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**Technical Report 1**

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**KITULO SHEEP RAISING PROJECT**

# **TANZANIA**

**LAND RESOURCES  
OF WESTERN NJOMBE DISTRICT**



**UNITED NATIONS DEVELOPMENT PROGRAMME**



**FOOD AND AGRICULTURE ORGANIZATION  
OF THE UNITED NATIONS** **ROME, 1971**

R. W. Borden

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Technical Report 1

FAO. Kitulo Sheep Raising Project, Tanzania.  
Land resources of Western Njombe District, based  
on the work of R.W. Borden and A.H. Kishimba.  
Rome, 1971. 93 p. 2 maps. AGA:SF/TAN 8.  
Technical Report 1.

## KITULO SHEEP RAISING PROJECT

ABSTRACT

### TANZANIA

A survey of the land resources of the Western Njombe District formed part of a project undertaken by the Government of Tanzania, with assistance from the United Nations Development Programme (Special Fund Sector) and the Food and Agriculture Organization of the United Nations. To develop a wool-sheep industry in the area.

#### LAND RESOURCES OF WESTERN NJOMBE DISTRICT

This survey was done by a consultant provided by the Government of Tanzania in 1969. Soils were inspected along roads and accessible tracks, and inaccessible areas were examined by aerial photographs. Landforms, vegetation, geology and soils were noted, and on the basis of this information thirteen land units were delineated and described. Report prepared for the Government of Tanzania

by  
the Food and Agriculture Organization of the United Nations  
acting as executing agency for  
the United Nations Development Programme

The report does not attempt to give a detailed interpretation of the findings with regard to land use.

based on the work of

R.W. Borden and A.H. Kishimba  
Soil Scientists

UNITED NATIONS DEVELOPMENT PROGRAMME  
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 1971

ADAPTED FROM  
Technical Report

UNITED NATIONS DEVELOPMENT PROGRAM

ANNEX I

LAND RESOURCES OF WESTERN HONOLULU DISTRICT

Report prepared for

This technical report is one of a series of reports prepared during the course of the UNDP/SF project identified on the title page. The conclusions and recommendations given in the report are those considered appropriate at the time of its preparation. They may be modified in the light of further knowledge gained at subsequent stages of the project.

based on the work of

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UNITED NATIONS DEVELOPMENT PROGRAM

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Chapter 2

AREA SURVEYED

- 2.1 Survey Method
- 2.2 Physiography
- 2.3 Geology
- 2.4 Climate

ABSTRACT

A survey of the land resources of the Western Njombe District formed part of a project undertaken by the Government of Tanzania, with assistance from the United Nations Development Programme (Special Fund Sector) and the Food and Agriculture Organization of the United Nations, to develop a wool-sheep industry in the area.

This survey was done by a consultant provided by the Government of Tanzania in 1969. Soils were inspected along roads and accessible tracks, and inaccessible areas were examined by aerial photographs. Landforms, vegetation, geology and soils were noted, and on the basis of this information thirteen land units were delineated and described. Representative pits were dug and soil samples collected for laboratory analysis. Detailed descriptions of soil profiles are given.

A soil map of the Western Njombe District (scale 1:125 000) was prepared, together with a second map of the soils of the Kitulo Plateau at a larger scale (1:25 000).

The report does not attempt to give a detailed interpretation of the findings with regard to land use.

Chapter 7

DETAILED DESCRIPTIONS OF THE SOILS OF THE  
 KITULO PLATEAU (Unit 1)

- 7.1 Subunit 1a
- 7.2 Subunit 1b
- 7.3 Subunit 1c
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- 7.6 Proposed Kitulo Irrigation Site

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Appendix 2

BIBLIOGRAPHY

The Food and Agriculture Organization is greatly indebted to the following individuals who assisted in the implementation of the project by providing information, advice and facilities: Mr. R.M. Baker, Senior Soil Scientist, Dar es Salaam; Mr. B.N. Patel, Soil Chemist, Ilonga; Mr. Charles Luanda and the Mbeya Land Planning staff.

ABSTRACT

A survey of the land resources of the Western Highlands District formed part of a project undertaken by the Government of Tanzania, with assistance from the United Nations Development Programme (Special Fund Sector) and the Food and Agriculture Organization of the United Nations, to develop a wool-staple industry in the area.

This survey was done by a committee provided by the Government of Tanzania in 1969. Soils were inspected along roads and accessible tracks, and inaccessible areas were examined by aerial photographs. Landforms, vegetation, geology and soils were noted, and on the basis of this information terrain maps were delineated and described. Representative pits were dug and soil samples collected for laboratory analysis. Detailed descriptions of soil profiles are given.

A soil survey of the Western Highlands District (code 125-000) was prepared together with a map of the district. The survey was done by a committee provided by the Government of Tanzania, with assistance from the United Nations Development Programme (Special Fund Sector) and the Food and Agriculture Organization of the United Nations. The report does not attempt to give a detailed interpretation of the findings with regard to land use.

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The purpose of the Kitulo Sheep Raising Project is to assist the development of a wool-sheep industry through the establishment of a pilot project on the Kitulo Plateau. The project is to make practical studies on the problems of breeding, nutrition, management and health of sheep, the problems of cereal, cash and forage crop cultivation as a preparatory step to the establishment of sheep pastures and on marketing of the products; also to prepare an integrated development programme for crop cultivation, pasture establishment and the breeding of wool sheep applicable to the plateau and to ecologically similar areas.

This land use survey was done at the request of the Kitulo Sheep Raising Project with a consultant supplied by the Government of Tanzania, in order that they might have information that would serve as a basis for preparing a programme of land use within the above terms of reference.

The entire area had previously been surveyed in 1969 (Edwards and Duckworth) on a scale of 1:250,000, but this was felt to be too general for the purposes of planning and future expansion. The Kitulo Project is at present being enlarged to include a Livestock Multiplication Centre which, together with the 9,312 hectare (23) Sheep Scheme, will cover an area of 29,355 ha.

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Chapter 1

INTRODUCTION

The purpose of the Kitulo Sheep Raising Project is to assist the development of a wool-sheep industry through the establishment of a pilot project on the Kitulo Plateau. The project is to make practical studies on the problems of breeding, nutrition, management and health of sheep, the problems of cereal, cash and forage crop cultivation as a preparatory step to the establishment of sheep pastures and on marketing of the products; also to prepare an integrated development programme for crop cultivation, pasture establishment and the breeding of wool sheep applicable to the plateau and to ecologically similar areas.

This land unit survey was done at the request of the Kitulo Sheep Raising Project with a consultant supplied by the Government of Tanzania, in order that they might have information that would serve as a basis for preparing a programme of land use within the above terms of reference.

The entire area had previously been surveyed in 1969 (Sturz and Duckworth) on a scale of 1:1 million, but this was felt to be too general for the purposes of planning and future expansion. The Kitulo Project is at present being enlarged to include a Livestock Multiplication Centre which, together with the 9 312 hectare (ha) Sheep Scheme, will cover an area of 29 555 ha.

Soils were inspected along all major roads and accessible tracks. Inaccessible areas were examined by means of aerial photographs. Landforms, vegetation, geology and soils were noted. On the basis of these findings, the units were delineated and described. When the soil types had been defined, soil profile descriptions were prepared for laboratory analysis and soil activity classed. The soil activity class was determined on the basis of soil profile descriptions and soil activity classed. The soil activity class was determined on the basis of soil profile descriptions and soil activity classed.

South and west of the Njombe Plain (Units 9, 10, 11), the basement is a complex of schists and gneisses which are mainly amphibolites. A thin layer of grey and white sandstone is overlain by a thin layer of red and white sandstone. The surveyed area is composed of undulating to rolling plateaus and mountains. Going from east to west, the undulating to rolling plain around Njombe (Unit 12) lies at an elevation of 1 800 to 2 100 m. It is out of numerous slow moving perennial rivers, along whose banks frequent outcrops appear.

## Chapter 2

### AREA SURVEYED

The area concerned in this report is approximately 8 200 square kilometres (km<sup>2</sup>) of the northwestern Njombe District, Tanzania, and falls within the coordinates 8°52' to 9°45', 33°46' to 34°45'E.

#### 2.1 SURVEY METHODS

Initially a 1:125 000 scale reconnaissance soil survey (Map 1) was conducted on all connecting and adjacent areas of the Kitulo Sheep Scheme more than 1 970 metres (m) above sea level. When this was completed, a more detailed survey (Scale 1:25 000) of the Kitulo Sheep and Livestock Projects was conducted (Map 2).

The survey commenced in September 1969. Field equipment consisted of a landrover, soil augers, spade, hoe, portable altimeter, abney level, aerial photographs of approximate scale 1:25 000 and planimetric and topographic maps of scale 1:50 000. Geological information (Harkin, 1960 and Stookley, 1948) and maps of scale 1:125 000 were available for most of the area. Several botanical publications and keys (Brenan and Greenway, 1949; Burt, 1953; Napper, 1965; White, 1962) were used in the identification of the vegetation.

Soils were inspected along all major roads and accessible tracks. Inaccessible areas were examined by means of aerial photographs. Landforms, vegetation, geology and soils were noted. On the basis of these findings, the units were delineated and described. When the soil types had been defined, 12 representative pits were dug and soil samples for laboratory analysis were collected.

In describing the units, all terms were taken from the FAO Guidelines for Soil Profile Description (FAO, Rome), and the USDA Soil Survey Manual (Soil Survey Staff). A Classification of East African Rangeland (Pratt, Greenway and Gwyne, 1966) was used as the basis for describing vegetative patterns. Soil profile depths were rated as shallow (0 to 30 centimetres) (cm), moderately deep (30 to 100 cm) and deep (greater than 100 cm). The adjective "heavy" before textures is used by the authors to refer to those textures approaching the next heavier category.

#### 2.2 PHYSIOGRAPHY

The surveyed area is composed of undulating to rolling plateaus and mountainous regions. Going from east to west, the undulating to rolling plain around Njombe (Unit 12) lies at an elevation of 1 800 to 2 100 m. It is cut by numerous slow moving perennial rivers, along whose banks frequent rock outcrops appear.

To the south of Njombe, the elevation rises above 2 100 m, and the topography becomes hilly and finally steeply dissected to mountainous adjacent to the Livingstone Mountains south and west of Matola (Unit 11). To the west of Njombe, the undulating to rolling Kipengere Plateau (Unit 9) rises sharply to 2 450 m south of Kipengere Mission.

Further west are the Ukinga Mountains, a series of long mountainous ridges divided by rolling to hilly valleys (Units 2, 6, 7 and 8). The elevation in this area ranges from 1 970 m to 2 700 m, and the variation becomes greater toward the Livingstone Mountains.

North of the Ukinga Mountains is the Kipengere Range, a long, mountainous, U-shaped ridge that rises abruptly to 2 600 m a few kilometres (km) west of Kipengere Mission. One arm (Unit 4) runs northwest to the Kitulo Plateau, and the highest peak (Mtorwi) is 2 944 m. The second arm is known as the Gofio Plateau (Unit 5). This is a large, undulating to rolling plateau, with numerous bedrock outcrops, running northwards from Kipengere Mission. This plateau is bounded on the east by the Kirengapassi Escarpment, but on the west it dips gently downwards to the Kimani River.

In the northwest of the map is the Kitulo (Elton) Plateau (Unit 1). This undulating to hilly afro-alpine moorland lies between the Kipengere Range and the Nyasa Escarpment. The plateau elevation ranges from 2 550 m at the base of the Kipengeres to 2 850 m along the escarpment. The highest point is Chaluhangi, an old volcano, which reaches 2 916 m. The Kitulo Plateau generally has long, narrow, undulating to rolling ridge crests divided by deeply incised perennial rivers that drain either to the north or east.

On the north side of the Kipengere Range, and above the Chimala Escarpment, lie the Matamba and Ikuwo Basins (Unit 3). These are both undulating to rolling plains separated by the Ndumbi River and the Magoye Ridge (a northward extension of the Kipengere Range). The altitude of the basins ranges between 1 970 m on the Chimala Escarpment to about 2 300 m along the mountains.

## 2.3 GEOLOGY

The entire map area has been influenced by previous volcanic eruptions and tectonic activity in the Nyasa Rift Trough. Much of the area has been folded and uplifted, and the bedrock has been greatly distorted by the tectonic action. The eruptions of Rungwe (25 km west of Kitulo) have covered the entire region with layers of volcanic pumice and ash.

The Njombe Plain (Unit 12) rests on acidic basement complex which contains quartz, mica, biotite, muscovite and feldspars. Derivations of granitic rocks that are migmatitic and gneissic are found throughout this area. Overlying these granitics is a thin layer of fine pumice and ash.

South and west of the Njombe Plain (Units 9, 11), the basement complex is overlain by metamorphosed sediments that are mainly exposed as schists, mylonites and quartzites. These are also overlain by a thin layer of pumice and ash.

The Ukinga Mountains (Units 2, 6, 7 and 8) consist mainly of folded gabbros with serpentine, hypersthene and magnetite amphiboles. There are also schists, olivines and granites throughout the region. On the other hand, the Livingstone Mountains, along the southwest edge of Units 6 and 7, are composed of sericitic, chloritic and quartzose schists of sedimentary origin and granitic mylonites of igneous origin. The overlay of pumice and ash is thick in the northern Ukinga Mountains but becomes very thin and almost negligible in the extreme south.

The Kipengere Range is mainly composed of quartzites, quartzitic sandstones and red phyllitic shales. The western extension (Unit 4) was at one time covered with pumice and ash, but this is now only seen on the lower slopes. The flatter Gofio Plateau (Unit 5) still contains a thick covering of pumice and ash.

The Kitulo Plateau (Unit 1) is underlain by basaltic and phonolitic lavas. Outcrops appear along the rivers, and occasionally on the ridge crests, and are mostly composed of tuffs and agglomerates. The southern part of the plateau is underlain by Ukinga granites and schists, which occasionally outcrop on the higher hills. Two thick layers of coarse pumice cover the entire area (though this may now be eroded from the steeper slopes) so that the lavas lie up to 5 m below the surface.

The Matamba and Ikuwo Basins (Unit 3) are also underlain by basaltic lavas which flowed through the gaps in the Kipengere Range from the higher Kitulo Plateau. These were later covered by a thick layer of pumice and ash.

Throughout the entire map area, the cover of volcanic pumice and ash has been eroded and removed from the steeper slopes to expose the bedrock, but this cover remains on the ridge crests and in the valleys.

## 2.4 CLIMATE

Meteorological stations have been in operation at Igeri Pyrethrum Research Station (approximately 9°32'S, 34°44'E; elevation 2 212 m) since 1963 and at Kitulo (approximately 9°25'S, 34°45'E; elevation 2 727 m) since 1965. Kibena-Njombe (9°25'S, 34°45'E; elevation 1 890 m) has been recording rainfall and maximum and minimum temperatures for the past 40 and 6 years, respectively. Many of the missions in the map area keep rainfall records, and the primary school at Bulongwa (approximately 9°20'S, 34°04'E; elevation 2 122 m) has also been recording daily temperatures with a nonscientific thermometer (Tables 1, 2 and 3).

Western Njombe District, on the whole, has a pleasant climate. The mean maximum and minimum temperatures are in the ranges of 15 to 19°C and 4 to 10°C, respectively, with the cooler temperatures recorded at the higher elevations. Ground frosts occur almost nightly during the dry season in the higher areas, and occasionally the air temperature dips below freezing. Kitulo has recorded absolute grass minimum temperatures as low as -11.6°C (August 1969) with mean grass minimum temperatures below 0°C for the months of June, July, August and September. The lowest absolute minimum air temperature recorded at Kitulo is -5.2°C (August 1968). Frequent mists and cloud cover along the Nyasa Escarpment and in the Tea Estate regions south of Njombe moderate the climate considerably in these areas during the dry season.

