the soil fauna as already described, it will be less subject to the sheet erosion which is continually moving away the sand particles from the surface. But also there is probably considerable formation of concretions in situ since the Mitumbati sands will receive iron-rich seepage water from the higher Namatula soils. It will be recalled that the impervious rock underlying Namatula soils hinders vertical drainage of rain-water (and thus causes seepage into the lower-lying soils) and also promotes solution of iron through water-logging.

Chiumbati Sands. These sands with a cemented slag-like ironstone horizon develop in sandy colluvium derived from the Namatula series; they also overlie acid gneiss at a shallow depth. Their genesis is therefore similar to that of the Mitumbati series. The development of their massive concretionary horizon appears to be due to the shallow underlying rock which brings seepage water near to the surface and so concentrates the precipitation of iron into a narrow horizon.

(6) Hardpan Soils — Nyati series

The impervious nature of the hardpan in these soils is partly due to a rise in the proportion of sodium in the exchange complex to over 10 per cent. There is also some illuviation of clay; in profile 151 the maximum clay content is in the 25-50 cm. horizon. (The much lower apparent clay content at depths greater than 100 cm. is probably due to cementation by iron oxides since the " silt + clay " content remains constant.)

Precipitation of carbonate in the lower horizons of the profile is due to these horizons receiving seepage water from higher up the slope. The impervious subsoil prevents this draining to lower levels so that in the profile as a whole evaporation and transpiration exceed downward movement of water.

The soils appear to have developed directly from the underlying acid gneiss though there is probably some addition of colluvial material to the upper horizons.

(7) Dark-coloured loams and clays at Nachingwea

The dark colour of these soils is due to the type of organic matter developed and not to there being much more of it than there is in the red and brown soils. This black organic matter is typical of organic matter formed under conditions of high base saturation.

It has already been pointed out that these dark soils develop on level or almost level sites where leaching is much reduced. In general the soils are allied to the calcareous black clays at Kongwa, but under the higher rainfall at Nachingwea there is usually sufficient leaching to prevent the precipitation of carbonate. The heavy texture of the Naunga clay hinders the drainage of these soils and so allows a slight accumulation of calcium carbonate in the lower horizons.

In the brown sub-series of the Nkumba soil there is appreciable leaching of the bases and therefore a browner colour. This soil corresponds to the Mankhunze series at Kongwa, though it is without the calcareous subsoil of the Mankhunze series.

II The Relation of the Soils of Kongwa and Nachingwea to other Tropical Soils

(i) *Red Earths*

The Red Earths at Kongwa and Nachingwea are similar to the " Kikungo " soils of Usukuma (Western Tanganyika) and to the red soils throughout the central Tanganyika plateau.

No satisfactory system of classification of these red tropical soils exists at present. It is evident that there is a wide range in properties. The soils have in common a kaolinitic type of clay and precipitated iron oxides. When the amount of iron oxide is low the silica-sesquioxide ratio is about 2 and the soil does not form stable aggregates, i.e. is non-friable. The Red Earths of Kongwa and Nachingwea belong to this group, which was described by Milne *et al.* (1936) as the " Non-laterised Red Earths ". This group appears to correspond to the " Rotlehm " of Kubiena (1953).

The other type of Red Earth, with a high proportion of secondary iron oxide, is friable and is the " Laterised Red Earth " of Milne *et al.* This group appears to correspond to the " Latosol " of Kellogg (1950), the Russian " Krasnozem " and Kubiena's " Roterde ". It does not occur at Kongwa or Nachingwea.

Some comparison of the Red Earths of Kongwa and Nachingwea with somewhat similar soils in South Africa can be made from data given by Van der Merwe and Heystek (1952). The East African soils have resemblances with these authors' brown to red-brown ferruginous lateritic soils, particularly with their Marikana No. 1 profile. Gibbsite, however, appears to be a common constituent of these South African soils; it has not been detected in any of the Kongwa or Nachingwea soils so far examined.

(2) *Pallid Soils.* (*Degraded Red Earths.*)

These are frequently known as " plateau soils " in East and Central Africa. The term appears to have originated with Milne *et al.* (1936) though in later communications Milne seemed to use the term in a wider sense, to include the whole complex of soils occurring on the Central Tanganyika plateau.

These pallid soils do not seem to have attracted much attention outside Africa.

(3) *Dark-coloured clays and loams* (*calcareous and non-calcareous*)

The dark-grey and black soils included under this heading have, in distinction from the pallid soils, received considerable notice in the literature. They are the " tropical black earths", " margalitic soils", " regur soils", " mbuga soils", " black cotton soils" of various authors. These soils have the common feature of being formed in wettish situations in a warm climate and under conditions which maintain a high base saturation with calcium as the dominating cation. The soils can be calcareous or non-calcareous, depending on the intensity of the calcification process. There is also a marked variation in the amount of shrinking on drying. This depends, to some extent at least, on the particular clay mineral present.

Soils similar to the Lubiri series have been described by Dames (1950), Tamhane (1950), van der Merwe (1950), Mohr and van Baren (1954) and others. The Naunga clay, with a colloid consisting of montmorillonite with accessory kaolinite, resembles the " subtropical black clays " developed on norite which have been described by van der Merwe (1950) and van der Merwe and Heystek (1955).

The dark grey and black soils met with in this survey could be classified as follows:—

(1) Calcareous, cracking: not represented.
(2) Calcareous, non-cracking: Lubiri series.
(3) Non-calcareous, cracking: Naunga series, Nkumba swamp.
(4) Non-calcareous, non-cracking: Nkumba black loam.

The dark brown soils are less easy to place. The Mankhunze brown loam appears to have affinities with the Chestnut Soil of Russian authors, as described by Stephens (1950), but at Kongwa it is not a zonal soil. The Nkumba brown loam, and perhaps the " low-lying sub-series " of the Nagaga soils, are intermediate between the Red Earths and the Black Earths. They have many of the characteristics of a " Prairie Soil," as described by Smith, Allaway and Riecken (1950). The resemblances include the dark-coloured surface horizon, the subsoil mottling and the somewhat unsaturated exchange complex. The Prairie soils, however, are said to have a 2:1 lattice clay while the Nkumba soil probably has a kaolinitic clay, though no identifications have yet been carried out.

(4) *Hillside Sands*

These soils are similar to the " lusanga " soils near Tabora and the " luseni " (or lusenye) soils of Usukuma described by Milne (1947). In fact Milne divides the lusanga soils into (i) an upper zone with reddish tints and (ii) a lower zone with drab tints. These correspond to the orange and brown subsoil phases of the Nailala series. The luseni soil, as seen by the writer at Ukiriguru, is a pale grey sand suffering from frequent water-logging in the wet season because of an underlying impervious clay horizon. In this it resembles the Nangoi sand at Nachingwea but the luseni soil is predominantly a fine sand, whereas the Nangoi series is a coarse sand.

The Mitumbati sand, with a greater development of concretionary ironstone, is similar to some of Van der Merwe's (1941) " brown to reddish brown ferruginous lateritic soils".

These hillside sands at Nachingwea have some affinities with the Pallid soils at Kongwa and Milne's Plateau soils though they are on the whole much sandier.

(5) *Soils with Massive Ironstone*

In these soils the ironstone horizon is more pronounced and nearer the surface than it is in the Mitumbati sands. They seem to resemble Van der Merwe's (1941) " brown to reddish-brown ferruginous lateritic soils developing on colluvial material " or perhaps the same author's " grey ferruginous lateritic soils ".

(6) *Mottled Clays*

The mottling in these soils is associated with scattered ironstone pisolites and is due to a fluctuating high water-table during the wet season. The soils therefore have affinities with the " Ground-water laterites ". The Naipingo soils with a sandy surface horizon and heavy subsoil seem to have a resemblance to the " Planosols " of American authors.

The " water-hole soils " have a greater development of concretions than the Naipingo and Kihue series and appear to be a nearer approach to a typical ground-water laterite than the others.

(7) *Hardpan soils*

Soils with hardpans of clayey material are of fairly frequent occurrence in Tanganyika. Milne (1947) describes such soils from the Central Province and Usukuma and suggests that they result from the presence of certain proportions of sand, silt and clay. The proportions are such that a very compact structure is formed, with the finer particles filling the spaces between the larger.

In the hardpan horizon of the Nyati soils at Nachingwea there is an appreciable proportion of sodium in the cation exchange complex. In another hardpan soil, from the Rufiji valley and recently examined by the writer, there was a high proportion of sodium in the exchange complex. A high sodium figure was also found by the authors of the Report on the Central African Rail Link Survey (1952) in the " Plains Soils " on the Usangu plain (S.W. Tanganyika) and is again associated with an impervious soil.

These hardpans are not irreversibly cemented; on moistening the material becomes plastic and sticky. Under natural conditions, however, it seems that often it is only the top few centimetres of the hardpan soil or horizon which becomes wet and that below this level little or no water penetrates. There is little or no cracking of these hardpan horizons when dry, not even in the upper layers which do regularly become wet. It seems, therefore, that these soils may be sodium soils in which the normal expansion and contraction of the clay on wetting and drying are prevented by the interlocking lattice of quartz grains. There is therefore no development of the domed columns typical of solonetz soils.

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APPENDIX I

Composition of the mineral fractions of Kongwa and Nachingwea soils

Particle size distribution

In most of the soils the main mineral fractions are the sand and the clay. Silt rarely exceeds 10 per cent of the mineral matter and most horizons with higher values of silt contain considerable precipitated iron oxide. In such cases the silt fraction consists largely either of iron oxide particles or of clay particles cemented by iron oxide.