The rainfall pattern is essentially unimodal with a slight decrease in January and February (Figs. 1, 2 and 3). There is a resemblance in pattern between the rainfall and the number of rainy days (Figs. 1 and 3), but a slight variation in the rainfall patterns between Kibena, Igeri and Kitulo. The first peak for Igeri and Kitulo occurs in December, while at Kibena it comes in January and is lower than that of the other two stations.

Air and soil temperatures (Fig. 4) at Kitulo show similar trends. The soil temperature at a depth of 5 cm approximates air temperature, but is generally higher during the rainy season and lower during the dry season. There is also an appreciable warming of the surface soil during the first two hours in the morning. The soil temperatures are low during the dry season, not only because of the lower air temperature, but also because of melting and evaporation of frost at the surface. Both air and soil temperatures reach maxima in March, the month of maximum cloud cover.

By contrast, maximum radiation and hours of sunshine (Fig. 5) occur during the dry season when the sky is clear. There is a dip in radiation values in September when the hours of sunshine begin to decrease, but this rises again in October to another peak when the angle of isolation becomes very small.

Table 1

SUMMARY OF METEOROLOGICAL DATA FROM THREE RECORDING STATIONS

	Kibena	Igeri	Kitulo
Mean annual rainfall (mm)	1 069.9	1 319.7	1 661.1
Mean maximum temperature (°C)	22.2	18.2	15.6
Mean minimum temperature (°C)	10.3	9.6	4.7
Mean hours of sunshine per day	-	5.5	6.4
Mean annual pan evaporation (mm)	-	1 481.0	-
Mean monthly solar radiation (cal/cm <sup>2</sup> /day)	-	-	398.8
Mean wind miles per day	-	127.4	-

Table 2

MEAN MONTHLY MAXIMUM AND MINIMUM TEMPERATURES AT KIBENA  
AND KITULO

Month	Kibena <sup>1/</sup>		Kitulo <sup>2/</sup>	
	Maximum °C	Minimum °C	Maximum °C	Minimum °C
January	23.0	12.5	15.7	7.5
February	22.7	12.3	15.6	7.8
March	22.8	12.3	16.0	7.5
April	21.4	12.5	16.0	6.8
May	20.8	9.8	15.1	4.5
June	20.7	7.4	14.6	0.4
July	19.4	6.8	15.0	0.8
August	20.8	7.3	16.0	0.6
September	22.3	8.4	17.3	3.0
October	23.6	10.2	18.8	4.1
November	24.9	11.9	15.1	6.0
December	23.8	12.6	15.6	7.7

1/ Kibena records for 1959 to 1965.

2/ Kitulo records for 1967 to 1969.

Table 3

AVERAGE MONTHLY RAINFALL AT EIGHT RECORDING SITES IN OR NEAR THE MAP AREA

Place Altitude (m)	Kibena 1 890.0	Uwemba 2 133.6	Igeri 2 212.0	Milo 2 084.8	Kipengere 2 152.0	Mwakete 2 133.6	Bulongwa 2 122.0	Kitulo 2 727.0
January	227.0	221.5	146.0	258.3	164.9	193.3	280.2	208.1
February	189.0	198.4	235.0	218.2	148.1	270.0	265.4	251.7
March	240.3	354.3	277.1	317.0	280.6	323.3	220.4	325.5
April	148.3	190.8	217.6	290.6	161.5	225.6	235.7	229.9
May	23.9	36.8	43.2	61.0	37.7	114.3	83.1	82.5
June	2.5	4.3	4.7	15.5	4.9	6.4	2.0	21.6
July	1.0	2.5	6.2	6.4	0.0	0.0	0.0	15.3
August	1.8	6.9	1.9	3.8	0.0	28.5	0.0	14.1
September	5.1	7.4	8.0	4.1	56.2	0.0	0.0	34.3
October	9.9	23.1	4.1	14.0	12.6	95.5	0.0	54.0
November	45.0	69.8	97.8	73.2	80.2	124.2	0.0	151.0
December	175.3	188.0	278.1	206.0	253.6	232.2	257.3	273.1
TOTAL	1 070.1	1 304.8	1 319.7	1 468.1	1 200.3	1 613.3	1 344.1	1 661.1
No. Rainy Days	115	122	?	146	145(?)	129	?	174
No. Years Recorded	40	5	5	22	5	2	3	5

Month	January	February	March	April	May	June	July	August	September	October	November	December
Величина осадков (мм)	10.0	12.0	15.0	18.0	20.0	22.0	25.0	28.0	30.0	32.0	35.0	38.0
Величина тумана (ч)	0.5	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.5	2.8	3.0	3.2
Величина росы (мм)	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
Величина инея (мм)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
Величина снега (мм)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
Величина дождя (мм)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
Величина снега (мм)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
Величина тумана (ч)	0.5	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.5	2.8	3.0	3.2
Величина росы (мм)	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
Величина инея (мм)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
Величина снега (мм)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
Величина дождя (мм)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
Величина снега (мм)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1

Величина осадков (мм) в среднем за месяц

Величина тумана (ч) в среднем за месяц

Величина росы (мм) в среднем за месяц

Величина инея (мм) в среднем за месяц

Величина снега (мм) в среднем за месяц

Величина дождя (мм) в среднем за месяц

Величина снега (мм) в среднем за месяц

FIG. 1 - ANNUAL RAINFALL (40 yr. avg.) AT KIBENA -

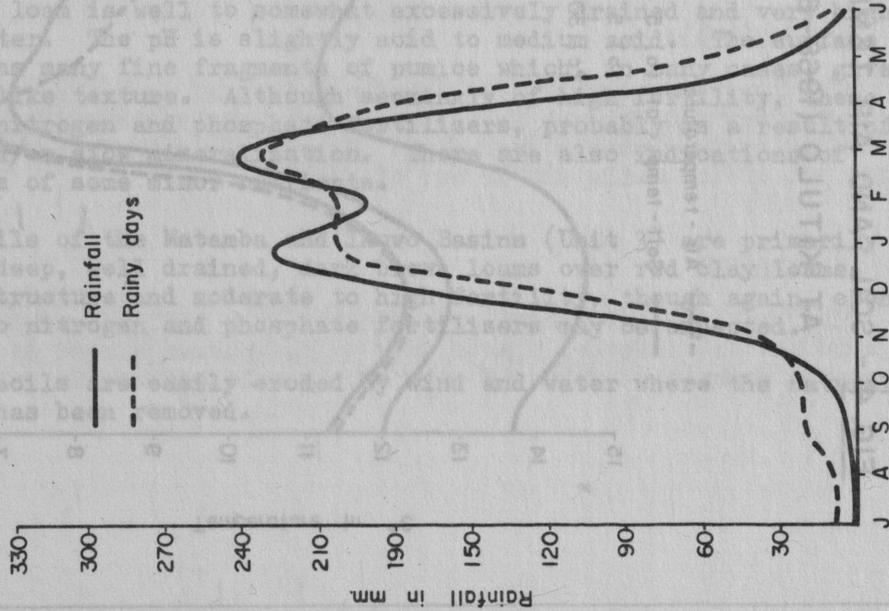


FIG. 2 - ANNUAL RAINFALL (5 yr. avg.) AT IGERI -

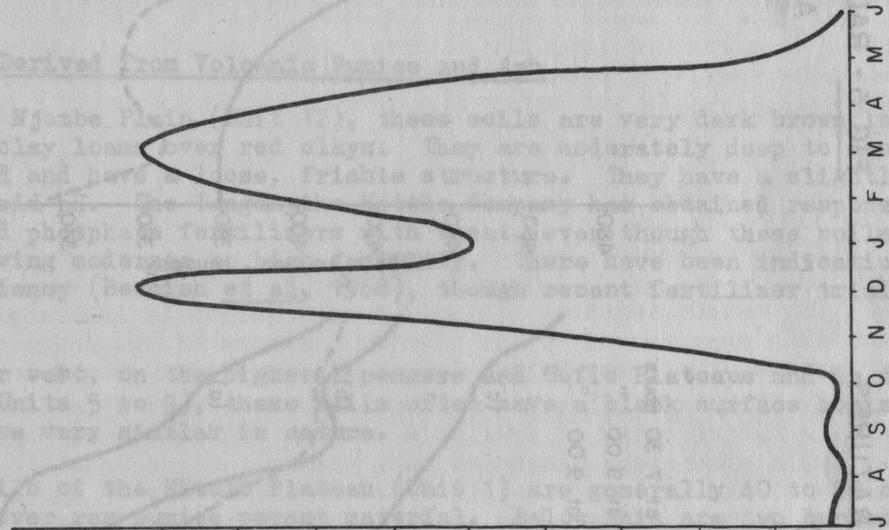
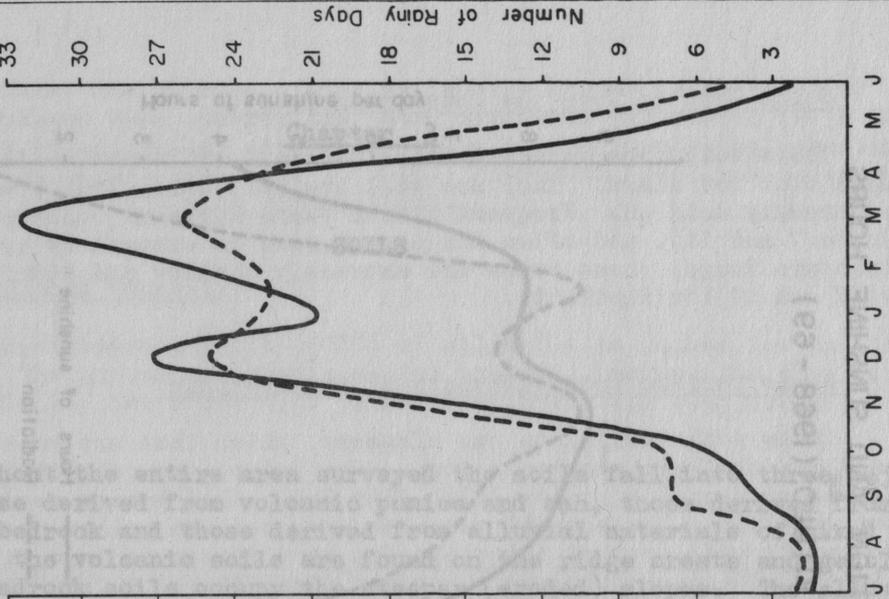
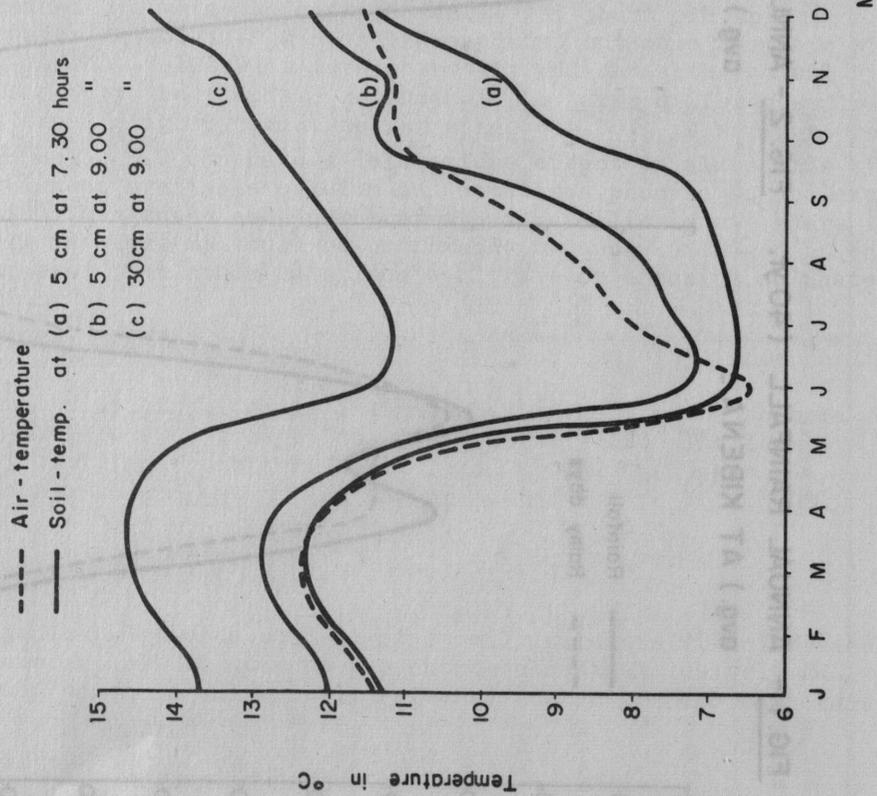


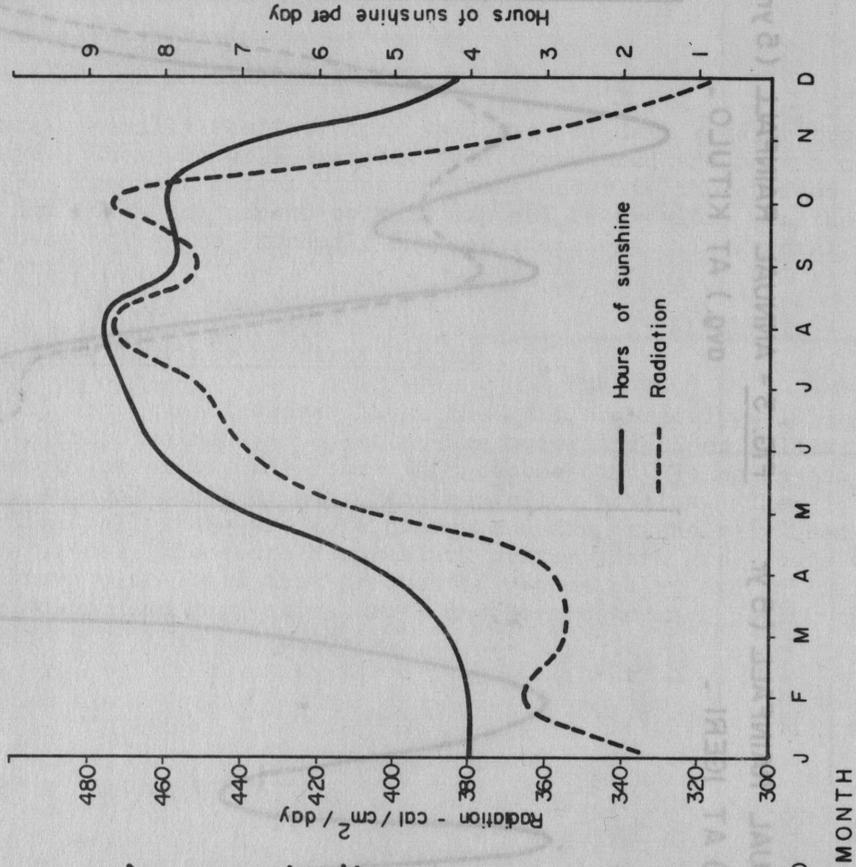
FIG. 3 - ANNUAL RAINFALL (5 yr. avg.) AT KITULO -



**FIG. 4 - SOIL AND AIR TEMPERATURES  
AT KITULO (1968-69)**



**FIG. 5 - RADIATION AND SUNSHINE HOURS  
AT KITULO (1968-69)**



## Chapter 3

### SOILS

#### 3.1 GENERAL

Throughout the entire area surveyed the soils fall into three major groups: those derived from volcanic pumice and ash, those derived from the underlying bedrock and those derived from alluvial materials of mixed origin. In general, the volcanic soils are found on the ridge crests and gentle slopes while the bedrock soils occupy the steeper (eroded) slopes. The alluvial soils are found on the narrow floodplains of all streams and rivers.

##### 3.1.1 Soils Derived from Volcanic Pumice and Ash

On the Njombe Plain (Unit 12), these soils are very dark brown loams over dark brown clay loams over red clays. They are moderately deep to deep, are well drained and have a loose, friable structure. They have a slightly acid to medium acid pH. The Tanganyika Wattle Company has obtained responses to nitrogen and phosphate fertilizers with wheat, even though these soils are rated as having moderate to high fertility. There have been indications of boron deficiency (Beamish *et al.*, 1968), though recent fertilizer trials do not prove this.

Further west, on the higher Kipengere and Gofio Plateaus and in the Ukinga Mountains (Units 5 to 9), these soils often have a black surface horizon, but are otherwise very similar in nature.

The soils of the Kitulo Plateau (Unit 1) are generally 40 to 50 cm of black loam over raw pumice parent material. Below this are two buried profiles - one derived from a second pumice layer and the other from the basement basalt. The surface loam is well to somewhat excessively drained and very high in organic matter. The pH is slightly acid to medium acid. The surface horizon also contains many fine fragments of pumice which, in many cases, gives a sandy loam-like texture. Although seemingly of high fertility, these soils respond to nitrogen and phosphate fertilizers, probably as a result of heavy leaching and/or slow mineralization. There are also indications of deficiencies of some minor nutrients.

The soils of the Matamba and Ikuwo Basins (Unit 3) are primarily moderately deep, well drained, dark brown loams over red clay loams. They have good structure and moderate to high fertility, though again, economic responses to nitrogen and phosphate fertilizers may be expected.

These soils are easily eroded by wind and water where the natural vegetation has been removed.

### 3.1.2 Soils Derived from the Underlying Bedrock

These soils are generally shallow, dark yellowish or dark reddish brown loams over red clays. They are well drained, well structured and have a medium to strongly acid pH. Frequent quartz stone horizons underlie the surface loams (Units 7 and 11), and often the parent rock is exposed by erosion. On the Kipengere Range, these soils are extremely shallow and stony. In general, these soils are of low fertility.

### 3.1.3 Soils Derived from Alluvials of Mixed Origin

These soils fall into two classes: those that are moderately well drained and those that are poorly drained. The latter are moderately deep, black silty loams over brownish yellow silty clay loams that become sandy loams in the lower profile. The subsoil contains many reddish yellow mottles. The moderately well drained alluvials are more common and are extensively used for growing subsistence crops. These are deep, black or very dark grey loams over very dark greyish brown clay loams that frequently become paler and sandier with depth. These soils have good structure and moderate to high fertility.

## 3.2 CHEMICAL ANALYSIS

### 3.2.1 pH

pH was determined by two methods, with results of about one unit difference. The water method is the normal procedure, but some chemists prefer the  $C_aCl_2$  method, as they believe it more correctly indicates the actual field conditions experienced by the plants. Because of the large differences in the two results, the terms "slightly acid, medium acid, etc." in this report refer to water pH's. pH below 5.0 can have a deleterious effect on plant life by inducing deficiencies of available calcium and sometimes phosphates and excesses of soluble aluminium, manganese and, perhaps, other metallic ions. Where the acidity of the soil is high, it would be preferable to apply nitrogen as calcium ammonium nitrate rather than ammonium sulphate nitrate or ammonium sulphate.

### 3.2.2 Conductivity

The low conductivity of all soils indicates that there is no soluble salt accumulation, and this is supported by the low available Na. The low conductivity is probably the result of heavy leaching which flushes the soluble salts out of the soils and on out of the map area.

### 3.2.3 Phosphorus

The total organic phosphorus content of a soil increases with increases in organic matter; however, plants take up phosphorus almost exclusively as inorganic phosphate, which is only slowly released as the organic compounds are

broken down. Thus, though some of the soils have higher percentages of inorganic phosphorus than others, the total available phosphorus (0.3N HCl extract) is low in all soils, especially since plants rarely use more than 30 percent of the amount available to them. Therefore, good responses to superphosphate are likely with annual crops.

#### 3.2.4 Cation Exchange Capacity

The cation exchange capacity (CEC) of all soils is rather low and is dependent upon the amount of organic matter present, because the clay content, primarily kaolinite, has a low CEC. Also, the percentage clay present in most soils is low.

#### 3.2.5 Calcium

Exchangeable calcium remains available until removed by the plant or by leaching, and the primary source of this nutrient is the basic bedrock described in Units 2, 6, 7, 8 and 12. Although it is always the most abundant cation in these soils, the content is low in several places. Where low available calcium and low pH combine, a deficiency may occur in calcium; therefore it would seem that liming could improve these soils. However, based on Kitulo experience, economic levels of lime would not necessarily raise the pH level significantly. The Kitulo Project obtained no response from liming annual crops, but on perennials, particularly legumes, there are indications of response. In the latter case, however, the response appears to be to additional available calcium as there was no change in pH. Where available calcium and pH levels are low, the seed microenvironment may be altered by planting calcium carbonate with the seed and thus reducing the high cost of raising the pH of the whole profile.

#### 3.2.6 Magnesium

The Mg/K ratio of most soils is wide, and magnesium deficiencies as a result of potassium depression are not likely to occur. Where there appears to be a magnesium deficiency, the soils may benefit from applications of dolomitic limestone.

#### 3.2.7 Potassium

Potassium levels are borderline in the surface horizon of most soils. Responses to potassium fertilizers are rare under African conditions, but where trials are conducted, applications should be in conjunction with dolomitic limestone so as not to induce magnesium deficiency.

#### 3.2.8 Manganese

The manganese content of most soils is low, but because of the low pH, almost all of it is likely to be available to plants. Where the available manganese content is high, a reduction in pH may lead to toxicity.

### 3.2.9 Base Saturation

The base saturation percentage is low due to intense leaching that has flushed the bases out of these soils, leaving the exchange complex saturated with hydrogen; this explains the high acidity.

### 3.2.10 Organic Carbon

The organic matter content is generally high in all soils and reflects, to a certain extent, the cool, wet climate of the area.

### 3.2.11 Nitrogen

Nitrogen levels are generally high, but the soil samples were taken at the end of the dry season when levels would be high because of mineralization. As a result of the high rainfall and low temperatures, it is possible that leaching and slow mineralization may result in nitrogen deficiencies during the growing season.

### 3.2.12 Carbon/Nitrogen Ratio

The carbon/nitrogen (C/N) ratio of the surface soils is high, and therefore applications of nitrogen fertilizer in the presence of superphosphate to non-legume crops are likely to give good responses.

## 3.3 MECHANICAL ANALYSIS

The mechanical analysis generally shows an increase in clay content with depth in all profiles. The exceptions to this are the pumice horizons where the clay content falls markedly. Silt and sand contents (usually in the form of raw pumice rather than quartz fragments) tend to be highest near the surface in most profiles. The same trend is noted in silt/clay ratios. These features are probably due to the latest deposition of ash being less weathered than the deeper horizons. The relatively high silt and sand content of these soils results in weak structural stability, and there is a tendency for them to erode rapidly when the organic matter has been broken down.

Throughout the map area, where slopes are not a limiting factor, the soils may be considered suitable for mechanical cultivation. However, extreme care will be required to maintain the structure of all soils and to reduce wind and water erosion in a minimum.

In preparing for planting pastures, the Kitulo Project breaks the land at the end of the rainy season and leaves it in broken clumps through the next rainy season. During this time much of the organic matter decomposes, but a sufficient amount remains to prevent erosion. The new pastures are then planted with a cover crop to prevent erosion during the growing season. In many cases, similar practices are used by the people living in the area.

### 3.4 FERTILIZER TRIALS

Fertilizer trials are being conducted by both the Tanganyika Wattle Company Limited at Kibena and the United Nations Sheep Raising Project at Kitulo. No firm recommendations can be made as yet, but the following will give some indications.

The Tanganyika Wattle Company is doing fertilizer experiments on maize (Zea mays), wheat (Triticum sativum), potatoes (Solanum tuberosum) and other crops. According to their Annual Research Report (Tanganyika Wattle Co Ltd., 1968-69) the best results seem to be obtained from the following (112 kilogrammes/hectare (kg/ha) equals 100 pounds/acre (lb/ac)):

- maize - 296 kg/ha of triple superphosphate and 445 kg/ha of ammonium sulphate nitrate;
- wheat - 104 kg/ha of triple superphosphate and 136 kg/ha of ammonium sulphate nitrate;
- potatoes - 445 kg/ha each of triple superphosphate and ammonium sulphate nitrate.

Borate fertilizers have been used with all crops, but there appears to be no response. All crops in the trials were grown after one year of wheat following either wattle or ley.

The Kitulo Project is carrying out two sets of fertilizer trials; one to determine the optimum rate of phosphate application and the other to determine which of the minor nutrients may be limiting.

While cereals were being grown at Kitulo, nitrogen and phosphorus were applied as diammonium phosphate at the rate of 168 kg/ha for oats (Avena sativum), 224 kg/ha for wheat and 336 kg/ha for barley (Hordeum vulgare). The severities of the climate were such that only oats grew well enough to give measurable results.

For potato cultivation 112 kg/ha of diammonium phosphate gave a threefold increase in yield by comparison with no application.

The planted pastures at the Kitulo Sheep Raising Project contain legumes in the mixture; therefore nitrogen applications are not required. Single superphosphate is applied at the rate of 112 kg/ha for establishment of these pastures and as an annual top dressing. Double superphosphate at 65 kg/ha and diammonium phosphate at 45 kg/ha can be used to establish pasture, but as a top dressing both are short of calcium and sulphur, plus minor nutrients which have not yet been identified. It is also possible to establish pasture without fertilizer on land which has been fallowed for one year to allow mineralization, but the results are generally poor.

In conclusion, it is too early to make fertilizer recommendations, but when rates have been established for the Njombe and Kitulo areas, it seems reasonable that they would serve as a good base for predicting rates for the volcanic soils of the entire map area. Rates for the bedrock soils will, however, have to be determined by special trials. It is possible that lighter rates of fertilization can be applied at lower elevations where the weather is milder and the likelihood of early dry season frost is low. In these areas, planting could be started later in the wet season, and thus there would be less loss of fertilizers through leaching than at Kitulo.

## Chapter 4

### VEGETATION

The vegetation of the entire map area is predominantly fire climax grassland of medium height. Small moist upland forests are found in the many ravines, and many areas support small forests of introduced Acacia mollissima (black wattle), Acacia dealbata (silver wattle) or Eucalyptus spp.

Medium Exothea abyssinica and Themeda triandra are found locally dominant or as codominants throughout the map area. Below 2 200 m these grasses are found with Loudetia simplex, Trachypogon spicatus and Digitaria diagonalis. On the afro-alpine moorland of the Kitulo Plateau they are codominant with Koeleria cristata, Festuca caprina, Eragrostis racemosa and Andropogon chrysostachyus. Throughout the entire map area there are numerous herbs and sedges growing with these grasses. Of these, the dominants are Helichrysum spp., Orobanchaceae and Cyperaceae.

Weeds of cultivation vary considerably, with some growing on recently disturbed land and others on abandoned cultivation. The main weeds are Oxalis obliquifolia, Cerastium octandrum, Chenopodium procerum, Senecio spp, Helichrysum spp, Selago thyrsoidea, Conyza spp, and Pteridium aquilinum.

Several species of Protea bushes grow throughout the grassland areas, particularly on the shallow, stony slopes. The most important shrubs are Dodonaea viscosa, Helichrysum spp, Athrixia rosmarinifolia, Blaeria spp, Erica kingaensis and Lobelia usafuensis.

The upland ravine forests, at all elevations, are dominated by Hagenia abyssinica, Agauria salicifolia var parvifolia, Pygeum africanum and Parinari excelsa. The Ndumbi Forest Reserve also contains Juniperus procera, Podocarpus latifolius and Khaya nyasica. The main bamboo of the area is Arundinaria alpina.

Along the northern edge of the map area (the Chimala Escarpment) and in eastern Wangama (Unit 10), there is open Brachystegia-Uapaca woodland of Brachystegia microphylla and Uapaca kirkiana with an undergrowth of tall Hyparrhenia micrathera grasses.

## Chapter 5

## LAND USE

Throughout the map area, the major agriculture is the growing of subsistence crops. These range from maize and assorted vegetables on the Njombe Plain to wheat, potatoes and vegetables in the higher elevations of Ukinga. Livestock is of minor importance throughout the map area. The missions have introduced fruits from temperate climates (peaches, pears, apples, etc.) and these are more and more becoming part of the diet. Ulanzi (Oxytenanthera braunii) is grown throughout the area for brewing beer.

The major cash crop of the area is pyrethrum (Chrysanthemum cinerariaefolium), though depressed prices the past few years have greatly reduced the acreage of this crop. Wattle (Acacia mollissima) and tea (Camellia thea) are the second and third ranking cash crops. The former is mainly produced by the Tanganyika Wattle Company Limited at Kibena and the latter by large estates in the Luponde area southwest of Njombe. However, small holders produce a substantial amount of wattle and tea which is sold to the Wattle Company and Tea Estates for processing. Less important are cash sales of pulses, rice, coffee (Coffea arabica), maize, sunflower and wheat. The Wattle Company has recently been growing large acreages of the latter.

The Kitulo and Gofio Plateaus are natural ranching areas, particularly since the elevation is too high for economic production of cereals. The Kitulo Sheep Raising Project has had good success with grazing Corriedale sheep on planted pastures, but failed in their cereal venture, due mainly to the severity of the climate. Of the cereals tried, oats gave the best results, though these were still economically marginal. The Project is now expanding to cattle with the idea of establishing a dairy stock multiplication centre.

Most of the map area is too rough for large scale mechanization of agriculture, but this can be done on most of the Njombe Plain and the Kitulo, Gofio and Kipengere Plateaus, and in large parts of Units 3, 10 and 11. Elsewhere, small areas may be found where mechanization might be feasible, but these would be few and far between.

Although many of the soils have moderate to high fertility, the high rainfall results in heavy leaching, and thus all soils may be expected to give economic responses to fertilizers and manures, particularly after a few years of cultivation.

There is good potential for increased yields of all cash and subsistence crops through improved varieties, application of fertilizers and increased extension services. Even though the mountain areas are not suitable for mechanized cultivation, improved methods of hand cultivation could be put to effective use. Throughout the map area there is plenty of potential for improved livestock, particularly dairy herds, and this potential could be even greater with planted pastures.

Chapter 6

## UNIT DESCRIPTIONS

## 6.1 UNIT 1 - KITULO PLATEAU

(a) Physiography

Undulating to hilly highlands known as the Kitulo Plateau. There are some steeply dissected areas in the south. The elevation ranges from 2 200 m on the eastern side to 2 864 m on the western side (Nyasa Escarpment), but is mainly between 2 630 m and 2 820 m.

(b) Geology

The area is underlain by a thick deposit of basaltic and phonolitic lava. These are overlain by two successive layers of coarse pumice containing numerous small fragments of basalt. In the southern part of the unit, schists and quartzites occasionally outcrop, particularly on the hill crests where the pumice and ash have been eroded.

(c) Climate

The Kitulo Sheep Raising Project records an average annual rainfall of 1 661.1 millimetres (mm), falling in 174 days from November to May, with a slight diminution in January (Fig.3). The mean maximum temperature is 15.6°C and the mean minimum is 4.7°C. Absolute minima fall below 0°C during the dry season, and ground frosts occur almost nightly. Average number of sunshine hours per day range from 4.0 in January, February and March to 8.7 in August. Radiation ranges between 300 and 500 cal/cm<sup>2</sup>/day. The climate along the Nyasa Scarp is somewhat milder due to the frequent mists in that zone.

(d) Soils

The soils of this unit are derived from volcanic pumice and are well to somewhat excessively drained. Some differences have been noted in horizon sequence in the profile, and these are outlined in detail in Chapter 7. In general, the soils of this unit have a thick black organic loam surface horizon underlain by raw pumice. Below this is a clay loam horizon that is either over bedrock, if the soils are shallow, or over a second pumice layer. In the deep profiles this second pumice is underlain by a clay loam or clay horizon and then bedrock. In the upper drainage ways the surface loam is likely to be over 100 cm deep and not quite as well drained as the normal profile.