For a few profiles the coarse sand fraction has been divided by sieving into 0·2 and 0·5 mm. and 0·5 to 2·0 mm. fractions. In the same profile the clay was separated by sedimentation into less-than-1 μ and 1 to 2 μ fractions. The results of these separations are given in Table 20.

In most samples examined there was more sand in the 0·2 to 0·5 mm. fraction than in the 0·5 to 2·0 mm. but in a few the reverse was the case. In all the clays, the particles were almost entirely in the less-than-1 μ fraction. Electron micrographs published by Muir *et al.* (1957) have demonstrated that the clay is, in fact, mostly less-than-0·1 μ in diameter. The particle size distribution shown by these soils is typical of predominantly chemical weathering.

Minerals in the Fine Sand

Table 21 gives the minerals found in the fine sand fraction of a number of the soils. In all cases quartz is predominant. Ilmenite and hornblende are fairly common in soils of the Chamaye and Nachingwea series. In some soils there is a fair amount of feldspar, e.g. P39 of the Mtanana series. Feldspar was also fairly common in the fine sand of three soils, of the Chamaye, Nagaga and Namatula series, examined by Muir *et al.* (1957).

The percentage of heavy minerals (S.G. over 2·9) varied from 3 to 6 per cent of the fine sand fraction for three Kongwa soils examined and from 1 to 8 for several Nachingwea soils.

Chemical composition of the clay fraction

A few of the less-than-1 μ clay separates have been analysed chemically (Table 22). For Chamaye, Mtanana and Nachingwea soils the silica-alumina ratios are near 2, confirming the identifications of the clay in these soils, given earlier, as kaolinite or halloysite. The silica-sesquioxide ratios are rather lower, particularly in the Nachingwea soil, due to the presence of secondary iron oxide.

In the Lubiri soil the silica-alumina ratio is about 3·5 supporting the identification of the clay as mainly illite but with some kaolinite. The potassium content of this clay is higher than that of the other clays, again according to expectation.

TABLE 20. *Size distribution of the mineral particles in three Kongwa soils and one Nachingwea soil*

Profile no. and soil series	P47—Chamaye			P3—Mtanana		P5—Lubiri		P17—Nachingwea	
Sample no. .. .. .. Horizon (cm.)	S1658 0-10	S1656 45-55	S1657 105-115	S1659 0-10	S1660 30-50	S1662 0-10	S1663 45-55	S1674 0-15	S1675 50-100
Fine earth, % of whole sample	98·6	96·5	94·7	95·2	69·8	99·5	99·3	99·7	99·7
Composition of fine earth, % of mineral matter:—									
Sand 2·0-0·5 mm.	27·3	19·6	23·7	26·8	26·4	25·4	17·3	12·5	10·9
0·5-0·2 mm.	33·7	17·8	14·4	45·6	30·4	24·2	24·8	36·7	16·0
Fine sand 0·2-0·02 mm. ..	15·2	13·7	20·6	13·9	13·9	11·9	12·3	18·0	8·7
Silt 0·02-0·002 mm.	1·9	3·0	11·0	1·9	2·2	3·3	2·7	2·5	1·9
Clay 2-1 μ	0·6	1·1	1·8	0·4	0·4	1·6	1·4	0·7	1·2
<1 μ	21·3	44·7	28·5	11·3	26·8	33·6	41·4	29·6	61·4

TABLE 21. *Minerals of the fine sand fraction of several Kongwa and Nachingwea soils*

Profile No. and series	Horizon (cm.)	Mineral			
		V. common	Common	Occasional	Rare
A. KONGWA					
P.47 Chamaye (Red subsoil)	0- 55	Quartz	Ilmenite Hornblende	Biotite	Rutile Zircon Apatite Garnet Oligoclase
	75-115	Quartz	Hornblende	Biotite Ilmenite	Zircon Epidote Oligoclase
	140-150	Quartz	Biotite	Hornblende	Albite
P.8 Chamaye (Orange subsoil, calcareous)	5- 30	Quartz	Microcline	Albite Ilmenite Epidote Hornblende	Kyanite Zircon
	60-105	Quartz	—	Microcline	Hornblende Albite White mica
P.3 Mtanana	5- 86	Quartz	—	Hornblende Biotite Microcline Albite	Albite Epidote Zircon
P.39 Mtanana	0- 50	Quartz	Albite Microcline	Biotite Hornblende	Zircon Rutile Epidote
P.5 Lubiri	0- 75	Quartz	—	Oligoclase Biotite Kyanite Enstatite Hornblende	Epidote
B. NACHINGWEA					
P.17 Nachingwea	0-150	Quartz	—	Hornblende Ilmenite	Rutile Zircon Mica Oligoclase
P.33 Nachingwea	0- 30	Quartz	Ilmenite Hornblende	White Mica Albite Zircon	Garnet Rutile
	90-100	Quartz	Ilmenite Hornblende	Zircon Biotite Albite	Garnet (?)
	140-150	Quartz	—	Hornblende Ilmenite	Zircon
SPS.58 Nachingwea	0- 70	Quartz	—	Ilmenite Kyanite	Rutile

TABLE 21 *continued*

Profile No. and series	Horizon (cm.)	Mineral			
		V. common	Common	Occasional	Rare
P.32 Namatula	0- 40	Quartz	—	Oligoclase Hornblende Ilmenite	Biotite Epidote Zircon
P.16 Nagaga	0- 90	Quartz	—	Oligoclase Biotite	Epidote Rutile Zircon
	125-200	Quartz	—	Oligoclase Biotite	Apatite Zircon Epidote
P.21 Nailala	0- 60	Quartz	—	Oligoclase Ilmenite Zircon	Rutile Hornblende
	145-200	Quartz	—	Oligoclase	Epidote Zircon Mica
P.35 Nailala	0- 60	Quartz	—	Zircon Biotite Ilmenite	Oligoclase Apatite
P.24 Nangoi	0-150	Quartz	—	Zircon Ilmenite	Epidote Garnet Hornblende

Mineral identifications in this table are by J.R. Harpum, Department Geological Survey, Tanganyika. Report X/3020 (1952).

Table 22

Chemical composition of the less-than-1 μ clay fraction of three Kongwa soils and one Nachingwea soil

Profile no. and soil series	P47—Chamaye			P3—Mtanana		P5—Lubiri		P17—Nachingwea	
Sample no.	S1658	S1656	S1657	S1659	S1660	S1662	S1663	S1674	S1675
Horizons (cm.)	0-10	45-55	105-115	0-10	30-50	0-10	45-55	0-15	50-100
	%	%	%	%	%	%	%	%	%
			(a)		(a)	(a)	(a)	(a)	(a)
SiO_2	46·67	47·91	45·6	50·24	51·7	58·2	57·7	44·4	45·0
Al_2O_3	35·55	36·43	39·5	34·55	39·3	26·8	28·1	41·7	39·2
Fe_2O_3	12·81	11·58	8·8	9·87	7·9	7·3	7·3	14·9	11·6
TiO_2	1·38	1·14	1·00	1·46	1·17	1·15	1·22	1·51	1·29
Mn_2O_3	trace	trace	0·02	0·03	0·02	0·05	0·07	0·05	0·04
P_2O_5	0·32	0·18	not det.	0·38	not det.	not. det.	not det.	not det.	not det.
CaO	0·02	0·00	0·01	0·02	0·01	0·50	0·59	0·01	0·02
MgO	0·58	0·50	0·27	0·68	0·49	1·93	1·96	0·11	0·07
K_2O	not det.	not det.	0·64	not det.	1·14	3·0	3·0	0·38	0·34
Na_2O	not det.	not det.	<0·3	not det.	<0·3	<0·3	<0·3	1·67	<0·3
SiO_2/Al_2O_3	2·28	2·24	1·96	2·47	2·24	3·68	3·52	1·81	1·95
SiO_2/R_2O_3	1·81	1·86	1·71	2·09	1·98	3·14	2·99	1·47	1·64
Al_2O_3/Fe_2O_3	4·26	4·93	6·97	5·49	7·81	5·77	6·03	4·40	5·29

(a) Analysis by C. L. Bascomb and H. H. LeRiche.

APPENDIX 2

Methods of Analysis

The " stone and gravel " fraction comprises all mineral particles failing to pass a 2 mm. sieve. This fraction is expressed as a percentage of the air-dry sample. All other determinations were carried out on the less-than-2 mm. fraction and, except for some of the mechanical analyses, percentage figures again refer to the air-dry sample.

Mechanical Analysis. The " International " pipette method was used, with sodium oxalate as dispersing agent. The fractions are:—

Coarse sand	2·0-0·2 mm.
Fine sand	0·2-0·02 mm.
Silt	0·02-0·002 mm.
Clay	<0·002 mm.

In determinations carried out in the writer's laboratory the fractions are expressed as percentages of the air-dry fine earth. In analyses done in the E.A.A.F.R.O. laboratories the fractions are expressed as percentages of the oven-dry soil and accordingly no figure appears in the " moisture " column.

pH Value. The figures in the " water " column refer to a 1:2·5 suspension in distilled water, measured after one hour's standing with occasional stirring. In some cases the pH was also determined in M/100 $CaCl_2$ solution as described by Schofield (1952). A glass electrode was used in conjunction with a saturated calomel electrode.

Conductivity. This was measured in a 1:5 soil suspension in distilled water at a temperature of 25°C., using a Marconi conductivity cell and bridge. The results are expressed as the specific conductivity in m-mhos.

Organic carbon. By the Walkley-Black method. The figures are corrected on the assumption that the method gives 80 per cent recovery. This figure is based on comparisons between results obtained on about twelve samples by two methods:—

(i) Walkley-Black method.
(ii) Method of Tinsley (1950).