(e) Vegetation

Medium Koeleria-Festuca-Exothea grassland. The major grasses are Koeleria cristata, Festuca abyssinica, F. caprina, Exothea abyssinica, Anthoxanthum nivale, Eragrostis racemosa, E. pseudohispida, Digitaria myurus, Panicum eickii, P. lukwangulense, Andropogon chrysostachyus, A. dummeri and Themeda triandra. The depressions and river channels frequently carry a medium Andropogon flabellifer seasonally flooded grassland with Juncus spp and Cyperus spp and Lobelia mildbraedii. Common sedges and herbs, found mostly in the gullies, are Artemisia afra, Helichrysum spp, Rhamnus princoides, Blaeria kiwuensis, Orchidaceae and Cyperus spp. Gallery upland moist forests are frequent in the ravines at the edges of the Plateau. The dominant trees in these are Hagenia abyssinica and Agauria salicifolia var parvifolia, with Arundinaria alpina appearing along the Nyasa Escarpment. Planted pastures on the Kitulo Project are mainly a mixture of Lolium perenne (perennial ryegrass), Dactylis glomerata (cocksfoot) and Trifolium repens var ladino (ladino white clover), and these are usually planted with a cover crop of oats. Weeds of cultivation include Oxalis obliquifolia, Senecio spp, Bulbostylis dense, Impatiens spp, Commelina africana, Cerastium octandrum, Chenopodium procerum and Morea spp. Common weeds of old pyrethrum fields and exhausted soils are Conyza ruwenzoriensis, Selago thyrsoidea, Plectranthus schizophyllus, Carduus nyassanus and Helichrysum spp.

(f) Features

The unit is predominantly used for sheep and cattle grazing, though in some parts pyrethrum, potatoes, wheat and barley are grown. The Kitulo Sheep Raising Project found the climate too severe for economic production of cereals, but have had good results with planted pastures. The area has good livestock potential and plans are to utilize it fully. Experimental trials indicate a minor nutrient deficiency, but it has not yet been identified. The Forestry Department planted several Pinus spp plots on the plateau during the early fifties and in these Pinus patula appears to be doing very well, though it was difficult to establish at first. The Kitulo Project has found that Eucalyptus salignum establishes quickly. Silver wattle (Acacia dealbata) also grows well in sheltered places above 2 400 m.

## 6.2 UNIT 2 - SALALA-KIDONI

(a) Physiography

Hilly to steeply dissected unit with small undulating to rolling areas. This unit has two parts, one around Mountain Salala, and the other south of Kidoni and Mwanigenge Hills. Occasional rock outcrops appear on the hillcrests and steeper slopes. The elevation is between 2 000 and 2 788 m.

(b) Geology

The northern part is underlain by granites and associated porphyries, and the southern part is underlain by pelitic schists, quartzites, phyllites, feldspars, mylonites, phonolites and shales.

(c) Climate

Rainfall, based on Kitulo records, is between 1 500 mm and 1 700 mm. Mean maximum temperature is about 15.6°C and mean minimum about 4.7°C. Maximum rainfall is in March. Frost is common in June, July and August.

(d) Soils

All soils are derived from the bedrock and appear not to have been influenced by volcanic ash. There are three soil types:

- i. deep, black (7.5YR 2/0) loam underlain by yellowish brown clay loam and, at about 91 cm, yellowish red clay;
- ii. moderately deep, black (5YR 2/1) loam underlain by dark brown clay loam over schistose bedrock;
- iii. shallow, very dark greyish brown (10YR 3/2) loam underlain by dark yellowish brown clay loam with few quartz gravel over weathered schistose bedrock.

(e) Vegetation

Medium Festuca-Koeleria grassland of Festuca caprina, Koeleria cristata, Exotheca abyssinica and Brachyachne fibrosa. The herbs and shrubs of the area include Erica kingaensis, Protea spp, Helichrysum spp and Pteridium aquilinum.

(f) Features

The main crops of the area are pyrethrum, potatoes, wheat and, at the lower elevations, maize. However, these are grown in only a small portion of the unit. Most of the area is used for grazing livestock.

## 6.3 UNIT 3a - MATAMBA

(a) Physiography

A large undulating to rolling plain lying between the northern end of the Kipongere Range and the Chimala Escarpment. The elevation ranges from 1 970 m along the escarpment to about 2 300 m along the mountains.

(b) Geology

Volcanic ash at one time covered the entire unit, but recent erosion has removed it in some places. In the northern and eastern parts (along the escarpment) the ash is underlain by ancient granites and associated porphyries. South of the Chimala River, the ash is underlain by basaltic lava.

(c) Climate

No data is available for this area. The average annual rainfall is estimated to be between 1 200 mm and 1 400 mm, with mean maximum and minimum temperatures of 15 to 19°C and 5 to 9°C.

(d) Soils

The soils are derived from volcanic ash, and a typical profile is this one observed just east of Kinyika village (2 100 m):

- 0 to 10 cm - dark brown (7.5YR 3/2) loam; weak fine subangular blocky; non-sticky, non-plastic, firm, slightly hard; high permeability; very few small stones;
- 10 to 50 cm - dark reddish brown (5YR 3/3) clay loam; moderate fine subangular blocky; slightly sticky, slightly plastic, firm, slightly hard; moderate permeability; very few small stones;
- 50 to 99 cm - red (2.5YR 4/6) clay loam; weak fine subangular blocky; slightly sticky, slightly plastic, loose, soft; moderate permeability; no stones;
- 99 + cm - dark red (2.5YR 3/6) heavy clay loam; structureless, massive; sticky, plastic; low permeability.

Closer to the mountains the surface horizon becomes a black loam, and fragments of pumice appear in the profile. Nearer the edge of the escarpment, the granitic bedrock influences result in high quantities of quartz fragments in the profile, or even in sandy loam textures. Along the Chimala River accelerated erosion has removed much of the top soil.

(e) Vegetation

Medium to tall Hyparrhenia-Themeda grassland dominated by Hyparrhenia micrathera, Themeda triandra, Exothea abyssinica and Arundinella naplensis grasses. Helicrysum spp and Pteridium aquilinum grow as weeds of cultivation. Along the escarpment there is Uapaca kirkiana-Brachystegia microphylla woodland with an understory of medium to tall Hyparrhenia spp, Brachiaria bizantha and Digitaria diagonalis grasses and Protea spp bushes. Remnant upland moist forests of Hagenia abyssinica and Agauria salicifolia appear in the higher ravines, and introduced Cupressus spp trees grow in and around the villages.

(f) Features

Maize, wheat, potatoes and other vegetables are the subsistence crops grown, and the main cash crop is pyrethrum. The soils are reasonably fertile, but the unit is heavily populated, resulting in increasing land pressure. Applications of fertilizers will no doubt assist in maintaining yields.

## 6.4 UNIT 3b - IKUWO

(a) Physiography

A broad undulating to rolling plain between the Chimala Escarpment and the Kipengere Range. There are some hilly areas in the south and southeast, and the plain is cut by several north-trending rivers. The elevation ranges from 1 970 m to 2 273 m from north to south.

(b) Geology

The entire unit is covered with a thin layer of volcanic ash and underlain by basaltic lava. The latter overlies older slates, shales and sandstones, which appear as exposures in the river valleys and along the edge of the escarpment.

(c) Climate

No data are available, but the average annual rainfall is estimated to be between 1 200 mm and 1 400 mm, and the mean maximum and minimum temperatures of the order of 15 to 19°C and 5 to 9°C.

(d) Soils

The soils are derived from volcanic ash and are dark brown to very dark brown loams over dark reddish brown heavy loams over dark red clay loams. These soils are moderately fertile. Along the southern, eastern and northern edges, the soils become sandier and siltier as a result of the influence of the older bedrock of the Kipengere Range and the escarpment area.

(e) Vegetation

Medium to tall Hyparrhenia-Exothea grassland dominated by Hyparrhenia mircathera and Exothea abyssinica. The higher ravines contain remnant upland moist Hagenia-Agauria forest, and there is Uapaca-Brachystegia woodland along the escarpment. The main trees are Hagenia abyssinica, Agauria salicifolia var parvifolia, Uapaca kirkiana and Brachystegia microphylla.

(f) Features

The unit is not heavily populated, but some areas are more intensively cultivated than others. The main crops are wheat, maize and sorghum (Sorghum vulgare). The soils are moderately fertile and could be much more productive. There is virtually no road into the area, but only a track that is precariously passable during the dry season. A road outlet to the north is now being made and will be a great asset to the area.

## 6.5 UNIT 4 - KIPENGERE RANGE

(a) Physiography

A steeply dissected to mountainous unit composed of the Kipengere Range, the Magoye Ridge and the Kirengapassi Escarpment. The Kipengere Range has an elevation of approximately 2 600 m at Pangulicala and 2 944 m at Mtorwi, and rises approximately 300 m to 400 m above the surrounding plateau. The Magoye Ridge, extending along the west side of the Ndumbi River, rises about 200 m above the Matamba and Ikuwo Basins. The Kirengapassi is nearly a sheer escarpment that rises about 600 m above the plain and decreases in elevation from 2 600 m to 2 000 m toward the north.

(b) Geology

The entire unit is composed of uplifted sediments, mainly reddish or purplish shales, siltstones and quartzitic sandstones. Along the edges, some granites, schists and quartz may be found. The lower slopes, particularly in the western part, are generally covered with volcanic pumice and ash.

(c) Climate

No data are available, but average annual rainfall is estimated to be between 1 400 mm and 1 700 mm, and freezing temperatures are likely to occur during the dry season.

(d) Soils

For the most part, the soils are shallow, well drained, very dark brown or dark greyish brown stony loams over bedrock. On the lower and more gentle slopes, the soils are deeper and more fertile. These are typically 30 cm of very dark grey or black loam over dark brown clay loam and frequently contain traces of pumice and fine quartz gravel.

(e) Vegetation

Medium Exothea-Themeda grassland dominated by Exothea abyssinica, Themeda triandra, Koeleria cristata, Festuca costata, Hyparrhenia spp and Panicum spp grasses. Dominant shrubs are Ageratinastrum fruticosum and

Helichrysum spp. A principal feature of the unit is the Ndumbi Forest Reserve, composed of Hagenia abyssinica, Juniperus procera, Podocarpus latifolius and Agauria salicifolia var parvifolia. The ravines frequently contain Hagenia-Agauria upland moist forest.

(f) Features

Some of the gentler slopes, where the soils are deep, are cultivated to pyrethrum, wheat and potatoes, but the unit is essentially unsuitable for cultivation, and in many parts it is too steep even for grazing livestock.

6.6 UNIT 5 - GOFIO PLATEAU

(a) Physiography

Undulating to rolling northeastern extension of the Kipengere Range known as the Gofio Plateau. The entire unit slopes gently downward to the west and the north and is bounded on the east and south by steep escarpments. Because of the westward dip, most of the unit drains to the Kimani and Ripera Rivers. Elevation ranges from 1 970 m in the northwest to 2 600 m in the south. There are three promontories; Pangulicala (2 600 m), Fulanngi Hill (2 450 m) and Kirengapanye (2 221 m).

(b) Geology

The plateau is covered with a deep layer of fine volcanic ash. This is underlain by sedimentary rock, principally quartzitic sandstones but also colour-banded shales and siltstones, which frequently outcrop.

(c) Climate

No data are available, but the average annual rainfall is estimated to be between 1 400 mm and 1 600 mm. Freezing temperatures are likely to occur during the dry season.

(d) Soils

The soils are derived from volcanic ash. The northern part has moderately deep to deep very dark grey or black loams over dark reddish brown clay loams over yellowish red clays, and the southern part has moderately deep to deep black loams over very dark grey clay loams over very dark greyish brown clays. Throughout the unit there are very shallow dark grey loams over bedrock. Approximately one third of the unit has shallow soils and rock outcrops.

(e) Vegetation

Short Koeleria-Panicum grassland dominated by Koeleria capensis, K. cristata and Panicum spp grasses. Many of the valleys contain upland moist forests of mainly Hagenia abyssinica.

(f) Features

The southern part of the unit is cultivated extensively to wheat, pyrethrum and potatoes, and the northern part is uncultivated. The soils are of moderate to high fertility, and there is good potential for cattle or sheep ranching. It is the only area that is comparable to the Kitulo Plateau.

## 6.7 UNIT 6 - MADAHANI-INIHO

(a) Physiography

Rolling to hilly with long slopes and a few rock outcrops. Elevation ranges from 2 000 m to 2 122 m.

(b) Geology

Most of this unit is underlain by basic-igneous rocks, mainly metagabbroic anorthosite, that are traversed by numerous belts of amphibolite. Tectonic schists, mylonites and phyllonites are common rock types along the eastern side of the unit, and on either side of the Rumakali River the bedrock is mainly olivine gabbros. Along the western edge (Nyasa Escarpment) young basaltic lava covers the basement complex. At a later date the entire unit was covered with a thick layer of volcanic ash and pumice, but much of this has since been eroded away.

(c) Climate

Average annual rainfall, as recorded at Bulongwa Primary School, is 1 217.5 mm, falling mostly in the months December through May. Approximate daytime temperatures range between 15.5 and 21.0°C with extremes of 9.0 and 29.0°C. Mists along the escarpment moderate the effect of the long dry season.

(d) Soils

Most of the soils are derived from volcanic ash and are deep, very dark brown loams, with traces of pumice, over reddish brown clays (Profile 1). These are generally of high fertility. Throughout the unit, where the ash cover has been eroded away, the soils are shallow dark brown loams over red clays, and they have low fertility.

(e) Vegetation

The unit appears to have originally been Hagenia-Agauria-Arundinaria forest, but now it is mostly cultivated. Remnant forests of Hagenia abyssinica, Agauria salicifolia var parvifolia, Olea spp and Arundinaria alpina can be seen throughout the unit with groves of introduced Acacia dealbata (silver wattle). The main grasses are Hyparrhenia micrathera, Exothea abyssinica, Setaria sphacelata and Trachypogon spicatus. Helychrysum spp, Selago thyrsoidea, Pteridium aquilinum and Digitaria scalarum are weeds of cultivation.

(f) Features

Wheat, maize, potatoes, various vegetables and several varieties of fruits grown in temperate climates (peaches, pears, apples, etc.) are cultivated on the deep fertile loams. Some pyrethrum is grown as a cash crop. The shallow red soils are used primarily for grazing livestock. There is little outside market because of poor communications and high transport costs.

## 6.8 UNIT 7 - TANDALA-BULONGWA

(a) Physiography

Generally hilly to steeply dissected, but containing broad valleys with rolling to hilly topography. The higher ridges are often rocky. Elevation ranges from approximately 2 000 m to 2 400 m.

(b) Geology

Most of this unit is underlain by basic-igneous rocks, mainly metagabbroic anorthosite, that are transversed by numerous belts of amphibolite. Tectonic schists, mylonites, phyllonites and quartz dykes cut through the centre and along the northeast edge of the unit. In the Ikonda-Mwakete area the bedrock is slates and phyllitic schists with quartzites and quartz schist horizons. Small areas of leuco and olivine-gabbros and related dolerites appear along the northeast edge of the unit and in the Bulonga area. Although this unit also had a covering of volcanic ash, most of it has eroded away because of the steepness of the slopes.

(c) Climate

Bulongwa Primary School records an average annual rainfall of 1 217.5 mm, falling in the months December through May. Approximate average daytime temperatures range between 15.5 and 21.0°C. Mwakete (approximately 9°22'S, 34°17'E at an elevation of 2 122 m) records for the years 1942 to 1944 indicate an annual rainfall of 1 612.6 mm during the months October to May.