The latter determinations were performed for the writer by Dr. Tinsley.

Nitrogen. By Kjeldahl digestion using selenium as catalyst with potassium sulphate added to raise the temperature. For the heavier soils a preliminary soaking in distilled water was given, according to Bal's modification as described by Piper (1949).

Exchangeable Bases. Extraction was by 1·0 n ammonium acetate solution. Determinations of cation exchange capacity in the writer's laboratory were carried out by displacement of the ammonium ions by potassium sulphate and distillation of the ammonia. In the case of soils analysed in the E.A.A.F.R.O. laboratories the cation exchange capacity was obtained by adding the exchangeable hydrogen to the total exchangeable bases, i.e. Ca, Mg, Mn, K, Na. In E.A.A.F.R.O. analyses, which can be recognised by the presence of a figure in the exchangeable H column, a value of " nil " in the " Na " column means less than 0·2 m.e.

Extractable phosphorus. Two methods were used:—

(i) A modification of the method of Baver and Bruner (1939) which forms the basis of the "Hellige" Phosphorus Test. The soil was shaken for 3 minutes with 0·3 n hydrochloric acid using a soil-solvent ratio of 1:2·5.

(ii) A modification of Dyer's extraction procedure with 1 per cent citric acid. This dissolved rather larger quantities of phosphorus than the previous method.

APPENDIX 3

Mechanical Analyses and Chemical Data for Sample Profiles from Kongwa and Nachingwea Sites

TABLE 23. *Kongwa Soils: Mechanical Analyses, pH Values and Conductivity*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction: Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Mois-ture	pH water	pH $CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
PAULING SERIES													
59	S2544	0- 12	5 YR 5/6	3·8	50·8	16·5	2·0	30·6	Nil	—	4·50	3·90	—
	2545	12- 40	2·5YR 4/8	4·2	54·9	14·6	3·0	26·5	Nil	—	4·35	3·80	—
	2546	40- 95	2·5YR 5/8	10·5	45·8	15·6	3·0	36·2	Nil	—	4·45	3·75	—
CHAMAYE SERIES, RED SUB-SERIES													
2	S 716	0- 5	5 YR 4/6	0·7	55·3	15·4	3·3	23·1	Nil	1·4	6·15	—	0·066
	717	5- 10	2·5YR 4/6	0·7	51·6	15·7	2·5	27·0	Nil	1·3	5·05	—	0·066
	718	10- 15	2·5YR 4/8	0·6	—	—	—	—	Nil	—	4·70	—	0·061
	719	15- 30	2·5YR 4/8	0·9	49·8	14·7	2·8	31·0	Nil	1·5	4·55	—	0·066
	720	30- 60	2·5YR 4/8	0·8	—	—	—	—	Nil	—	4·50	—	0·072
	721	60- 92	2·5YR 4/8	1·3	47·0	16·5	5·8	28·0	Nil	1·6	4·80	—	0·072
	722	92-122	2·5YR 4/8	1·7	—	—	—	—	Nil	—	4·85	—	0·072
	723	122-155	2·5YR 4/8	2·5	44·2	26·2*	11·2	13·2	Nil	1·7	4·65	—	0·075
	1088	160-215	2·5YR 4/6	57·7	—	—	—	—	Nil	—	5·45	—	0·123
	1089	215-235	2·5YR 4/6	32·8	—	—	—	—	Nil	—	5·25	—	0·191
47	S1596	0- 12	2·5YR 4/6	—	52·0	21·7	1·9	20·4	Nil	1·5	6·50	—	0·106
	1597	12- 30	2·5YR 4/8	3·9	43·7	18·2	2·5	32·5	Nil	1·9	5·00	—	0·049
	1598	45- 55	2·5YR 4/8	2·8	37·1	18·2	8·0	32·3	Nil	2·6	4·95	—	0·066
	1599	75- 85	2·5YR 4/8	3·5	38·1	21·1	8·7	26·4	Nil	2·5	4·95	—	0·059
	1600	105-115	2·5YR 4/8	11·4	36·3	25·4	9·5	23·7	Nil	2·8	5·40	—	0·054
	1601	140-150	2·5YR 4/8	49·7	61·8	26·6	5·8	2·8	Nil	2·0	6·80	—	0·057
CHAMAYE SERIES, ORANGE SUB-SERIES													
63	S2557	0- 10	10 YR 6/4	1·3	56·0	14·6	2·0	27·0	Nil	—	6·00	5·40	—
	2558	10- 40	7·5YR 6/6	1·3	45·4	14·5	2·0	29·1	Nil	—	4·55	3·80	—
	2559	40-140	7·5YR 6/8	1·6	29·0	23·5	1·5	46·4	Nil	—	4·40	3·60	—
	2560	150-170	10 YR 8/8	43·0	—	—	—	—	Nil	—	4·45	3·70	—

*Includes iron oxide pseudo-sand.

TABLE 23 *continued*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction: Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Moisture	pH water	pH $CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
CHAMAYE SERIES, RED SUB-SERIES WITH LIMESTONE													
78	S2599	0- 10	5 YR 4/4	1·7	53·8	21·3	2·0	22·4	Nil	—	6·30	5·50	0·054
	2614	10- 25	2·5YR 3/6	2·0	44·7	19·7	3·0	34·7	Nil	—	5·55	4·90	0·064
	2615	25- 45	2·5YR 4/6	3·2	45·0	16·4	1·0	35·2	Nil	—	5·45	4·75	0·057
	2601	50-125	2·5YR 4/6	3·3	41·7	17·5	3·0	37·7	Nil	—	6·25	5·70	0·072
	2602	125-140	2·5YR 4/6	67·3	44·0	18·3	9·0	28·6	0·55	—	8·25	7·40	0·210
CHAMAYE, ORANGE SUB-SERIES WITH LIMESTONE													
81	S2621	0- 12	10 YR 4/3	0·4	54·9	15·8	3·5	26·0	Nil	—	7·20	6·65	—
	2622	12- 25	7·5YR 4/4	0·5	47·0	13·2	2·5	38·3	Nil	—	6·90	6·10	—
	2623	25- 90	5 YR 4/8	0·9	43·5	10·3	3·0	41·3	Nil	—	5·15	4·35	—
	2624	90-165	7·5YR 5/8	1·1	37·3	17·5	9·0	29·1	Nil	—	5·85	5·10	—
	2625	165-190	7·5YR 5/8	1·4	46·8	26·9	10·0	10·7	Nil	—	6·50	5·95	—
MTANANA SERIES													
3	S 724	0- 5	7·5YR 5/5	3·3	—	—	—	—	Nil	—	5·75	—	0·059
	725	5- 10	7·5YR 5/5	4·6	62·9	20·9	1·9	12·5	Nil	0·9	4·85	—	0·043
	726	10- 15	7·5YR 5/5	4·6	—	—	—	—	Nil	—	4·60	—	0·072
	727	15- 30	7·5YR 6/6	9·2	58·4	20·4	2·0	17·4	Nil	1·3	4·55	—	—
	728	30- 50	5 YR 6/8	15·3	56·7	16·6	1·9	23·4	Nil	1·6	4·40	—	0·107
	730	65- 85	5 YR 5/8	26·7	52·2	15·9	3·1	25·9	Nil	2·1	4·55	—	0·123
	731	85-112	5 YR 5/8	15·6	—	—	—	—	Nil	—	4·65	—	0·048
39	S1349	0- 12	10 YR 6/3	3·0	68·0	23·1	2·0	6·4	Nil	0·3	4·40	—	—
	1350	15- 30	10 YR 6/4	3·2	67·7	22·2	1·5	7·5	Nil	0·3	4·20	—	—
	1351	40- 50	—	4·5	—	—	—	—	Nil	—	4·20	—	—
	1352	80- 90	10 YR 6/5	5·6	64·9	17·8	2·0	9·9	Nil	0·5	4·35	—	—
	1353	120-130	10 YR 6/4	68·0	—	—	—	—	Nil	—	4·40	—	—
	1354	150-160	5 YR 6/6	42·5	—	—	—	—	Nil	—	4·25	—	—
MTANANA SERIES, WITH LIMESTONE													
76	S2590	0- 10	2·5 Y4/2	1·2	56·9	13·0	2·5	26·5	Nil	—	6·90	6·35	0·122
	2591	10- 40	10 YR 6/4	2·0	41·7	9·0	2·0	44·4	Nil	—	6·95	6·35	0·072
	2592	40- 75	10 YR 7/4	1·2	32·2	13·2	2·0	53·6	0·83	—	8·25	7·65	0·141
	2593	75-130	10 YR 7/4	13·1	49·5	15·5	7·0	23·5	0·31	—	8·25	7·50	0·172

TABLE 23 *continued*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction								
					Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Mois-ture	pH water	pH $CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
DRAINAGE CHANNEL SOILS													
89	S2653	0- 18	10 YR 5/3	0·8	72·6	10·0	2·0	17·9	Nil	—	5·35	5·00	—
	2654	18- 32	10 YR 6/4	4·2	63·6	9·5	2·5	26·0	Nil	—	4·65	4·10	—
	2655	32-100	10 YR 6/6	1·0	60·5	8·1	1·0	32·6	Nil	—	4·45	3·85	—
	2656	100-160	10 YR 6/4	2·4	54·7	9·5	2·5	38·3	Nil	—	4·70	4·15	—
	2657	160-180	10 YR 6/4	51·2	—	—	—	—	Nil	—	5·75	5·05	—
MANKHUNZE SERIES													
65	S2564	0- 12	10 YR 4/3	0·7	40·4	10·4	2·5	42·3	Nil	—	7·45	6·90	0·139
	2565	12- 40	10 YR 4/3	0·8	36·4	11·9	3·0	41·3	Nil	—	6·70	6·25	0·210
	2566	40-100	10 YR 5/2	1·1	37·2	11·2	4·0	43·9	Nil	—	6·95	6·50	0·134
LUBIRI SERIES													
5	S1606	0- 10	10 YR 3/1	0·2	41·8	14·7	5·3	32·1	Nil	5·1	6·85	—	0·072
	1607	15- 25	10 YR 4/2	0·3	38·1	14·1	3·9	37·8	0·02	6·4	7·40	—	0·123
	1608	45- 55	10 YR 5/3	0·3	36·9	14·3	3·8	38·4	0·18	6·7	7·85	—	0·143
	1609	65- 75	—	40·5	25·9	12·0	1·5	41·9	13·25	6·7	8·30	—	0·246
9	S 772	0- 5	10 YR 5/1	0·3	20·6	8·4	1·8	48·7	0·68	8·5	8·35	—	0·172
	773	5- 10	10 YR 4/1	0·3	19·1	8·4	0·9	54·5	0·50	8·7	8·45	—	0·172
	774	10- 15	10 YR 5/1	0·2	—	—	—	—	1·59	—	8·35	—	0·215
	775	15- 30	10 YR 5/1	0·3	17·5	8·9	0·9	57·3	4·50	8·4	8·65	—	0·215
	776	30- 50	10 YR 6/1	4·3	14·8	6·6	1·3	44·1	13·62	7·8	8·75	—	0·215
	777	50- 80	10 YR 7/1	10·3	19·3	7·6	2·5	35·5	17·50	8·3	8·85	—	0·286

TABLE 24. *Kongwa Soils: Chemical Analyses*

Profile No.	Horizon (cm.)	Org. C %	N %	C/N	Exchangeable Bases (m.e./100g soil) Ca	Mg	Mn	K	Na	T.E.B.	H	B.E.C.	% satn	Extractable P 0·3N HCl	1% citric
														mg./100g	soil
PAULING SERIES															
59	0- 12	0·44	0·055	8	1·2	1·1	0·025	0·60	Nil	2·9	3·5	6·4	45	0·08	0·18
	12- 40	0·27	0·053	5	1·0	0·3	0·029	0·47	Nil	1·8	4·3	6·1	30	0·03	0·15
	40- 95	0·25	—	—	1·1	1·0	0·034	0·45	Nil	2·6	3·9	6·5	40	0·03	—
CHAMAYE SERIES, RED SUB-SERIES															
2	0- 5	0·86	0·088	10	2·7	1·3	0·213	1·07	Nil	5·3	—	6·1	87	0·10	—
	5- 10	0·71	0·080	9	1·5	1·1	0·145	0·85	Nil	3·6	—	6·2	59	0·10	—
	15- 30	0·44	0·083	5	0·44	0·39	0·035	0·59	0·02	1·48	—	5·5	27	0·05	—
	60- 92	0·27	—	—	0·69	1·05	0·043	0·62	0·06	2·46	—	5·2	48	0·02	—
	122-155	0·25	—	—	—	—	—	—	—	—	—	—	—	0·05	—
47	0- 12	1·44	0·129	11	4·6	1·7	0·144	0·75	0·03	7·2	—	8·3	87	0·24	0·46
	12- 30	0·41	0·055	7	2·4	1·5	0·010	0·80	—	4·7	—	6·7	70	0·19	0·52
	45- 55	0·34	0·052	7	2·4	1·9	0·008	0·77	—	5·1	—	7·4	70	0·12	0·25
	75- 85	0·25	0·039	6	1·9	1·9	0·058	0·92	0·04	4·8	—	7·1	67	1·04	0·77
	105-115	0·25	—	—	3·2	2·6	0·009	0·72	—	6·5	—	8·3	78	0·08	0·46
	140-150	0·16	—	—	3·2	2·5	0·068	0·69	0·23	6·7	—	7·2	93	0·17	0·36
CHAMAYE SERIES, ORANGE SUB-SERIES															
63	0- 10	0·86	0·083	10	2·7	1·4	0·040	0·98	Nil	5·1	2·3	7·4	69	0·32	0·49
	10- 40	0·39	0·046	8	0·8	0·6	0·025	0·55	Nil	2·0	3·7	5·7	35	0·05	0·18
	40-140	0·27	0·034	8	1·0	0·8	0·015	0·68	Nil	2·5	5·6	8·1	31	0·02	—
CHAMAYE SERIES, RED SERIES WITH LIMESTONE															
78	0- 10	0·74	0·062	12	4·5	1·3	0·079	0·78	Nil	6·7	0·9	7·6	88	0·95	1·55
	10- 25	0·57	0·060	10	5·3	2·0	0·064	0·51	Nil	7·9	2·1	10·0	79	0·17	0·36
	25- 45	0·30	0·038	6	4·6	2·0	0·047	0·25	Nil	6·9	2·6	9·5	73	0·13	0·36
	50-125	0·24	—	—	5·9	1·8	0·040	0·22	Nil	8·0	1·5	9·5	84	0·19	0·39
	125-140	0·27	—	—	9·7	2·3	0·018	0·29	Nil	12·3	0·0	12·3	100	0·16	0·75
CHAMAYE SERIES, ORANGE SUB-SERIES WITH LIMESTONE															
81	0- 12	0·83	0·084	10	6·3	2·0	0·031	0·91	Nil	9·3	0·0	9·3	100	0·06	0·23
	12- 25	0·56	0·060	9	6·1	3·9	0·029	1·17	Nil	11·2	0·0	11·2	100	0·05	0·16
	25- 90	0·31	0·048	8	3·4	3·2	0·027	0·85	Nil	7·5	2·8	10·3	73	0·13	0·19
	90-165	0·19	0·040	5	6·0	3·1	0·020	0·56	Nil	9·7	2·6	12·3	79	0·15	0·19
	165-190	0·16	—	—	6·4	3·2	0·018	0·65	Nil	10·2	3·2	13·5	76	0·13	0·21

TABLE 24 *continued*

Profile No.	Horizon (cm.)	Org. C %	N %	C/N	Exchangeable Bases (m.e./100g soil)									Extractable P	
					Ca	Mg	Mn	K	Na	T.E.B.	H	B.E.C.	% satn	0·3N HCl	1% citric
														mg./100g soil	
MTANANA SERIES															
3	0- 5	0·53	0·045	12	1·3	0·9	0·057	0·80	0·01	3·1	—	3·80	82	0·15	0·37
	5- 10	0·45	0·046	10	0·95	0·21	0·028	0·72	0·02	1·9	—	4·10	47	0·15	0·34
	10- 15	0·49	0·039	13	0·87	0·39	0·090	0·59	0·03	2·0	—	4·38	45	0·10	—
	15- 30	—	—	—	—	—	—	—	—	—	—	—	—	0·10	—
	30- 50	0·41	—	—	—	—	—	—	—	—	—	—	—	0·12	0·39
	65- 85	0·33	—	—	—	—	—	—	—	—	—	—	—	0·15	—
39	0- 12	0·30	0·030	10	0·19	0·07	0·003	0·13	0·11	0·50	—	1·7	29	0·18	—
	15- 30	0·24	0·021	11	0·13	0·18	0·002	0·13	0·03	0·47	—	1·9	25	0·09	—
	40- 50	0·15	—	—	—	—	—	—	—	—	—	—	—	0·08	—
	80- 90	0·16	0·014	11	0·14	0·29	0·003	0·19	0·08	0·70	—	2·2	32	0·06	—
	120-130	0·11	—	—	—	—	—	—	—	—	—	—	—	0·05	—
MTANANA SERIES, WITH LIMESTONE															
76	0- 10	0·97	0·077	13	8·7	2·6	0·070	1·80	Nil	13·2	0·7	13·9	95	238·0	—
	10- 40	0·44	0·055	8	9·9	2·0	0·030	1·88	Nil	13·8	0·7	14·5	95	3·8	—
	40- 75	0·30	0·045	7	12·2	1·8	0·011	1·75	Nil	15·8	0·0	15·8	100	4·5	—
	75-130	0·16	—	—	8·9	3·8	0·016	3·90	Nil	16·6	0·0	16·6	100	4·6	—
DRAINAGE CHANNEL SOILS															
89	0- 18	0·54	0·055	10	1·7	1·8	0·031	0·62	Nil	4·2	0·9	5·1	82	0·25	—
	18- 32	0·34	0·044	8	1·3	2·0	0·023	0·65	Nil	4·0	2·4	6·4	63	0·07	—
	32-100	0·24	—	—	1·0	2·7	0·017	0·57	Nil	4·3	2·5	6·8	63	0·08	—
	100-160	0·17	—	—	1·4	1·0	0·015	0·58	Nil	3·0	1·8	4·8	63	0·04	—
MANKHUNZE SERIES															
65	0- 12	0·97	0·092	11	11·7	4·2	0·031	2·40	0·20	18·5	0·0	18·5	100	0·15	0·51
	12- 40	0·60	0·065	9	10·7	5·6	0·052	2·50	0·00	18·9	0·0	18·9	100	0·08	0·32
	40-100	0·31	0·041	8	15·7	4·1	0·029	1·60	0·31	21·8	0·0	21·8	100	0·04	0·16
LUBIRI SERIES															
5	0- 10	1·04	0·103	10	14·1	3·4	0·073	2·13	0·30	20·0	—	—	—	0·20	—
	15- 25	0·74	0·067	11	14·9	4·3	0·029	2·02	0·34	21·6	—	—	—	0·12	—
	45- 55	0·59	0·050	12	16·3	4·3	0·011	1·74	0·22	22·6	—	—	—	0·13	—
	65- 75	0·44	—	—	18·7	5·3	—	1·61	—	—	—	—	—	2·30	—
9	0- 5	2·24	0·229	10	—	—	—	—	—	—	—	—	—	2·50	—
	5- 10	2·17	0·214	10	12·9	3·7	—	0·67	0·26	17·5	—	—	—	2·44	—
	10- 15	—	—	—	—	—	—	—	—	—	—	—	—	2·75	—
	15- 30	1·36	0·112	12	9·8	3·4	—	0·87	0·22	14·3	—	—	—	0·63	—
	50- 80	0·43	—	—	5·5	6·6	—	1·33	0·26	13·7	—	—	—	Nil (a)	—

(a) Acid neutralised by carbonate.