(d) Soils

The following profile, examined approximately 2 km southeast of Kisinga Mission, is typical of the soils in this unit:

- 0 to 18 cm - dark brown (7.5YR 3/2) loam; weak crumb; non-sticky, non-plastic, friable, slightly hard; high permeability;  
 18 to 33 cm - dark reddish brown (5YR 3/4) clay loam; weak, very fine, subangular, blocky; slightly sticky, slightly plastic, friable, slightly hard; moderate permeability;  
 33 to 84 + cm - dark red (2.5YR 3/6) heavy clay loam; moderate, fine, subangular, blocky; slightly sticky, slightly plastic, friable, slightly hard; moderate permeability.

Some soils have a thin layer of weathered pumice at about 30 cm below the surface (compare Profiles 2 and 7), and in some areas there is a quartz stone line below the surface horizon.

(e) Vegetation

Medium to tall Exothea-Hyparrhenia grassland dominated by Exothea abyssinica, Hyparrhenia spp, Panicum maximum, Melinis ambigua, Andropogon spp and Setaria sphacelata. Imperata cylindrica grass, along with Helichrysum spp, Selago thyrsoidea and Pteridium aquilinum are weeds of cultivation. The ridge tops support large stands of Arundinaria alpina, Dodonaea viscosa and introduced Eucalyptus spp and Acacia dealbata. Throughout the unit, particularly where soils are shallow, there are local areas of Protea bushland or Protea-Themeda bushed grassland. The main species are Protea kingaensis, P. hehmanniana and P. rubrobracteata.

(f) Features

The area supports only a small population. The subsistence crops are wheat, maize, peas, potatoes and other vegetables. Some pyrethrum is grown as a cash crop, and some coffee is grown in the southern area around Luwumbu. Most of the crops are grown on terraced hillsides. Most of the soils are shallow and relatively infertile, but those soils which are suitable are utilized fully.

## 6.9 UNIT 8 - MANG'OTO - IWAWA

(a) Physiography

Hilly to steeply dissected with occasional rock outcrops. Elevation is 2 250 m to 2 400 m.

(b) Geology

Volcanic ash covers the ridge crests but has been eroded away from the steeper slopes. The underlying bedrock is primarily argillaceous rock, with interbedded quartzites, which has been intensively folded and overfolded and converted to slates and phyllitic schists. The northern side of the unit is underlain by colour-banded shales, siltstones, ferruginous sandstones and current-bedded quartzitic sandstones.

(c) Climate

Rainfall, falling mainly from November to May, is approximately 1 200 mm to 1 300 mm, based on data recorded at Kipengere Mission and Bulongwa Primary School (both outside the unit). Rainfall is likely to be higher along the northern side of the unit due to the effect of the Kipengere Range. The mean maximum and minimum temperatures are estimated to be about 18 and 9°C, respectively.

(d) Soils

The soils derived from the volcanic ash are found mainly on the ridge crests and are typically like the following, examined about 2 km west of Iwawa Cooperative:

- 0 to 36 cm - black (5YR 2/1) loam; weak, fine, subangular, blocky; non-sticky, non-plastic, friable; high permeability; high organic matter;
- 36 to 51 cm - dark reddish brown (5YR 3/4) loam; weak, fine, subangular, blocky; non-sticky, non-plastic, friable; high permeability; moderate organic matter;
- 51 to 94 cm - dark brown (7.5YR 3/2) clay loam; moderate, fine, subangular, blocky; slightly sticky, slightly plastic, friable; high permeability;
- 94 + cm - dark brown (10YR 3/3) clay loam.

These soils are well drained, have fairly good structure and moderately high fertility. Occasionally traces of pumice may be seen in the profile. Soils derived from the underlying bedrock are found on the steeper slopes.

A typical profile is the following, examined about 5 km southeast of Nkenja:

- 0 to 15 cm - dark reddish brown (5YR 3/3) loam;
- 15 to 81 cm - dark red (2.5YR 3/6) clay loam;
- 81 + cm - dark red (10R 3/6) clay.

These soils are well drained and moderately well structured, but have low fertility. In some profiles a quartz stone line appears below the surface horizon.

(e) Vegetation

Medium Exothea-Thameda grassland dominated by Exothea abyssinica, Themeda triandra, Hyparrhenia spp, Panicum spp and Andropogon spp grasses. Associated vegetation includes Helichrysum spp herbs and shrubs, introduced Acacia dealbata, and, in the upper stream channels, Hagenia abyssinica forest.

(f) Features

Cultivation (less than 50 percent of the unit) is carried out by hand on the volcanic soils. Only a few small areas are suitable for mechanized cultivation. Wheat, peas and potatoes are grown as subsistence crops, while some pyrethrum is grown as a cash crop. As elsewhere, phosphate and nitrogen fertilizers are likely to give economic response.

## 6.10 UNIT 9 - KIPENGERE PLATEAU

(a) Physiography

Broad undulating to rolling ridge crests with hilly to steeply dissected areas adjacent to the drainage ways. Occasional rock outcrops break the surface. Elevation ranges from 2 000 m in the north to 2 500 m in the south.

(b) Geology

Volcanic ash covers the ridge crests and is underlain by argillaceous rocks, with interbedded quartzites, which have been intensively folded and overfolded and converted to slates and phyllitic schists.

(c) Climate

Rainfall recorded at Kipengere Mission (9°17'S, 34°26'E at an elevation of 2 152 m) is 1 200 mm, falling in the months November to May. Rainfall may be slightly higher in the southern part of the unit. The mean maximum and minimum temperatures are probably similar to those at Igeri, i.e. 18.2 and 9.6°C, respectively.

(d) Soils

The majority of the soils of the unit are derived from volcanic ash. These are black or very dark brown loams over reddish brown loams over dark red clay loams or clays (Profiles 4 and 5). These soils have a very favourable structure and are of moderately high fertility (Beamish, 1968). The soils of the hilly to steeply dissected areas seem to be derived from the underlying bedrock. These are typically 25 cm of dark reddish brown (5YR 3/4) clay loam over dark red clay or red clay or bedrock. A quartz stone line frequently occurs at 25 to 30 cm depth.

(e) Vegetation

Medium Trachypogon-Themeda-Exothea grassland dominated by Trachypogon spicatus, Themeda triandra and Exothea abyssinica, each of which may be locally dominant. Other grasses include Brachiaria dictyoneura, Microchloa kunthii, Panicum calvum, P. maximum, Loudetia spp and Rendlia altera. Protea spp and Dodonaea viscosa are shrubs of the grassland while Selago thyrsoidea Pteridium aquilinum are weeds of cultivation. The ravines support a Hagenia-Agauria upland moist forest, and the main trees are Hagenia abyssinica, Agauria salicifolia var parvifolia, Olea spp and Rhamnus princoides.

(f) Features

The major crops of the unit are wheat, maize, potatoes, peas and pyrethrum. Kitulo grass trials yielded well. The area lends itself to mechanized cultivation and has good agricultural potential. As elsewhere, it is likely that economic responses will be obtained from nitrogen and phosphate fertilizers.

## 6.11 UNIT 10 - WANGAMA

(a) Physiography

Rolling to hilly with occasional small bedrock outcrops. The unit is drained by the Mbarali River and its tributaries. Elevation ranges from about 1 950 m at the Mbarali River west of Kidugala Mission to 2 300 m at Fulanangi Hill.

(b) Geology

Most of the unit is underlain by granites, primarily potassic granites, that frequently contain microcline porphyroblasts. In the north, and in other small areas, there are foliated granodiorites and some biotite gneisses. Along the western side, sediments occur in the form of colour-banded shales, siltstones and ferruginous sandstones. It appears that the area once had a thin covering of volcanic ash.

(c) Climate

No data are available, but on the basis of records from Kipengere Mission 5 km south of the unit, the annual rainfall is estimated to be 1 200 mm to 1 300 mm.

(d) Soils

The soils are typically shallow to moderately deep dark reddish brown loams over bedrock and often contain a quartz stone line at a depth of about 30 to 40 cm. A second soil type, found east of the Mbarali River, is a dark brown loam over red clay loam or clay; the entire profile contains fine quartz fragments.

(e) Vegetation

Medium to tall Exothea-Themeda-Hyparrhenia grassland dominated by Exothea abyssinica, Themeda triandra, Hyparrhenia spp and Setaria longiseta, each often locally dominant. The higher ridges and ravines carry a Hagenia abyssinica-Dodonaea viscosa bushland, and the intermediate slopes often carry a regrowth Themeda-Lankea bushed grassland. Uapaca kirkiana and Brachystegia microphylla woodland is common on the eastern side of the unit.

(f) Features

Maize is grown at the lower elevations and wheat, potatoes and other vegetables at the higher levels. Erosion is a serious problem over most of the unit, and generally the soils are of poor to moderate fertility.

## 6.12 UNIT 11 - SUNJE-LUSITU

(a) Physiography

This unit lies along the northern side of the Livingstone Mountains. It is generally hilly with steeply dissected to mountainous areas in the Nkiwe River-Sunje section. Many of the higher ridges have bedrock outcrops and escarpments on their crests. The narrow valleys often contain remnant forests. Elevation ranges from 2 000 m in the southeast to 2 400 m north of Sunje.

(b) Geology

The southeastern section of the unit is underlain by metamorphosed sediments, mainly phyllonites, mylonites and schists. At Sunje the bedrock is primarily foliated granodiorites. To the north of Sunje, as far as Tandala and Mang'oto, the unit is underlain by slates and phyllitic schists that contain several quartzite and quartz schist horizons. Within this area are exposures of granites and acid migmatites. Many of the schist exposures have weathered to a fine white or pinkish powder.

(c) Climate

No climatological data are available for the unit. Data derived from records at Igeri, Milo, Kipengere and Bulongwa (all outside the unit) indicate a rainfall of between 1 200 mm and 1 500 mm, and mean maximum and minimum temperatures of about 20 and 9°C, respectively.

(d) Soils

A typical soil profile for this unit is the following, described about 11 km south of Mang'oto on the Tandala road:

- 0 to 25 cm - dark brown (7.5YR 3/2) loam; no stones;
- 25 to 48 cm - dark yellowish brown (10YR 4/4) clay loam;
- 48 to 53 cm - dominant small quartz gravel;
- 53 + cm - light red (10YR 6/8) schistose bedrock with frequent small quartz gravel throughout.

Deep, very dark brown (10YR 2/2) loam over reddish clay loam is found in local areas throughout the unit.

(e) Vegetation

Medium Loudetia-Sporobolus-Exothea grassland dominated by Loudetia simplex, L. kagerensis, Sporobolus spp, Exothea abyssinica, Hyparrhenia spp, Panicum spp Trachypogon spicatus, Digitaria diagonalis and Eragrostis lukwangulensis. Common sedges are Carex spicato-paniculata, Bulbostylis spp and Pycurus spp. Some ridges have an Exothea-Protea bushed grassland of Exothea abyssinica, Protea kilimandscharica, P. rubrobracteata or P. kingaensis. The ravines support an upland moist forest of Hagenia abyssinica, Agauria salicifolia, Olea spp and Arundinaria alpina. Helichrysum spp and Pteridium aquilinum are weeds of abandoned cultivation.

(f) This unit is very sparsely settled, probably because of the shallow infertile soils. Where the soils are deeper, wheat, potatoes and peas are grown as subsistence crops and pyrethrum as a cash crop. Sunje and Matola Missions grow a variety of fruits from temperate climates (plums, pears, peaches, apples, etc.) with success.

## 6.13 UNIT 12 - NJOMBE PLAIN

(a) Physiography

An undulating to rolling plain with a few hilly areas in the south and west. The numerous perennial rivers and streams often expose small rock outcrops, and occasionally the bedrock breaks the crest of a ridge or hill leaving a boulder rubble. Elevation ranges from 1 803 m at Njombe to 2 242 m near Matola and 2 150 m just east of Kipengere Mission.

(b) Geology

Much of the unit is underlain by coarse potassic granites that contain pink microcline porphyroblasts. Closely related to these granites are older foliated granodiorites. Along the south and west, and overlying the granites, are purplish shales and schists with several quartzite and quartz bands. There are a few isolated occurrences of phyllitic shales or slates and ferruginous sandstones. Volcanic ash was deposited over the entire unit, but this has largely eroded away.

(c) Climate

The 40 year rainfall average at Kibena is 1 069.9 mm, falling in an average of 115 days, December through April (Fig. 1). The mean maximum and minimum temperatures are 22.0 and 10.3°C, respectively. At Igeri, the annual average rainfall for the past five years is 1 319.7 mm (Fig. 2). The mean maximum and minimum temperatures are 18.2 and 9.6°C, respectively. The mean relative humidity recorded at 0900 hours is 91.4 percent, and the mean sunshine hours per day is 5.5. The mean wind miles per day ranges from 111.3 in 1965 to 137.8 in 1968. Yearly mean total evaporation (pan) is 1 481.0 mm. Mists and cloud cover during the dry season moderate the climate significantly in the Tea Estate region around Igeri.

(d) Soils

The soils of the unit are of two types, those derived from volcanic ash and those derived from the underlying bedrock.

- i. Soils derived from volcanic ash are generally found on the undulating ridge crests. The typical profile is about 20 cm of very dark brown loam over dark brown clay loam over red clay, with a thin layer of weathered pumice at about 20 cm below the surface (Profile 6). These soils are generally considered very fertile (Darby, 1954). They are well drained and aerated and have a loose and friable structure;
- ii. soils derived from the underlying bedrock are generally found on the rolling valley slopes. The typical profile is about 25 cm of dark reddish brown heavy loam over dark red clay loam or clay (Profile 3). These soils are generally considered to have poor fertility (Darby, 1954). They are well drained and have good structure.

(e) Vegetation

The area has a fire climax vegetation of veld grasses.

- i. Medium Loudetia-Exothea grassland dominated by Loudetia simplex, L. kagerensis, Exothea abyssinica, Trachypogon spicatus, Eragrostis congesta, Koeleria spp, Digitaria diagonalis, D. scalarum, Ehrharta abyssinica and Hyparrhenia spp. Cyperus gracilinux is a common sedge. Introduced Acacia mollissima (black wattle) grows throughout the unit and there are frequent forests of Eucalyptus spp, Hagenia abyssinica is a common tree in the drainage ways;
- ii. medium Exothea-Themeda-Loudetia grassland dominated by Exothea abyssinica, Themeda triandra and Loudetia simplex. Introduced Acacia mollissima grows as planted forest. Hagenia abyssinica is common in the drainage ways.

(f) Features

The main subsistence crops of the area are wheat, maize, peas and potatoes. Cash crops are pyrethrum, wattle and tea, though wattle and tea are grown mostly on large estates. Only small amounts of wheat are marketed, and most of that by the Wattle Company. Wattle grows well on bedrock soils, while tea and other crops do best on the volcanic soils. Prins found that grass grew luxuriantly, at Iohenga (volcanic soil) indicating excellent opportunity for improved pasture. Trials at Matola (bedrock soil) were disappointing and supported the chemical analysis data of very low fertility and strong acidity. On volcanic soils of moderate to high fertility, responses to phosphate and nitrogen fertilizers have been obtained with wheat, maize and potatoes. Preliminary tests conducted by the Wattle Co. indicated responses to boron fertilizers as well (Beamish, 1968) but later trials fail to support this (Tanganyika Wattle Co. Ltd., 1968/69). Erosion is high on slopes exceeding 5 percent. This unit has good agricultural potential, and large parts are suitable for mechanized cultivation.

the soil of the hill side

(b) Soils

The soil of the hill side is a light brown loam, with a sandy subsoil. It is well drained and contains a fair amount of humus. The soil is generally well suited for the growth of a wide variety of crops. The soil is generally well suited for the growth of a wide variety of crops. The soil is generally well suited for the growth of a wide variety of crops.

The soil of the hill side is a light brown loam, with a sandy subsoil. It is well drained and contains a fair amount of humus. The soil is generally well suited for the growth of a wide variety of crops. The soil is generally well suited for the growth of a wide variety of crops. The soil is generally well suited for the growth of a wide variety of crops.