Table 25. *Nachingwea Soils: Mechanical Analyses, pH Values and Conductivity*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction: Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Moisture	pH water	pH $CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
NACHINGWEA SERIES (SANDY LOAM)													
17	S 950	0- 10	2·5YR 3/5	Nil	39·3	24·0	4·3	28·3	Nil	1·8	5·85	4·97	—
	951	10- 22	2·5YR 3/6	Nil	36·3	17·1	3·4	40·2	Nil	2·2	4·85	4·13	—
	952	22- 35	10 YR 3/8	Nil	—	—	—	—	Nil	—	4·90	4·19	—
	953	35- 50	10 YR 3/8	Nil	42·7	11·6	1·8	41·3	Nil	2·2	5·10	4·16	—
	954	50-100	10 YR 3/8	Nil	—	—	—	—	Nil	—	5·15	4·14	—
	955	100-150	10 YR 3/8	0·4	37·6	13·3	4·3	42·3	Nil	2·1	5·20	4·15	—
	956	150-200	10 YR 3/8	0·6	—	—	—	—	Nil	—	5·15	4·13	—
	S1677	215-230	—	54·3	—	—	—	—	Nil	—	—	—	—
95	N 36	0- 15	5 YR 3/3	0·2	49·3	26·2	4·9	16·5	Nil	1·5	6·25	5·50	—
	37	15- 35	2·5YR 3/4	0·5	40·5	20·8	3·0	33·6	Nil	1·8	5·35	4·70	—
	38	35- 60	2·5YR 3/4	0·4	27·0	13·9	3·8	53·3	Nil	2·5	4·95	4·20	—
	39	60-120	10 R 3/6	0·4	28·2	15·7*	13·0	39·0	Nil	2·3	5·30	4·25	—
	40	120-210	10 R 3/6	0·8	27·9	26·3*	16·8	26·9	Nil	2·5	5·60	4·80	—
NAGAGA SERIES (SANDY LOAM)													
16	S 940	0- 7	7·5YR 4/2	0·0	42·2	39·0	2·9	12·3	Nil	1·2	6·60	6·04	—
	941	7- 17	7·5YR 4/3	0·3	38·8	41·5	2·8	15·3	Nil	1·0	6·30	5·58	—
	942	17- 30	2·5YR 4/5	0·2	—	—	—	—	Nil	—	5·25	4·34	—
	943	30- 45	—	1·7	44·9	16·3	1·3	34·8	Nil	1·8	5·10	—	—
	944	45- 65	5 YR 5/6	7·4	—	—	—	—	Nil	—	5·00	4·09	—
	945	65- 90	5 YR 6/6	5·6	42·4	13·2	2·4	39·8	Nil	2·0	5·20	4·18	—
	946	90-125	5 YR 6/8	22·0	—	—	—	—	Nil	—	5·15	4·22	—
	947	125-150	5 YR 6/8	17·6	45·9	15·0	3·7	33·5	Nil	1·9	5·20	4·25	—
	948	150-165	7·5YR 6/6	20·2	—	—	—	—	Nil	—	5·30	4·28	—
	949	190-200	—	25·0	44·2	15·5	3·6	34·7	Nil	1·9	5·30	—	—
NAGAGA SERIES (SAND)													
112	N 203	0- 18	7·5YR 3/2	0·5	60·3	24·4	2·8	10·4	Nil	1·2	6·12	5·44	—
	204	18- 30	5 YR 4/4	0·4	56·2	22·1	2·5	17·2	Nil	1·5	6·23	5·56	—
	205	30- 70	2·5YR 4/6	0·7	42·6	15·4	1·9	37·8	Nil	3·1	5·13	4·33	—
	206	70-110	2·5YR 5/8	2·1	38·2	14·3	2·6	42·5	Nil	3·1	4·89	4·19	—
	207	110-140	2·5YR 5/8	16·3	—	—	—	—	Nil	—	5·24	4·36	—
	208	140-200	5 YR 5/8	25·1	—	—	—	—	Nil	—	5·24	4·48	—

*Much iron oxide pseudo-sand.

K

TABLE 25 *continued*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction						pH		
					Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Mois-ture	water	$CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
NAGAGA SERIES (LOW-LYING LOAM)													
139	N 465	0- 15	5 YR 2/1	0·3	35·9	24·7	7·6	24·6	Nil	5·4	6·02	5·53	0·048
	466	15- 30	5 YR 3/3	0·9	31·8	22·6	5·8	34·2	Nil	5·8	5·65	5·17	0·032
	467	30- 60	5 YR 4/6	0·3	25·9	15·7	4·8	46·2	Nil	9·2	5·57	4·96	0·031
	468	60-100	2·5YR 4/8	0·3	16·0	9·9	6·5	57·7	Nil	13·0	5·90	5·07	0·021
	469	100-155	5 YR 5/8	0·5	17·5	11·5	11·9	47·1	Nil	11·8	6·44	5·57	0·011
NAMATULA SERIES, SANDY SUBSOIL													
105	N 94	0- 20	10 YR 4/3	2·4	48·2	36·7	4·5	8·8	Nil	0·6	5·95	5·35	—
	95	20- 35	5 YR 5/6	2·3	50·1	28·7	4·0	15·9	Nil	0·8	5·50	5·00	—
	96	35- 70	2·5YR 5/6	2·7	46·8	24·4	4·1	23·5	Nil	1·1	5·15	4·60	—
	97	70-100	2·5YR 5/6	4·3	46·0	21·7	3·5	27·4	Nil	1·2	5·15	4·45	—
	98	100-140	2·5YR 5/6	12·0	52·0	19·2	6·0	21·1	Nil	1·2	5·20	4·30	—
	99	140-165	2·5YR 5/6	27·3	—	—	—	—	Nil	0·7	5·55	4·95	—
NAMATULA SERIES, CLAYEY SUBSOIL													
117	N 233	0- 15	10 YR 3/2	1·1	44·1	41·2	2·0	9·6	Nil	1·1	6·12	5·40	—
	234	15- 30	5 YR 4/3	1·6	44·3	36·2	2·2	14·9	Nil	1·3	6·03	5·38	—
	235	30- 45	2·5YR 4/6	2·9	38·4	24·4	2·8	32·1	Nil	2·5	6·02	5·29	—
	236	45- 65	2·5YR 4/6	4·8	34·7	17·9	2·8	40·1	Nil	3·8	6·08	5·30	—
	237	65-120	5 YR 4/6	36·3	—	—	—	—	Nil	—	6·45	5·74	—
	238	120-175	5 YR 4/6	18·9	—	—	—	—	Nil	—	6·66	6·03	—
	239	175-205	mottled	50·9	—	—	—	—	Nil	—	6·56	6·05	—
NAILALA SERIES, ORANGE SUBSOIL													
94	N 30	0- 15	2·5Y 4/1	0·6	58·5	29·4	1·8	8·2	Nil	0·7	6·30	5·70	—
	31	15- 35	7·5YR 4/2	1·2	60·7	27·3	1·4	9·1	Nil	0·6	6·05	5·65	—
	32	35- 60	5 YR 4/4	1·3	54·3	25·1	1·3	17·6	Nil	0·9	5·10	4·40	—
	33	60- 90	5 YR 5/4	2·8	52·2	17·1	1·5	28·0	Nil	1·3	5·25	4·60	—
	34	90-170	7·5YR 6/6	31·5	50·0	16·1	2·8	28·6	Nil	1·7	5·95	5·30	—
	35	170-185	—	63·6	—	—	—	—	Nil	0·6	—	—	—
NAILALA SERIES, BROWN SUBSOIL													
93	N 7	0- 15	10 YR 4/1	0·1	55·2	34·7	3·0	6·3	Nil	0·6	6·95	6·15	0·049
	8	15- 35	10 YR 4/2	0·0	56·6	37·7	2·0	6·5	Nil	0·4	6·05	5·55	0·037
	9	35- 60	7·5YR 5/4	0·0	52·8	31·0	1·5	14·2	Nil	0·8	5·15	4·25	0·019
	10	60-100	7·5YR 6/4	0·1	47·2	24·4	2·1	25·6	Nil	1·4	5·15	4·25	0·029
	11	100-140	10 YR 6/4	0·3	48·1	20·3	1·8	28·6	Nil	1·6	5·55	4·80	0·039
	12	140-200	10 YR 6/3	20·4	—	—	—	—	Nil	0·4	6·20	5·50	0·034