(c) Vegetation

The area has a fine clear vegetation of tall grasses. The vegetation is generally well suited for the growth of a wide variety of crops. The vegetation is generally well suited for the growth of a wide variety of crops. The vegetation is generally well suited for the growth of a wide variety of crops.

The area has a fine clear vegetation of tall grasses. The vegetation is generally well suited for the growth of a wide variety of crops. The vegetation is generally well suited for the growth of a wide variety of crops. The vegetation is generally well suited for the growth of a wide variety of crops.

(f) Features

The moderately well drained soils are used extensively for the production of subsistence crops, but the poorly drained soils have little or no potential. Since this unit is found in all parts of the map area, its potential and development should be considered with that of the unit surrounding it.

7.2 SUBMIT 13 (COMPARE PROFILES 5 and 11)

At the request of the Kintu Sheep Raising Project, the soils of the Kintu Plateau were mapped and described in more detail than those of other areas. Four basic profiles were identified and used as the basis of the units in which they were found to be representative of at least 90 percent of the profiles. Some variations appear along the stream and on abrupt changes in slope, but there is no uniform pattern (i.e. catena) as shown in the section on location where two of the five profiles taken near the stream were the same type as the major unit. There seems to be little evidence for the difference between 1a and 1b, as the topography, elevation, climate and vegetation are essentially the same for both. In the bedrock is frequently within one meter of the surface, and the land is mostly often hilly to steeply dissected. In the soil of the waterlogged depressions and stream channels. These soil differences are shown on Map 2. The larger areas of undulating to rolling topography have been delineated by dashed lines. These represent the approximate areas and locations that may be geographically correlated.

(a) Physiography

0	to	23	no	-	black (7.5R 2/0) clay
23	to	44	no	-	very dark gray (1.0R 3/1) clay
44	to	61	no	-	very dark gray (1.0R 3/1) clay
61	to	75	no	-	very dark gray (1.0R 3/1) clay
75	to	87	no	-	very dark gray (1.0R 3/1) clay

(b) Soils

0	to	30	no	-	black (7.5R 2/0) clay
30	to	44	no	-	very dark gray (1.0R 3/1) clay
44	to	61	no	-	very dark gray (1.0R 3/1) clay
61	to	75	no	-	very dark gray (1.0R 3/1) clay
75	to	87	no	-	very dark gray (1.0R 3/1) clay

(g) Vegetation

General description of the unit and other related features. The vegetation is generally a mix of grass and shrubs. The soil is generally a mix of clay and silt.

(h) Soils

0	to	45	no	-	black (7.5R 2/1) loam; rich organic matter
45	to	67	no	-	brownish yellow (10YR 6/8) loam
67	to	100	no	-	very dark grayish brown (10YR 3/2) clay loam
100	to	148	no	-	brownish yellow (10YR 6/8) loam
148	to	184	no	-	dark brown (7.5YR 3/2) clay

(2)

Chapter 7

DETAILED DESCRIPTIONS OF THE SOILS OF THE KITULO PLATEAU (UNIT 1)

At the request of the Kitulo Sheep Raising Project, the soils of the Kitulo Plateau were mapped and described in more detail than those of other areas. Four basic profiles were identified and used as the bases of the units, in which they were found to be representative of at least 90 percent of the profiles. Some variations appear along the stream and on abrupt changes in slope, but there is no uniform pattern (i.e. catena), as shown in the section on irrigation where two of the five profiles taken near the stream were the same type as the major unit. There seems to be little evidence for the differences between 1a and 1b, as the topography, elevation, climate and vegetation are essentially the same for both. In 1c the bedrock is frequently within one metre of the surface, and the land form is most often hilly to steeply dissected; 1d is the soil of the waterlogged depressions and stream channels. These soil differences are shown on Map 2. The larger areas of undulating to rolling topography have been delineated by dashed lines. These represent the approximate areas and locations that may be mechanically cultivated.

7.1 SUBUNIT 1a (COMPARE PROFILES 9 and 10)

(a) Physiography

Undulating to hilly, elevation 2 560 m to 2 860 m.

(b) Geology

Volcanic ash and pumice.

(c) Location

Generally in the centre of the unit and along the Nyasa Escarpment.

(d) Soils

0	to	42 cm	-	black (5YR 2/1) loam; high organic matter;
42	to	67 cm	-	brownish yellow (10YR 6/8) pumice;
67	to	100 cm	-	very dark greyish brown (10YR 3/2) clay loam;
100	to	148 cm	-	brownish yellow (10YR 6/8);
148	to	161+cm	-	dark brown (7.5YR 3/2) clay.

(e) Vegetation

Medium Koeleria-Festuca-Exothea grassland in which the major species are Koeleria cristata, Festuca abyssinica, F. caprina, Exothea abyssinica, Eragrostis racemosa and Themeda triandra.

## 7.2 SUBUNIT 1b (COMPARE PROFILES 8 and 11)

(a) Physiography

Undulating to hilly, elevation 2 200 m to 2 850 m.

(b) Geology

Volcanic ash and pumice.

(c) Location

Generally in the northern and eastern parts of the unit.

(d) Soils

0	to	23	cm	-	black (7.5YR 2/0) loam; high organic matter;
23	to	41	cm	-	very dark grey (10YR 3/1) loam;
41	to	61	cm	-	brownish yellow (10YR 6/8) pumice;
61	to	76	cm	-	very dark greyish brown (10YR 3/2) clay loam with fragments of reddish yellow (7.5YR 6/8) pumice;
76	to	147+	cm	-	dark brown (10YR 3/3) clay;
					or
0	to	30	cm	-	black (7.5YR 2/0) loam; high organic matter;
30	to	71	cm	-	very dark grey (10YR 3/1) clay loam;
71	to	86	cm	-	strong brown (7.5YR 3/6) pumice mixed with clay loam;
86	to	112+	cm	-	very dark brown (10YR 2/2) clay loam;

(e) Vegetation

Medium Festuca-Exothea grassland in which the main species are Festuca caprina, F. costata, Exothea abyssinica, Themeda triandra, Rendlia altera and Eragrostis pseudohispida.

## 7.3 SUBUNIT 1c

(a) Physiography

Rolling to steeply dissected, elevation 2 570 m to 2 820 m.

(b) Geology

Volcanic ash and pumice.

(c) Location

Generally along the Kipengere Range and on the higher, steeper hills in the southern part of the unit.

(d) Soils

0	to	18	cm	-	black (10YR 2/1) loam; high organic matter;
18	to	36	cm	-	very dark greyish brown (10YR 3/2) loamy pumice;
36	to	107	cm	-	dark brown (7.5YR 3/2) clay loam;
107	to	130	cm	-	dark yellowish brown (10YR 3/4) clay with fragments of pumice;
130+	cm			-	dark brown (10YR 3/3) clay;

or

0	to	15	cm	-	black (10YR 2/1) loam; high organic matter;
15	to	46	cm	-	yellowish red (5YR 5/8) loamy pumice;
46	to	68	cm	-	dark brown (7.5YR 4/2) heavy clay loam;
68+	cm			-	weathered schistose bedrock.

(e) Vegetation

Short to medium Koeleria-Festuca grassland in which the main species are Koeleria cristata, Festuca costata, F. caprina, Rendlia altera, Exothea abyssinica and Andropogon chrysostachyus.

## 7.4 SUBUNIT 1d (COMPARE PROFILE 12)

(a) Physiography

Flat to almost flat, elevation 2 500 m to 2 800 m.

(b) Geology

Alluvial sediments of mixed origin.

(c) Location

Found in waterlogged depressions and in stream channels.

(d) Soils

0 to 61 cm - black (10YR 2/1) peaty loam; very poorly drained;  
 61 to 91 cm - light olive brown (2.5Y 5/4) weathered pumice;  
 91 + cm - light yellowish brown (2.5Y 6/4) fine pumice and loamy sand;

(e) Vegetation

Medium Andropogon flabellifer seasonally flooded grassland with Andropogon dummeri around the margins. Common sedges are Juncus oxycarpus, Cyperus rigidifolius and Schoenorhophium lanceum. Common herbs are Sopubia ramosa, Erica whyteana, Cephalaria spp and Lobelia mildbraedi.

(f) Features

No agricultural use.

## 7.5 PUMICE

Since the raw pumice layer lies so near the surface on the Kitulo Plateau, a sample was taken from the second horizon of a Subunit 1a profile and submitted for chemical analysis. The data are as follows:

pH H <sub>2</sub> O	pH CaCl <sub>2</sub>	Conduct- ivity (micromho)	Phosphorus			% Org. C	% N	C/N
			0.3N HCl Extract	Total ppm	% Org.			
6.3	5.3	14.0	1.5	265.0	25.0	0.66	0.06	11.0

## Exchangeable Bases (meq/100 gm)

Ca	Mg	Na	K	Mn	Total
1.8	0.6	0.11	0.5	0.08	3.09

The organic carbon level and exchangeable bases are extremely low in this horizon. This, plus the fact that it has taken about 200 years for the surface horizon to develop, gives strong emphasis to the need for careful soil conservation. Once the surface loams have been lost through erosion, it will take many years before the area is productive again.

7.6 PROPOSED KITULO IRRIGATION SITE

An area along the river below the main buildings was selected by the Kitulo Project as a possible site for irrigated pasture. The idea behind this was to provide late dry season pasture for the breeding rams in the hope of improving their condition before they were put to work.

While adequate water is available from the river, the soil leaves much to be desired. Of five profiles investigated, two were Subunit 1a type, one each of 1b and 1c type, and the fifth was 56 cm of loam over 100+ cm of mixed pumice and sand. These profiles are all well to somewhat excessively drained and have a very low water holding capacity. A further limitation may be increased leaching of the surface horizon with the addition of irrigation water.

Within the proposed irrigation area, Paddocks 15 and 16 would be the most suitable, as each has 114 cm of surface mineral soil above the first pumice layer.

In view of the undulating topography of the site and the high permeability of the soil, sprinkler irrigation is likely to be the most effective and least expensive irrigation method. However, the idea must be considered very carefully before any action is taken, as the benefits are not likely to outweigh the costs of installation.

C/W	pH	CaCO <sub>3</sub>	Cation Exchange Capacity		pH	pH
			CEC	CEC		
15	5.5	0.0	1.0	1.0	5.5	5.5
16	5.5	0.0	1.0	1.0	5.5	5.5

Table 1. Soil characteristics of paddocks 15 and 16.

(a) Exchangeable cations

Level	Ca	Mg	K	Na	Sum
0-10	0.0	0.0	0.0	0.0	0.0
10-20	0.0	0.0	0.0	0.0	0.0
20-30	0.0	0.0	0.0	0.0	0.0

The organic carbon level and exchangeable bases are extremely low in this horizon. This, plus the fact that it has taken about 200 years for the surface horizon to develop, gives strong emphasis to the need for careful soil conservation. Once the surface loam has been lost through erosion it will take many years before the area is productive again.



Plate 1: Typical Kitulo Plateau (Unit 1) soil profile: 0 to 41 cm, black loam; 41 to 96 cm, pumice; 96 to 122 cm, very dark brown clay loam; 122+ cm, pumice with fragments of basalt. Dominant grass is Festuca costata.



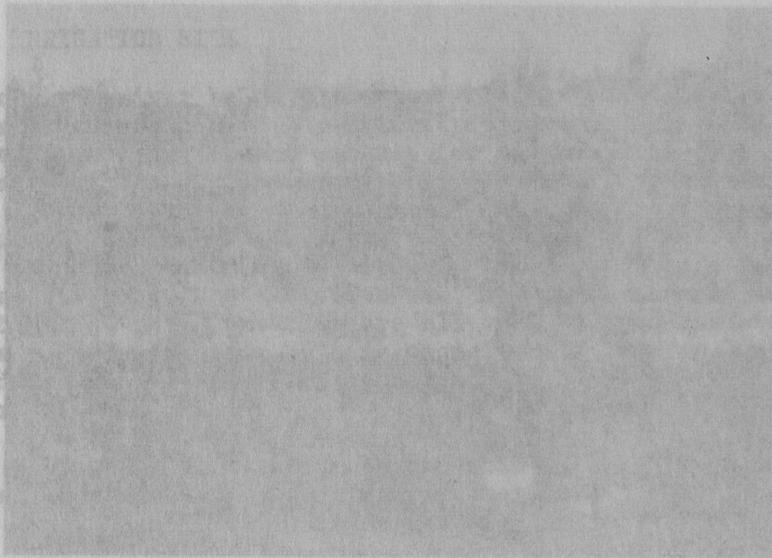
Plate 2: Kitulo Plateau with Chaluhandi on the horizon. The dark areas are recent cultivation. The foreground shrub is Protea kilimandscharica.

7.6 PROPOSED KITULO IRRIGATION SYSTEM

An area also...  
Kitulo Project...  
this was to prov...  
hope of improv...

While adequ...  
to be desired...  
one each of 1b...  
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In view of the undulating topography of the area and the high permeability of the soil, sprinkler irrigation is likely to be the most effective and economical method. Typical Kitulo Plateau (Series 1) soil characteristics considered very good for pumice are: 0 to 41 cm, black loam; 41 to 73 cm, dark brown clay loam; 73 to 96 to 122 cm, very dark brown clay loam. Dominant grasses with fragments of basal. Dominant grasses in Festuca contracta.



Plate 2: Kitulo Plateau with Chulabani on the horizon. The dark areas are recent cultivation. The foreground shows a Protea kilimandscharica.



Plate 3: Gneissic rock outcrop on hill crest in southern part of the Kitulo Plateau.

Plate 5: Forestry Department 1938-39 trial plot on the Kitulo Plateau.



Plate 4: Basaltic lava exposure (about 5 metres high) on the Kitulo Plateau.

Plate 6: Highland mixed forest in the northern part of the Kitulo Plateau. The foreground is a typical Malawi-forest grassland.



Plate 2: Basaltic rock outcrop on hill crest in southern part of the Kilauea Plateau.



Plate 4: Basaltic lava exposure (about 5 metres high) on the Kilauea Plateau.



Plate 5: Forestry Department Pinus spp trial plot on the Kitulo Plateau.



Plate 6: Hagenia-Agauria upland moist forest in the ravines of the Kitulo Plateau. The foreground is medium Koeleria-Festuca grassland.



Plate 5: Forestry Department Pinus spp. trial plot on the Kivulo Plateau.

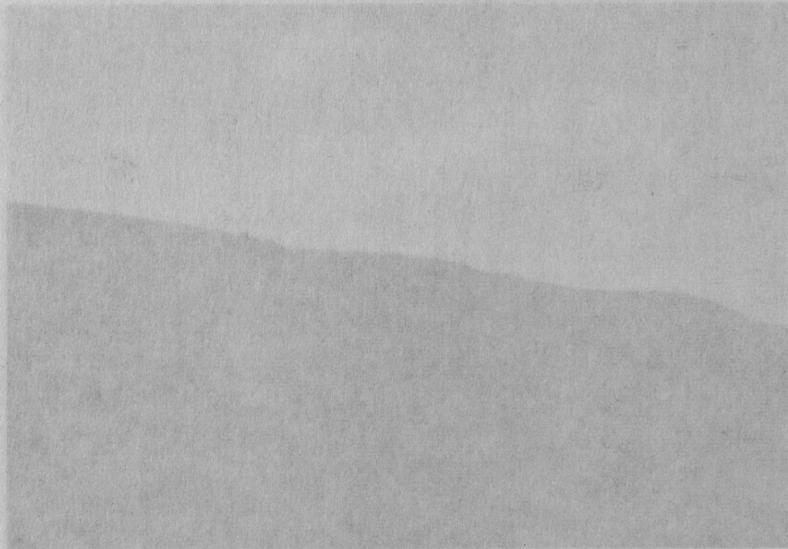


Plate 6: Harania-Acacia upland moist forest in the ravines of the Kivulo Plateau. The foreground is medium Koeleria-Vetiver grassland.

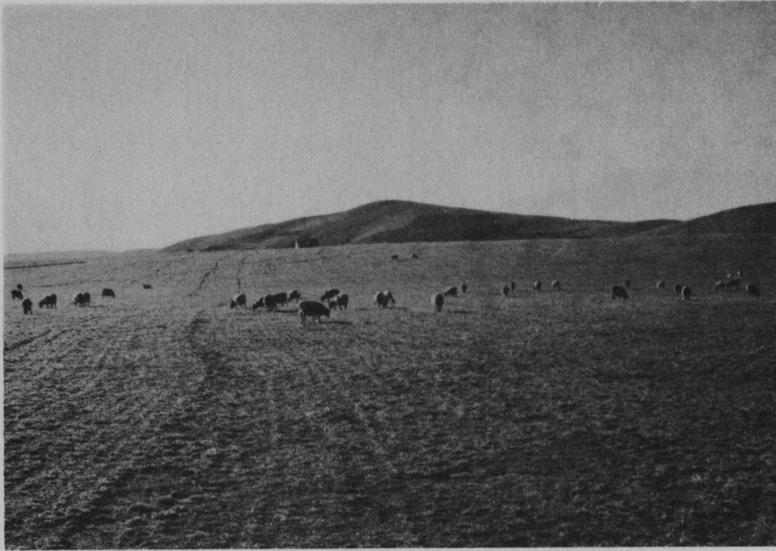


Plate 7: Dry season planted pasture and Corriedale sheep at the Kitulo Sheep Raising Project.

Wtarsi on the right, the Ikuwo Basin is back-ground centre, and, on the horizon, the Gofie Plateau.



Plate 8: Pyrethrum (Chrysanthemum cinerariifolium) growing on the Kitulo Plateau.

Plate 10: In the foreground showing terraced cultivation on the hillsides and gallery forests in the ravines (Unit 2).

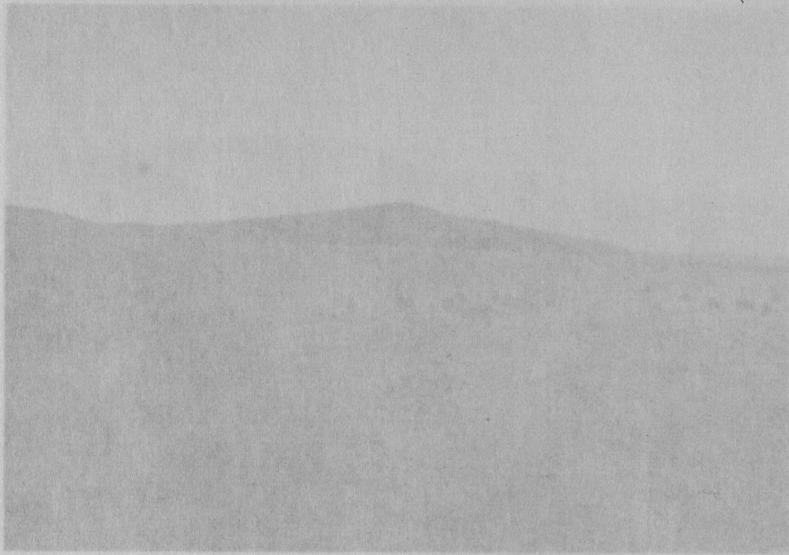


Plate 7: Dry season planted pasture and Corriedale sheep at the Kitulo Sheep Raising Project.

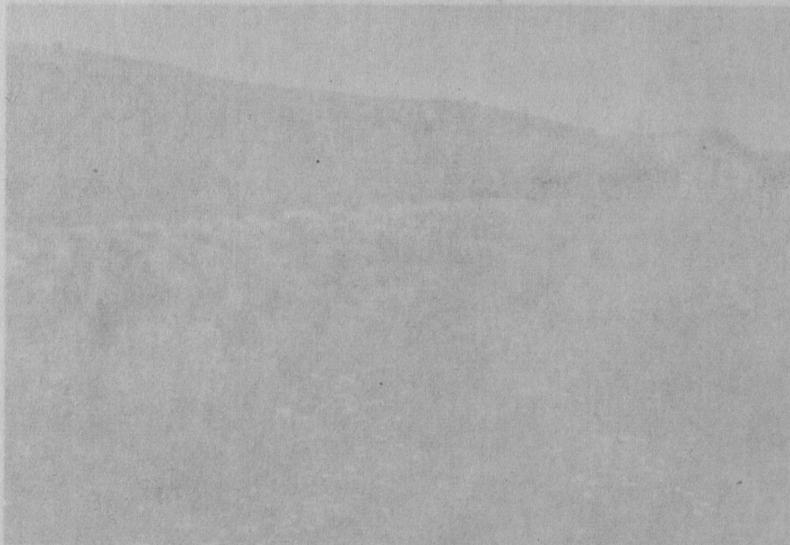


Plate 8: Pyrethrum (Carvum cinerifolium) growing on the Kitulo Plateau.



Plate 9: Looking through the Ndumbi Gap from the Kitulo Plateau. The Ndumbi Forest Reserve is centre, Ntorwi on the right, the Ikuwo Basin is background centre, and, on the horizon, the Gofio Plateau.



Plate 10: Ukinga Mountains in the foreground showing terraced cultivation on the hillsides and gallery forests in the ravines (Unit 2).



Plate 9: Looking through the Humber Gap from the Kettle Plateau. The Humber Forest Reserve is centre, Humber on the right, the Kettle Basin is back-ground centre, and, on the horizon, the Gothic Plateau.

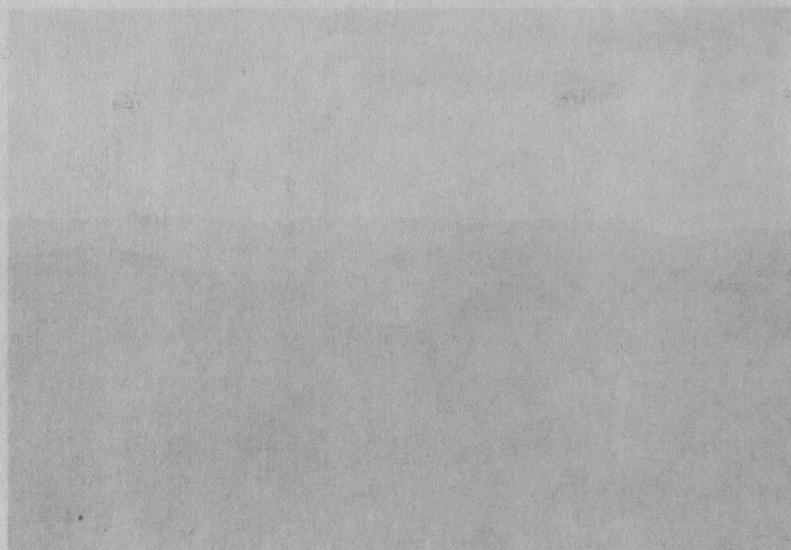


Plate 10: Ureina Mountains in the foreground showing terraced cultivation on the hillsides and gallery forests in the ravines (Unit 2).



Plate 11: Southern part of the Kirengapassi Escarpment, looking north from the Kipengere Plateau. On the left is Pangulicala and on the right, Fulanengi Hill.



Plate 12: The Kipengere Plateau (Unit 9). In the foreground is a fallow field overgrown to Pteridium aquilinum and associated weeds. Dark patches are present cultivation.



Plate 11: Southern part of the Kipengere Plateau, looking north from the Kipengere Plateau. On the left is Pangulala and on the right, Wilimanyi Hill.



Plate 12: The Kipengere Plateau (Unit 9). In the foreground is a yellow field overgrown to *Eragrostis amabilis* and associated weeds. Dark patches are present on the plateau.



Plate 13: Part of the Livingstone Mountain Range south of Kipengere (Unit 11). Lake Nyasa is in centre background. Vegetation in foreground (Unit 9) is Themeda triandra grassland with Protea spp shrubs.



Plate 14: Southwest corner of the Njombe Plain, showing undulating to rolling medium Exothecca-Themeda-Loudetia grassland on shallow, infertile dark reddish brown soils (Unit 12).



Plate 13: Part of the Livingston Mountain Range south of Kibungwe (Unit 11). Lake Nyasa is in centre background. Vegetation in foreground (Unit 9) is Themeda grandis grassland with Protea spp shrubs.

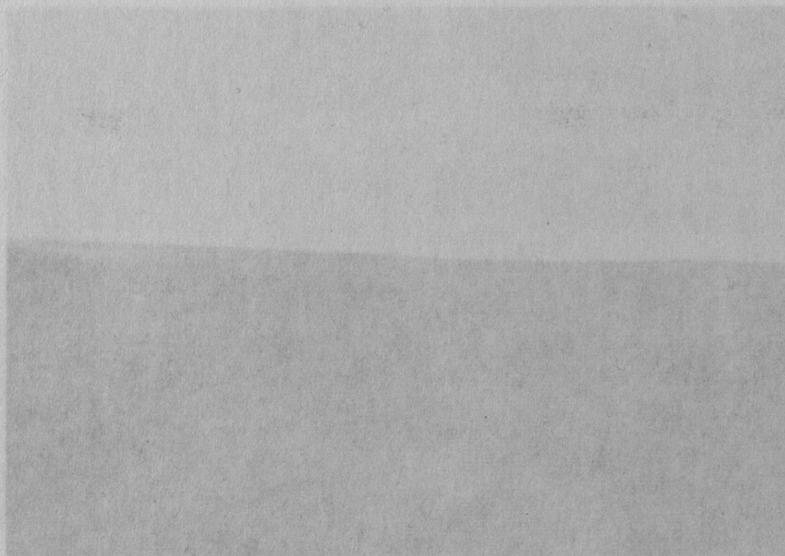


Plate 14: Southwest corner of the Njombe Plain, showing undulating to rolling medium Themeda-Themeda-Loudetia grassland on shallow, infertile dark reddish brown soils (Unit 12).

Appendix 1DETAILED PROFILE DESCRIPTIONS

**Plate 15:** Maize and black wattle cultivated on fertile loams near Njombe (Unit 12).

1. Information of the Site(a) Profile name:(b) Unit no.:(c) Location:(d) Elevation:(e) Land use:

ii) surrounding land form: hilly, nearby slopes of a plateau along the Nyasa Escarpment.

(f) Slope:(g) Land use:

at the time of examination the site was under alpine forest, nearby were fields of maize and potatoes.

(h) Climate:

no data are available at the site, but Malouge Primary School, about 6 km west, records an average annual rainfall of 217.5 mm, the day temperatures range between 15.3 and 21.0°C on the average; the dry season climate is modified by the presence of mists along the escarpment.

2. General Information on the Soil(a) Parent material: Volcanic ash over basic bedrock;(b) Drainage: Class 4, well drained;(c) Moisture conditions in profile: moist throughout;



Plate 12: White and black wattle cultivated on fertile loams  
near Njombe (Unit 12).

## Appendix 1

## DETAILED PROFILE DESCRIPTIONS

Soil Profile Number 11. Information on the Site

- (a) Profile name: Madahani;
- (b) Unit number: six;
- (c) Location: road cut near Madahani Church, approximately 6 km west of Bulonga, Njombe District, Tanzania. Approximately  $9^{\circ}20'S$   $34^{\circ}00'E$ ;
- (d) Elevation: 2 133 m;
- (e) Land form:
- i) physiographic position: near crest of convex slope;
  - ii) surrounding land form: hilly, nearby slopes to 50 percent along the Nyasa Escarpment;
- (f) Slope on which profile is sited: moderately steep (17 percent);
- (g) Land use: at the time of examination the site was under Arundinaria alpina forest, nearby were fields of maize and potatoes;
- (h) Climate: no data are available at the site, but Bulongwa Primary School, about 6 km east, records an average annual rainfall of 1 217.5 mm, the day temperatures range between 15.5 and 21.0°C on the average; the dry season climate is modified by the presence of mists along the escarpment.

2. General Information on the Soil

- (a) Parent material: volcanic ash over basic bedrock;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in profile: moist throughout;

- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0 - free;
- (h) Human influence: slight.

### 3. Brief Description of the Profile

The soil is a well drained dark brown loam, changing to clay loam in the lower profile. The pumice has almost weathered away.

### 4. Detailed Profile Description

- 0 to 25 cm - very dark brown (10YR 2/2) moist, loam; fine subangular blocky; non-sticky, non-plastic, firm; many medium pores; high permeability; high organic matter; many fine roots; fauna present (sampled);
- 25 to 50 cm - dark brown (10YR 3/3) moist, heavy loam; fine subangular blocky; slightly sticky, slightly plastic, firm; common fine pores; moderate permeability; moderate organic matter; few medium and many fine roots; fauna present (sampled);
- 50 to 84 cm - dark brown (7.5YR 4/4) moist, loam mixed with weathered pumice; structureless, single grain; non-sticky, non-plastic, loose; many fine pores; high permeability; low organic matter; few medium and many fine roots; fauna present (sampled);
- 84 + cm - reddish brown (5YR 4/4) moist, heavy clay loam; massive, breaking to fine subangular blocky; slightly sticky, slightly plastic, firm; few very fine pores; moderate permeability; low organic matter; few medium and many fine roots; fauna present (sampled).

### 5. Interpreted Characteristics of the Soil

This soil has fairly high fertility. The profile is medium to strongly acid. Exchangeable manganese is very high in the surface horizon. Potassium is higher in the first two horizons than in most soil profiles, but calcium is lower. The latter is perhaps due to the low calcium content of the parent pumice. There may be a tendency to induce magnesium deficiency as the Mg/K ratio in the subsoil is narrow. Even though the available phosphorus is the highest of any profile, it is still to be considered low, as is the total phosphorus. The C/N ratio is wide. Thus, responses to nitrogen and phosphate fertilizers are likely. Physically, this soil has good structure. In the third horizon most of the sand fraction is, in fact, weathered pumice.

Profile 1 Analytical Data

Horizon Depth (cm)	0-25	25-50	50-84	84+
pH - 1:2.5 water	5.5	5.4	5.9	5.1
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.5	4.4	5.0	4.0
Conductivity - 1:5 micromhos/cm	75.0	24.0	17.0	12.0
<b>Phosphorus</b>				
0.3N HCl extract - ppm	6.3	1.5	0.9	-
Total ppm	630.0	420.0	350.0	-
% organic in total	58.0	69.0	76.0	-
<b>Exchangeable bases - meq/100 g</b>				
Ca	4.9	1.8	0.9	1.4
Mg	2.3	0.8	0.3	0.4
Na	0.19	0.17	0.11	0.10
K	0.96	1.34	0.76	0.88
Mn	1.70	0.16	0.11	0.13
Total	10.05	4.27	2.18	2.91
Capacity	28.0	-	-	11.8
Base saturation %	36.0	-	-	25.0
Organic Carbon %	7.31	2.70	2.10	-
Nitrogen %	0.51	0.20	-	-
C/N ratio	14.3	13.5	-	-
<b>Mechanical analysis</b>				
Sand %	41.2	40.0	54.0	40.0
Silt %	19.8	24.0	24.8	20.6
Clay %	27.0	31.8	17.0	37.9
Total	88.0	95.8	95.8	98.5
Textural class	SCL	CL	SL	CL

Soil Profile Number 21. Information on the Site

- (a) Profile name: Bulongwa;
- (b) Unit number: seven;
- (c) Location: approximately 200 m east of the market place, Bulongwa, Njombe District, Tanzania; approximately 9°20'S, 34°04'E;
- (d) Elevation: 2 103 m;
- (e) Land form:
- i) physiographic position, near crest of convex slope;
  - ii) surrounding land form, hilly;
- (f) Slope on which profile is sited: moderately steep (24 percent);
- (g) Land use: at the time of examination the site was under Exothea abyssinica-Hyparrhenia micrathera grassland; sometime previously the site was under cultivation;
- (h) Climate: average annual rainfall, as recorded at Bulongwa Primary School, is 1 217.5 mm which falls between December and May; temperatures range between 15.5 and 21.0°C, with extremes of 9.0 and 29.0°C; mists frequently occur during the dry season.