TABLE 25 *continued*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction						pH		
					Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Moisture	water	$CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
NANGOI SERIES													
133	N 363	0- 12	10 YR 3/1	0·1	74·1	18·4	1·1	4·4	Nil	0·5	7·06	6·50	—
	364	12- 30	10 YR 4/2	0·1	71·9	21·2	1·0	5·2	Nil	0·3	6·87	6·33	—
	365	30- 60	10 YR 5/6	0·1	—	—	—	—	Nil	—	6·84	6·22	—
	366	60-100	5 YR 6/6	0·2	66·3	23·3	0·8	8·9	Nil	0·3	6·62	6·10	—
	367	100-150	5 YR 6/3	0·1	—	—	—	—	Nil	—	6·42	5·90	—
	368	150-200	7·5YR 6/6	0·3	67·7	23·8	0·8	7·2	Nil	0·2	8·60	7·82	—
MITUMBATI SERIES													
116	N 229	0- 10	10 YR 4/1	1·8	60·4	30·3	2·0	5·3	Nil	1·7	6·77	6·21	0·039
	230	10- 35	10 YR 5/3	3·4	56·7	35·0	2·0	6·0	Nil	0·5	6·55	6·00	0·029
	231	35- 70	10 YR 5/4	7·3	51·9	33·2	1·5	11·9	Nil	0·8	5·51	4·68	0·021
	232	70-130	mottled	52·7	—	—	—	—	Nil	—	6·03	5·23	0·017
CHIUMBATI SERIES													
118	N 240	0- 12	10 YR 4/1	4·1	61·7	31·3	1·5	3·4	Nil	0·3	5·98	5·30	0·021
	241	12- 30	7·5YR 5/3	3·7	63·4	31·6	1·2	2·8	Nil	0·3	6·16	5·51	0·023
	242	30- 52	10 YR 6/3	8·2	54·7	40·5	1·2	2·8	Nil	0·2	6·17	5·61	0·021
NAIPINGO SAND													
127	N 327	0- 10	10 YR 3/1	0·1	63·7	22·0	3·4	9·1	Nil	0·8	6·83	6·27	0·057
	328	10- 25	10 YR 2/2	0·1	66·0	20·6	3·0	9·7	Nil	0·7	6·84	6·23	0·032
	329	25- 50	10 YR 4/3	0·0	57·7	22·1	2·0	17·0	Nil	0·9	6·52	5·94	0·029
	330	50- 80	10 YR 7/6	0·2	56·0	13·9	1·7	27·6	Nil	1·5	5·20	4·46	0·014
	331	80-140	10 YR 7/6	0·1	—	—	—	—	Nil	—	4·96	4·23	0·023
	332	140-190	10 YR 6/4	1·4	45·2	13·7	2·9	37·6	Nil	1·8	4·91	4·19	0·027
	333	190-210	10 YR 8/4	39·6	—	—	—	—	Nil	—	5·00	4·20	0·023
NAIPINGO, SANDY LOAM													
125	N 314	0- 12	10 YR 2/1	0·1	57·7	26·8	2·8	10·3	Nil	1·0	6·69	6·13	0·039
	315	12- 25	10 YR 4/2	0·3	51·3	32·6	2·4	12·2	Nil	0·9	6·62	5·91	0·026
	316	25- 50	10 YR 5/4	0·2	49·3	28·4	2·1	19·2	Nil	1·0	5·34	4·61	0·018
	317	50- 75	10 YR 5/6	0·5	—	—	—	—	Nil	—	5·18	4·36	0·018
	318	75- 95	10 YR 6/6	0·9	37·0	12·3	2·9	45·8	Nil	2·4	5·33	4·50	0·015
	319	95-125	10 YR 7/5	9·4	—	—	—	—	Nil	—	5·77	4·90	0·026
	320	125-190	mottled	9·9	—	—	—	—	Nil	—	6·53	5·75	0·018

TABLE 25 *continued*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction: Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Moisture	pH water	pH $CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
KIHUE SERIES													
126	N 321	0- 8	10 YR 3/2	0·5	42·4	22·3	4·5	27·7	Nil	2·2	6·47	5·84	0·034
	322	8- 18	10 YR 7/6	1·5	30·7	14·2	3·8	48·4	Nil	3·1	5·40	4·81	0·022
	323	18- 40	10 YR 7/6	1·0	—	—	—	—	Nil	—	4·98	4·19	0·014
	324	40- 75	10 YR 7/6	11·7	28·5	11·8	5·0	52·6	Nil	3·1	4·97	4·15	0·011
	325	75-120	mottled	29·2	—	—	—	—	Nil	—	5·07	4·29	0·021
	326	120-175	mottled	14·7	—	—	—	—	Nil	—	5·21	4·37	0·020
WATER-HOLE SOILS													
51	S1853	0- 12	10 YR 3/2	2·6	46·1	17·0	5·0	28·3	Nil	2·7	5·90	—	0·066
	1854	12- 40	10 YR 6/6	2·4	33·7	13·1	4·0	47·7	Nil	4·3	5·00	—	0·039
	1855	40- 72	10 YR 6/6	5·0	32·8	12·3	3·8	48·6	Nil	4·2	5·05	—	0·037
	1856	72-112	10 YR 6/3	6·6	—	—	—	—	Nil	—	5·10	—	0·066
	1857	112-186	10 YR 6/3	11·4	38·5	13·6	3·0	42·9	Nil	3·8	5·40	—	0·037
NYATI SERIES													
151	N 644	0- 10	10 YR 3/1	1·4	50·1	25·2	4·3	17·9	Nil	2·0	5·99	5·46	0·030
	645	10- 25	5 YR 4/1	3·6	47·8	17·7	4·5	26·2	Nil	2·9	5·21	4·66	0·028
	646	25- 50	5 YR 4/1	4·0	20·9	12·2	3·5	56·8	Nil	8·4	5·56	4·91	0·041
	647	50-100	10 YR 4/1	3·6	26·0	13·1	4·0	51·6	Nil	7·7	6·81	6·22	0·078
	648	100-135	4/0	3·7	25·2	14·7	14·5	39·5	0·41	7·8	8·05	7·45	0·145
	649	135-150	10 YR 6/2	9·2	—	—	—	—	0·64	—	8·43	7·81	0·245
	650	150-180	10 YR 6/1	20·7	27·4	14·6	21·0	31·3	0·91	6·9	8·53	7·87	0·285
NKUMBA BROWN LOAM													
140	N 470	0- 12	5 YR 2/1	0·2	31·9	31·0	8·5	20·8	Nil	5·0	5·67	5·20	0·033
	471	12- 30	7·5YR 3/2	0·6	30·6	26·3	6·0	30·0	Nil	6·1	5·77	5·32	0·019
	472	30- 60	5 YR 3/4	1·2	21·7	15·6	4·5	48·4	Nil	10·1	5·82	5·21	0·012
	473	60-100	5 YR 4/6	2·5	19·0	12·5	6·0	52·4	Nil	11·1	6·01	5·32	0·014
	474	100-155	7·5YR 4/4	4·5	23·8	13·3	6·1	47·4	Nil	10·2	6·29	5·67	0·020
NKUMBA BLACK LOAM													
138	N 459	0- 15	10 YR 2/1	0·1	32·6	27·4	5·4	26·5	Nil	5·7	6·49	5·96	0·072
	460	15- 35	10 YR 2/2	0·4	30·3	29·3	5·0	28·0	Nil	5·4	6·49	5·87	0·042
	461	35- 65	10 YR 3/3	0·2	35·0	20·8	4·4	32·8	Nil	6·2	6·19	5·60	0·033
	462	65-100	10 YR 3/2	0·8	24·4	20·3	5·6	43·2	Nil	8·0	6·26	5·64	0·032
	463	100-140	10 YR 3/1	0·6	32·0	20·9	5·3	34·7	Nil	7·0	6·19	5·61	0·033
	464	140-165	10 YR 3/2	0·1	33·0	21·9	4·9	35·0	Nil	5·9	6·17	5·45	0·033

TABLE 25 *continued*

Profile No.	Sample No.	Horizon (cm.)	Colour (Munsell)	Stones and Gravel	Analysis of fine earth fraction								
					Coarse sand	Fine sand	Silt	Clay	$CaCO_3$	Mois-ture	pH water	pH $CaCl_2$	Sp. Cond.
				%	%	%	%	%	%	%			m-mhos
NKUMBA SWAMP SOIL													
134	N 129	0- 8	10 YR 4/1	Nil	6·6	7·4	10·0	67·7	Nil	6·8	5·20	4·50	0·072
	130	8- 15	10 YR 4/2	Nil	5·0	4·7	8·6	74·3	Nil	6·9	5·85	5·10	0·048
	131	15- 30	10 YR 4/2	Nil	5·9	7·7	10·8	68·3	Nil	11·1	6·40	5·70	0·057
	132	30- 45	10 YR 4/1	Nil	—	—	—	—	Nil	—	6·45	5·75	0·062
	133	45- 60	10 YR 5/2	0·2	11·7	8·6	7·0	66·6	Nil	11·1	6·40	5·70	0·048
	134	60- 76	10 YR 5/2	0·3	—	—	—	—	Nil	—	6·45	5·60	0·051
	135	76- 91	10 YR 5/2	1·0	23·5	10·8	5·9	61·1	Nil	8·3	6·20	5·55	0·091
	369	95-130	10 YR 4/3	0·4	—	—	—	—	Nil	—	6·45	5·73	0·023
	370	130-170	10 YR 4/3	0·5	29·8	14·4	5·3	48·9	Nil	3·5	6·18	5·50	0·019
NAUNGA CLAY													
137	N 453	0- 15	2/0	0·02	39·7	19·8	3·1	29·2	Nil	6·2	6·67	6·21	0·072
	454	15- 30	5 YR 2/1	0·01	38·3	17·5	3·8	33·8	Nil	6·3	6·83	6·29	0·061
	455	30- 65	4/0	0·01	30·6	14·6	3·6	43·7	Nil	8·4	7·33	6·81	0·077
	456	65-100	4/0	0·10	30·8	13·6	4·3	44·7	0·05	8·7	8·12	7·51	0·169
	557	100-140	4/0	0·01	16·3	10·9	5·0	60·2	0·59	8·3	8·16	7·62	0·478
	559	140-210	3/0	Nil	20·4	13·3	4·8	54·4	1·18	9·5	8·08	7·70	0·716
MANDAI SERIES													
150	N 560	0- 10	7·5YR 3/2	6·1	27·8	21·9	11·0	32·1	Nil	4·7	6·30	5·77	0·049
	561	10- 50	10 YR 3/2	1·3	32·1	22·5	8·8	31·0	Nil	4·4	6·16	5·62	0·039
	562	50- 64	10 YR 3/2	17·0	70·1	12·0	3·3	12·7	Nil	1·5	6·35	5·82	0·030
	563	64-152	7·5YR 4/2	2·5	36·0	29·6	8·8	24·4	Nil	3·1	6·38	5·85	0·028
	564	152-164	7·5YR 4/2	9·7	61·5	24·1	2·0	10·9	Nil	1·3	6·75	6·20	0·023
	565	164-200	7·5YR 4/3	0·6	50·8	29·2	3·8	14·2	Nil	4·8	6·75	6·25	0·030
IMMATURE SOILS													
152	N 674	0- 2	5 YR 2/2	72	22·6	14·1	17·8	20·9	Nil	9·4	6·96	6·62	—
	675	2- 10	5 YR 3/3	88	36·0	20·6	10·3	24·6	Nil	5·3	6·66	6·24	—
	676	10- 25	5 YR 3/3	88	39·8	21·4	7·0	23·6	Nil	5·1	6·06	5·56	—
153	N 727	0- 3	5 YR 3/4	4·3	44·3	37·1	5·4	11·5	Nil	2·6	6·46	5·58	—
	728	3- 7	5 YR 3/4	4·5	42·0	37·5	5·8	12·7	Nil	3·2	6·47	5·63	—
	729	7- 12	5 YR 3/4	—	—	—	—	—	Nil	—	6·26	5·36	—

TABLE 26. *Nachingwea Soils: Chemical Analyses*

Profile No.	Horizon (cm.)	Org. C. %	N. %	C/N.	Exchangeable Bases (m.e./100g. soil)									Extractable P	
					Ca	Mg	Mn	K	Na	T.E.B.	H	B.E.C.	% satn.	0·3N HCl	1% citric
														mg./100g soil	
NACHINGWEA SERIES (SANDY LOAM)															
17	0- 10	1·09	0·066	17	2·6	3·2	0·20	0·42	—	6·4	—	8·6	74	0·05	—
	10- 22	0·86	0·045	19	0·5	2·1	0·12	0·21	—	2·9	—	7·2	40	0·07	—
	22- 35	—	—	—	—	—	—	—	—	—	—	—	—	0·08	—
	35- 50	0·31	0·025	12	0·2	2·5	0·04	0·16	—	2·9	—	6·6	44	0·02	—
	50-100	—	—	—	—	—	—	—	—	—	—	—	—	0·02	—
	100-150	0·29	0·027	11	0·3	2·2	0·06	0·14	—	2·7	—	6·5	42	0·01	—
95	0- 15	1·85	0·100	19	4·7	2·5	0·138	0·56	0·31	8·2	1·6	9·8	84	0·11	—
	15- 35	1·10	0·075	15	1·7	2·2	0·154	0·28	0·29	4·6	3·5	8·1	57	0·04	—
	35- 60	0·79	0·065	12	0·7	2·5	0·077	0·18	0·59	4·0	4·6	8·6	47	0·03	—
	60-120	0·31	0·035	9	0·4	2·5	0·040	0·25	0·26	3·5	3·0	6·5	54	0·02	—
	120-210	0·25	0·025	10	0·5	2·5	0·026	0·18	0·31	3·5	1·8	5·3	66	0·02	—
NAGAGA SERIES (SANDY LOAM)															
16	0- 7	1·25	0·066	19	4·5	1·8	0·15	0·37	—	6·8	—	7·6	90	0·25	—
	7- 17	0·68	0·045	15	2·4	1·0	0·17	0·27	—	3·8	—	5·2	73	0·05	—
	17- 30	0·36	0·035	10	0·5	2·1	0·04	0·25	—	2·9	—	6·0	48	0·03	—
	30- 45	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—
	45- 65	—	—	—	—	—	—	—	—	—	—	—	—	0·02	—
	65- 90	0·23	0·023	10	0·3	1·8	Nil	0·25	—	2·4	—	6·2	39	0·02	—
	90-125	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—
	125-150	0·13	—	—	0·3	2·0	Nil	0·15	0·29	2·7	—	5·6	48	0·01	—
NAGAGA SERIES (SAND)															
112	0- 18	0·61	0·038	16	0·67	1·2	0·07	0·19	—	2·1	—	3·9	54	—	0·50
	18- 30	0·35	0·031	11	0·58	1·9	0·01	0·32	—	2·8	—	5·1	55	—	0·16
	30- 70	0·21	0·026	8	0·66	2·7	0·06	0·30	—	3·7	—	6·2	60	—	0·06
	70-110	0·14	—	—	0·33	2·6	0·03	0·30	—	3·3	—	5·8	57	—	0·11
NAGAGA SERIES (LOW-LYING LOAM)															
139	0- 15	2·25	0·129	17	5·2	5·8	Nil	0·66	—	11·7	—	17·4	67	—	0·17
	15- 30	1·24	0·081	15	5·1	3·7	Nil	0·53	—	9·3	—	14·1	66	—	0·12
	30- 60	0·84	0·066	13	4·2	4·5	Nil	0·41	—	9·1	—	13·2	69	—	0·06
	60-100	0·48	—	—	—	—	—	—	—	—	—	—	—	—	0·13
	100-155	0·30	—	—	2·7	5·0	Nil	0·20	0·17	8·1	—	10·2	79	—	0·03

TABLE 26 *continued*

Profile No.	Horizon (cm.)	Org. C. %	N. %	C/N.	Exchangeable Bases (m.e./100g. soil) Ca	Mg	Mn	K	Na	T.E.B.	H	B.E.C.	% satn.	Extractable P 0·3N HCl	1% citric
														mg./100g	soil
NAMATULA SERIES, SANDY SUBSOIL															
105	0- 20	0·82	0·035	23	2·4	0·6	0·089	0·23	—	3·3	1·0	4·3	77	0·40	0·65
	20- 35	0·43	0·024	18	1·0	0·8	0·042	0·33	—	2·2	1·2	3·4	65	0·05	0·08
	35- 70	0·22	0·025	9	0·4	1·2	0·076	0·36	—	2·0	1·8	3·8	53	0·03	0·06
	70-100	0·18	0·025	7	0·4	1·0	0·048	0·53	—	2·0	1·2	3·2	62	Nil	0·07
	100-140	0·18	0·017	11	0·5	1·3	0·072	0·48	—	2·4	1·4	3·8	63	0·01	0·05
	140-165	0·13	0·020	7	0·7	0·9	0·040	0·32	—	2·0	0·4	2·4	83	Nil	0·01
NAMATULA SERIES, CLAYEY SUBSOIL															
117	0- 15	0·79	0·060	13	2·2	1·8	0·122	0·16	0·04	4·3	—	5·8	74	0·30	—
	15- 30	0·41	0·037	11	2·0	1·5	0·088	0·25	—	3·8	1·2	5·0	76	0·04	—
	30- 45	0·33	0·037	9	1·8	3·3	0·067	0·34	—	5·5	1·5	7·0	79	0·02	—
	45- 65	0·33	0·039	8	3·0	3·4	0·062	0·38	—	6·8	1·6	8·4	81	0·02	—
NAILALA SERIES, ORANGE SUBSOIL															
94	0- 15	0·76	0·05	15	3·1	1·1	0·043	0·25	—	4·5	—	5·1	88	—	1·32
	15- 35	0·39	0·03	13	1·7	0·9	0·080	0·16	—	2·8	—	3·7	76	—	0·32
	35- 60	0·21	0·03	7	—	—	—	—	—	—	—	—	—	—	0·40
	60- 90	0·20	0·03	7	1·6	1·5	0·044	0·19	0·16	3·5	—	4·8	73	—	0·16
NAILALA SERIES, BROWN SUBSOIL															
93	0- 15	0·70	0·035	20	3·1	0·9	0·065	0·23	0·20	4·5	—	4·2	100	0·30	—
	15- 35	0·25	0·015	17	1·3	0·6	0·063	0·08	0·03	2·1	—	2·5	84	0·21	—
	35- 60	0·20	0·02	10	0·7	0·8	0·065	0·09	0·06	1·7	—	3·0	57	0·08	—
	60-100	0·20	0·02	10	—	—	—	—	—	—	—	—	—	0·06	—
	100-140	0·19	0·02	10	1·8	1·6	0·023	0·12	0·16	3·7	—	4·7	79	0·06	—
NANGOI SERIES															
133	0- 12	0·65	0·049	13	3·6	0·9	0·045	0·17	0·06	4·8	—	4·4	100	1·36	—
	12- 30	0·30	0·026	12	1·2	0·70	0·080	0·24	—	2·2	0·7	2·9	76	0·26	—
	30- 60	—	—	—	—	—	—	—	—	—	—	—	—	0·12	—
	60-100	0·28	0·011	25	1·2	0·45	0·047	0·17	—	1·9	1·3	3·2	59	0·04	—
	100-150	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—
	150-200	0·06	—	—	3·7	0·38	0·016	0·11	0·07	4·3	-ve	4·3	100	0·05	—
MITUMBATI SERIES															
116	0- 10	0·69	0·041	17	3·4	1·0	Nil	0·18	—	4·6	—	4·8	96	0·28	—
	10- 35	0·23	0·017	14	0·7	1·2	Nil	0·13	—	2·0	—	2·4	83	0·04	—
	35- 70	0·15	—	—	0·5	1·3	Tr.	0·30	0·23	2·3	—	3·1	74	0·03	—

TABLE 26 *continued*

Profile No.	Horizon (cms.)	Org. C. %	N. %	C/N.	Exchangeable Bases (m.e./100g. soil)									Extractable P	
					Ca	Mg	Mn	K	Na	T.E.B.	H	B.E.C.	% satn.	0·3N HCl	1% citric
														mg./100g	soil
CHIUMBATI SERIES															
118	0- 12	0·39	0·028	14	1·4	0·7	0·058	0·13	—	2·3	3·1	5·4	42	0·13	—
	12- 30	0·30	0·028	11	1·3	0·5	0·021	0·12	—	1·9	0·9	2·8	68	0·06	—
	30- 52	0·18	0·017	9	0·7	0·7	0·020	2·00	—	3·4	0·6	4·0	85	0·05	—
NAIPINGO SAND															
127	0- 10	1·11	0·063	18	6·0	2·7	0·021	0·22	—	8·9	1·1	10·0	89	0·35	—
	10- 25	0·46	0·032	14	2·8	1·6	0·025	0·15	—	4·6	0·7	5·3	87	0·05	—
	25- 50	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—
	50- 80	0·11	0·015	7	0·5	2·6	0·051	0·17	—	3·3	1·9	5·2	63	0·03	—
	80-140	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—
	140-190	0·16	—	—	0·7	1·8	0·020	0·17	—	2·7	3·5	6·2	44	0·05	—
NAIPINGO SANDY LOAM															
125	0- 12	0·93	0·056	17	5·6	1·4	0·020	0·45	—	7·5	—	7·4	100	0·41	1·12
	12- 25	0·50	0·031	16	2·6	1·2	0·051	0·29	—	4·1	—	5·1	80	0·04	0·22
	25- 50	0·27	0·023	12	2·0	1·0	0·082	0·22	—	3·3	—	4·6	72	0·01	0·08
	50- 75	—	—	—	—	—	—	—	—	—	—	—	—	—	0·13
	75- 95	0·16	—	—	2·9	2·1	0·004	0·16	0·17	5·3	—	8·6	62	Nil	0·03
KIHUE SERIES															
126	0- 8	1·16	0·075	15	6·2	3·2	0·018	0·16	—	9·6	4·2	13·8	70	0·09	0·11
	8- 18	0·46	0·045	10	4·5	3·0	0·073	0·23	—	7·8	2·8	10·6	74	0·03	0·03
	18- 40	0·21	0·030	7	2·8	3·2	0·040	0·16	—	6·2	6·6	12·8	48	0·03	Nil
	40- 75	0·20	0·021	10	1·9	1·6	0·110	0·16	—	3·8	5·7	9·5	40	0·03	Nil
WATER-HOLE SOILS															
51	0- 12	1·35	0·088	15	3·6	1·1	—	0·23	0·10	—	—	—	—	0·10	—
	12- 40	0·33	0·032	10	4·3	3·5	—	0·15	—	—	—	—	—	0·03	—
	40- 72	0·20	—	—	3·7	4·3	—	0·15	0·08	—	—	—	—	0·03	—
	72-112	0·20	—	—	4·1	4·0	—	0·15	—	—	—	—	—	0·04	—
	112-186	0·13	—	—	6·3	4·2	—	0·23	0·39	—	—	—	—	0·03	—
NYATI SERIES															
151	0- 10	1·31	0·070	19	5·5	3·2	0·011	0·17	0·13	9·0	—	10·5	86	—	0·72
	10- 25	0·85	0·052	16	3·2	2·8	0·108	0·08	0·46	6·7	—	10·1	66	—	0·50
	25- 50	0·57	0·046	12	5·0	6·3	0·027	0·20	1·07	12·6	—	15·3	82	—	0·16
	50-100	0·36	—	—	—	—	—	—	—	—	—	—	—	—	0·12
	100-135	0·29	0·020	15	7·0	7·7	Tr.	0·26	1·91	16·9	—	16·5	100	—	0·16

TABLE 26 *continued*

Profile No.	Horizon (cm.)	Org. C. %	N. %	C/N.	Exchangeable Bases (m.e./100 g. soil) Ca	Mg	Mn	K	Na	T.E.B.	H	B.E.C.	% satn.	Extractable P 0·3N HCl	1% citric
														mg./100g soil	
NKUMBA BROWN LOAM															
140	0- 12	1·73	0·130	13	8·1	3·9	0·012	0·60	—	12·6	—	17·4	72	—	0·16
	12- 30	1·19	0·081	15	5·9	3·7	Trace	0·51	—	10·1	—	13·6	74	—	0·05
	30- 60	0·74	0·065	11	3·0	2·8	Nil	0·48	—	6·3	—	13·3	47	—	0·05
	60-100	0·49	—	—	—	—	—	—	—	—	—	—	—	—	Nil
	100-155	0·36	—	—	4·5	2·7	Nil	0·23	0·23	7·7	—	13·7	56	—	Nil
NKUMBA BLACK LOAM															
138	0- 15	2·54	0·127	20	12·6	7·5	Nil	0·70	—	20·8	—	23·0	90	—	2·65
	15- 35	1·55	0·090	17	8·8	5·2	Nil	0·52	—	14·5	—	18·6	78	—	0·56
	35- 65	0·89	—	—	—	—	—	—	—	—	—	—	—	—	0·13
	65-100	0·48	0·029	17	6·9	6·6	Trace	0·55	—	14·1	—	16·4	86	—	0·05
	100-140	0·58	—	—	—	—	—	—	—	—	—	—	—	—	0·06
	140-165	0·53	0·034	16	5·6	5·0	Trace	0·19	0·21	11·0	—	15·0	73	—	0·12
NKUMBA SWAMP SOIL															
134	0- 8	2·25	0·150	15	9·5	6·8	Tr.	0·61	—	16·9	—	27·0	63	—	8·4
	8- 15	1·15	0·102	11	—	—	—	—	—	—	—	—	—	—	0·56
	15- 30	0·83	0·068	12	11·1	7·8	Tr.	0·39	—	19·3	—	24·3	79	—	0·22
	30- 45	—	—	—	—	—	—	—	—	—	—	—	—	—	0·12
	45- 60	0·56	0·054	10	10·4	8·3	Nil	0·36	—	19·1	—	21·8	88	—	0·12
	60- 76	—	—	—	—	—	—	—	—	—	—	—	—	—	0·22
	76- 91	0·48	0·047	10	5·6	3·9	0·02	0·45	0·43	10·4	—	16·2	64	—	0·16
	95-130	0·25	—	—	—	—	—	—	—	—	—	—	—	—	0·03
	130-170	0·24	—	—	6·3	3·7	Tr	0·19	0·37	10·6	—	14·0	76	—	0·16
NAUNGA CLAY															
137	0- 15	2·31	0·153	15	18·3	5·0	Nil	0·26	0·30	23·9	—	27·4	87	—	0·58
	15- 30	1·24	0·087	14	16·7	7·3	Nil	0·12	0·36	24·5	—	25·4	97	—	0·27
	30- 65	0·56	—	—	—	—	—	—	—	—	—	—	—	—	0·15
	65-100	0·54	0·031	17	20·0	11·4	Nil	0·15	1·52	33·1	—	33·0	100	—	0·18
	100-140	0·27	—	—	—	—	—	—	—	—	—	—	—	—	0·43
	140-210	0·20	0·014	18	28·5	19·9	Nil	0·23	2·50	51·1	—	48·7	100	—	0·76

TABLE 26 *continued*

Profile No.	Horizon (cm.)	Org. C. %	N. %	C/N.	Exchangeable Bases (m.e./100 g. soil)									Extractable P	
					Ca	Mg	Mn	K	Na	T.E.B.	H	B.E.C.	% satn.	0·3N HCl	1% citric
														mg./100g soil	
MANDAI SERIES															
150	0- 10	2·44	0·158	15	16·8	5·3	0·40	0·83	—	23·3	—	30·0	78	—	1·18
	10- 50	1·39	0·093	15	16·9	4·1	0·56	0·43	—	22·0	—	26·9	82	—	1·63
	50- 64	0·26	—	—	6·0	2·3	0·22	0·25	—	8·8	—	8·7	100	—	5·64
	64-152	0·59	0·041	14	12·6	5·2	0·19	0·29	—	18·3	—	19·1	96	—	4·66
	152-164	—	—	—	—	—	—	—	—	—	—	—	—	—	14·4
	164-200	0·40	0·018	22	8·5	3·4	0·04	0·19	0·08	12·2	—	12·1	100	—	14·0
IMMATURE SOILS															
152	0- 2	17·9	1·08	17	21·7	17·4	0·03	1·33	—	40·5	—	54·2	75	—	33·0
	2- 10	7·7	0·55	14	16·4	10·2	0·01	0·89	—	27·5	—	30·6	90	—	15·0
	10- 25	4·1	0·33	12	7·2	5·6	Tr.	0·74	—	13·5	—	18·2	74	—	5·6
153	0- 3	0·59	0·053	11	4·1	3·3	0·018	0·20	—	7·6	—	11·0	69	—	10·8
	3- 7	0·54	0·045	12	3·3	2·4	Tr.	0·25	—	6·0	—	12·0	50	—	9·6