2. General Information on the Soil

- (a) Parent material: apparently derived from weathered gabbros and schists, but possibly influenced by volcanic ash;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in profile: dry throughout;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;

- (f) Evidence of erosion: slight sheet erosion;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: slight, confined to surface horizon; the soil appears exhausted.

### 3. Brief Description of the Profile

Dark brown loam that changes to red clay loam in the lower profile. The profile has good structure and roots are present throughout.

### 4. Detailed Profile Description

- 0 to 18 cm - very dark brown (10YR 2/2) moist, loam; weak fine subangular blocky; non-sticky, non-plastic; many fine and medium pores; high permeability; high organic matter; many fine and medium roots (sampled);
- 18 to 43 cm - dark brown (7.5YR 3/2) moist, loam; strong fine subangular blocky; non-sticky, non-plastic; common fine pores; moderate permeability; low organic matter; few fine and medium roots;
- 43 to 61 cm - yellowish red (5YR 4/6) moist, loam; few small stones; strong fine to medium subangular blocky; slightly sticky, slightly plastic; common very fine pores; moderate permeability; low organic matter; few fine roots;
- 61+ cm - red (2.5YR 4/6) moist, clay loam; few small stones; strong medium subangular blocky; slightly sticky, slightly plastic; common very fine pores; low permeability; low organic matter; few fine roots (sampled).

### 5. Interpreted Characteristics of the Soil

This soil has poor fertility. The profile is strongly acid. It would seem that good responses will be received from applications of nitrogen and phosphate fertilizers and, perhaps, lime. Physically, this soil has good structure. It appears that the soil has been exhausted and eroded by past husbandry practices, and careful attention will be required to revive it.

Profile 2 Analytical Data

Horizon Depth (cm)	0-18	61+
pH - 1:2.5 water	5.4	5.3
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.3	4.1
Conductivity - 1:5 micromhos/cm	16.0	8.0
<b>Phosphorus</b>		
0.3N HCl extract - ppm	4.2	-
Total ppm	400.0	-
% organic in total	56.0	-
<b>Exchangeable bases - meq/100 g</b>		
Ca	3.7	1.2
Mg	0.9	0.4
Na	0.15	0.12
K	0.56	0.24
Mn	0.57	0.04
Total	5.88	2.00
Capacity	19.8	-
Base saturation %	30.0	-
Organic Carbon %	6.37	-
Nitrogen %	0.39	-
C/N ratio	16.3	-
<b>Mechanical analysis</b>		
Sand %	50.0	42.0
Silt %	18.7	24.0
Clay %	21.0	30.7
Total	89.7	96.7
Textural class	L	CL

Soil Profile Number 31. Information on the Site

- (a) Profile name: Matola;
- (b) Unit number: 12;
- (c) Location: near Kitulo grass trial, approximately 2 km west of the main buildings on the Imiliwaha Sisters Farm, Matola, Njombe District, Tanzania; approximately 9°35'S, 34°37'E;
- (d) Elevation: 2 418 m;
- (e) Land form:
- i) physiographic position: mid-convex slope;
  - ii) surrounding land form: rolling;
- (f) Slope on which profile is sited: sloping (7 percent);
- (g) Land use: at the time of examination the site was an abandoned pyrethum field; nearby was a good stand of black wattle;
- (h) Climate: no data are available at the site, but records kept at Igeri (approximately 16 km northeast) show an average annual rainfall of 1 319.7 mm; mists are frequent during the dry season; average maximum and minimum temperatures are 18.2 and 9.6°C, respectively.

2. General Information on the Soil

- (a) Parent material: apparently derived from ferruginous sandstones, shales and slates;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in the profile: top 28 cm of profile dry, moist below;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, few pink quartz gravel; no rocks
- (f) Evidence of erosion: moderate sheet erosion;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: some confined to surface horizon; the soil appears exhausted after several years of continuous cultivation.

### 3. Brief Description of the Profile

The soil is dark reddish brown heavy loam over clay loam, with weak subangular blocky structure and low fertility.

### 4. Detailed Profile Description

- 0 to 15 cm - dark reddish brown (5YR 3/3) moist, heavy loam; moderate fine subangular blocky; slightly hard; many fine pores; high permeability; very low organic matter; few fine roots; fauna present (sampled);
- 15 to 28 cm - dark reddish brown (5YR 3/4) moist; heavy loam; weak fine subangular blocky; non-sticky, non-plastic, slightly hard; common fine pores; moderate permeability; very low organic matter; very few fine and very fine roots;
- 28 to 91 cm - yellowish red (5YR 5/6) moist, clay loam; few angular quartz gravel; massive, structureless; slightly sticky, slightly plastic, firm; common very fine pores; moderate permeability; no organic matter; very few very fine roots; few small irregular ironstone nodules (sampled).

### 5. Interpreted Characteristics of the Soil

This soil have very low fertility. The profile is very strongly acid. Chemically it has been completely exhausted and should respond to chemical and organic fertilizers. Physically, the soil has good structure, but years of erosion have exposed the subsoil. Extreme conservation care will be required to revive this soil to a productive stage and to maintain it.

Profile 3 Analytical Data

Horizon Depth (cm)	0-15	28-91
pH - 1:2.5 water	4.9	4.7
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.0	3.9
Conductivity - 1:5 micromhos/cm	15.0	30.0
Phosphorus		
0.3N HCl extract - ppm	2.7	0.9
Total ppm	410.0	190.0
% organic in total	77.0	72.0
Exchangeable bases - meq/100 g		
Ca	1.1	0.8
Mg	0.4	0.2
Na	0.11	0.08
K	0.36	0.17
Mn	0.32	0.13
Total	2.29	1.38
Capacity	9.8	-
Base saturation %	23.0	-
Organic Carbon %	3.28	1.39
Nitrogen %	0.20	-
C/N ratio	16.4	-
Mechanical analysis		
Sand %	70.4	60.8
Silt %	12.6	20.2
Clay %	12.3	17.4
Total %	95.3	98.4
Textural class	SL	SL

Soil Profile Number 4

1. Information on the Site

- (a) Profile name: Kipengere Ridge;
- (b) Unit number: 9;
- (c) Location: Next to Kitulo grass trial, approximately 10 km south of Kipengere Mission on the road to Sunje, Njombe District, Tanzania; approximately 9°23'S, 34°25'E;
- (d) Elevation: 2 468 m ;
- (e) Land form:
- i) physiographic position: near the crest of a convex slope;
  - ii) surrounding land form: undulating;
- (f) Slope on which profile is sited: gently sloping (4 percent);
- (g) Land use: at the time of examination the site was surrounded by fields of wheat, pyrethrum, peas and potatoes; there appears to be a crop rotation pattern;
- (h) Climate: no data are available for the site, but the average annual rainfall is probably slightly higher than the 1 200 mm recorded at Kipengere Mission, 10 km to the north and over 300 m lower. The rain falls mostly between November and May. The estimated maximum and minimum temperatures are about 18.0 and 8.0°C, respectively.

2. General Information on the Soil

- (a) Parent material: derived from volcanic ash;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in profile: top 13 cm of profile dry, moist below;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: confined to the surface horizon.

3. Brief Description of the Profile

Very fertile, deep, well drained, black loam underlain by dark red clay loam. Good root distribution.

4. Detailed Profile Description

- 0 to 13 cm - black (10YR 2/1) moist, loam; weak fine subangular blocky; non-sticky, non-plastic, friable, loose; many medium pores; high permeability; high organic matter; many very fine roots (sampled);
- 13 to 38 cm - reddish brown (5YR 4/4) moist, loam; moderate fine subangular blocky; non-sticky, non-plastic, firm; many fine and medium pores; moderate permeability; moderate organic matter; very few very fine roots (sampled).
- 38 to 94 cm - dark red (10R 3/6) moist, clay loam; massive, breaking to weak subangular blocky; slightly sticky, slightly plastic, firm; many fine pores; low permeability; low organic matter; very few very fine roots (sampled).

5. Interpreted Characteristics of the Soil

This soil has fairly high fertility. The profile is medium to very strongly acid. The base exchange capacity of the profile is high, but low available phosphorus and wide C/N ratio indicate that this soil will respond to phosphate and nitrogen fertilizers. Physically, this soil is deep and has fairly good structure.

2. Soil Information

a) Parent material: apparently derived from ash, but probably influenced by volcanic ash;

b) Drainage: Class 4, well drained;

c) Moisture conditions in profile: top 25 cm of profile dry, middle 25 cm moist, bottom 44 cm very moist;

d) Depth of groundwater table: unknown;

e) Presence of surface stones: Class 0, none;

f) Evidence of erosion: none;

g) Presence of soluble salts: Class 0, free;

h) Human influence: confined to the surface horizon. The soil appears to be a natural soil, but the top 25 cm may be a surface horizon, derived from volcanic ash, which has been exhausted.

Textural class: silt loam

Profile 4 Analytical Data

Horizon Depth (cm)	0-13	13-38	38-94
pH - 1:2.5 water	5.6	5.0	4.8
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.7	4.2	4.2
Conductivity - 1:5 micromhos/cm	70.0	27.0	25.0
Phosphorus			
0.3N HCl extract - ppm	5.5	2.8	1.3
Total ppm	960.0	525.0	470.0
% organic in total	68.0	71.0	74.0
Exchangeable bases - meq/100 g			
Ca	8.6	1.6	1.2
Mg	2.5	0.9	0.7
Na	0.11	0.08	0.07
K	0.48	0.36	0.23
Mn	0.38	0.08	0.03
Total	12.07	3.02	2.23
Capacity	26.4	-	-
Base saturation %	46.0	-	-
Organic Carbon %	6.80	3.54	0.94
Nitrogen %	0.48	-	-
C/N ratio	14.2	-	-
Mechanical analysis			
Sand %	61.3	50.4	42.5
Silt %	20.0	35.7	15.8
Clay %	9.2	10.4	38.7
Total %	90.5	96.5	98.0
Textural class	SL	L	CL

Soil Profile Number 5

1. Information on the Site

- (a) Profile name: Kipengere Mission;
- (b) Unit number: 9;
- (c) Location: approximately 200 m west of the school at Kipengere Mission, Njombe District, Tanzania; approximately 9°17'S, 34°26'E;
- (d) Elevation: 2 152 m;
- (e) Land form:
- i) physiographic position: convex midslope;
  - ii) surrounding land form: rolling;
- (f) Slope on which profile is sited: sloping (7 percent);
- (g) Land use: at the time of examination the site was under a poor cover of Eragrostis congesta, Koeleria spp and Hyparrhenia micrathera grasses; some years previously the site was under cultivation;
- (h) Climate: the average annual rainfall is 1 200.3 mm, falling mostly from November to May. The estimated maximum and minimum temperatures are about 18.0 and 8.0°C, respectively. June, July and August are the coldest months, and frost may occur during this time.

2. General Information on the Soil

- (a) Parent material: apparently derived from schists, but probably influenced by volcanic ash;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in profile: top 25 cm of profile dry, moist below;
- (d) Depth of groundwater table: unknown
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: confined to the surface horizon. The soil appears exhausted, and possibly much of the original top soil has been eroded away.

3. Brief Description of the Profile

Well drained, very dark brown loam over dark reddish brown clay over dark red clay loam, with good structure throughout the profile. The second horizon has a noticeably higher clay content. Traces of pumice were noticed at about 12 cm depth. Root distribution in the profile is good.

4. Detailed Profile Description

- 0 to 10 cm - very dark brown (10YR 2/2) moist, loam; strong fine to medium subangular blocky; non-sticky, non-plastic, hard; many fine pores; high permeability; moderate organic matter; many fine and very fine roots; fauna present; clear, smooth boundary (sampled);
- 10 to 25 cm - dark reddish brown (2.5YR 3/4) moist, clay; traces of weathered pumice; strong medium subangular blocky; sticky, plastic; many fine pores; moderate permeability; very low organic matter; few fine and very fine roots; diffuse, smooth boundary (sampled);
- 25 to 92 cm - dark red (10YR 3/6) moist, clay loam; massive, breaking to fine subangular blocky; slightly sticky, slightly plastic, hard; few very fine pores; moderate permeability; no organic matter; very few very fine roots (sampled).

5. Interpreted Characteristics of the Soil

This soil has low fertility. The profile is strongly acid. The exchangeable manganese is fairly high. As this soil appears to have been exhausted through continued cultivation, and perhaps surface erosion, additions of organic matter and chemical fertilizers should give good response. Physically this soil has good structure.

3. Brief Description of the Profile

Deep, fertile, well developed soil. The soil has a dark red clay at 48 cm. The soil has a weak structure, and roots are mostly confined to the first 13 cm of the profile.

Profile 5 Analytical Data

Horizon Depth (cm)	0-10	10-25	25-92
pH - 1:2.5 water	5.7	5.3	5.8
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.7	4.3	4.9
Conductivity - 1:5 micromhos/cm	15.0	12.0	10.0
Phosphorus			
0.3N HCl extract - ppm	4.1	2.2	1.0
Total ppm	530.0	310.0	290.0
% organic in total	72.0	73.0	76.0
Exchangeable bases - meq/100 g			
Ca	4.5	2.6	2.3
Mg	1.8	1.2	0.5
Na	0.12	0.10	0.12
K	1.00	0.76	0.56
Mn	0.90	0.16	0.04
Total	8.32	4.82	3.52
Capacity	15.8	-	-
Base saturation %	53.0	-	-
Organic Carbon %	3.15	1.05	0.38
Nitrogen %	0.22	0.10	-
C/N ratio	14.3	10.5	-
Mechanical analysis			
Sand %	42.4	40.2	43.0
Silt %	24.8	16.0	15.2
Clay %	29.0	41.2	38.8
Total	96.2	97.4	97.0
Textural class	CL	C	CL

3. Brief Description of the ProfileSoil Profile Number 6

Well drained, very dark red clay loam, with weak structure throughout the profile. The second horizon has a noticeably higher clay content. Traces of nodules were noticed.

1. Information on the Site

- (a) Profile name: Ichenga;
- (b) Unit number: 12;
- (c) Location: adjacent to Kitulo grass trial, Ichenga Experimental Station, Njombe District, Tanzania, approximately 9°28'S, 34°46'E;
- (d) Elevation: 2 133 m;
- (e) Land form:
- i) physiographic position: almost flat crest;
  - ii) surrounding land form: undulating;
- (f) Slope on which profile is sited: flat (1 percent);
- (g) Land use: the site had been under cultivation until shortly before the time of examination; nearby were trials of wheat, barley and grasses, all yielding well; originally the site appears to have been a Hagenia abyssinica upland moist forest;
- (h) Climate: no data are available at the site, but Uwemba Mission, about 3 km northeast, records an average annual rainfall of 1 304.8 mm. The rain falls from October to May. Temperatures, based on Igeri records, about 10 km to the southwest, are about 18.2 and 9.6°C for maximum and minimum, respectively. June, July and August are the cold months, but these are moderated to some extent by mist and cloud cover.

2. General Information on the Soil

- (a) Parent material: apparently derived from volcanic ash overlying the basement complex;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in profile: top 48 cm of profile dry, moist below;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0, none;
- (h) Human influence: confined to the surface horizon.

3. Brief Description of the Profile

Deep, fertile, well drained, very dark brown loam underlain by dark red clay at 48 cm. The soil has weak structure, and roots are mostly confined to the first 13 cm of the profile.

4. Detailed Profile Description

- 0 to 13 cm - very dark brown (10YR 2/2) moist, loam; weak very fine granular; non-sticky, non-plastic, loose, soft; many fine to medium pores; high permeability; high organic matter; many very fine roots; fauna present (sampled);
- 13 to 22 cm - dark brown (7.5YR 3/2) moist, clay loam; weak fine subangular blocky; sticky, plastic, firm; many fine pores; high permeability; moderate organic matter; few fine and very fine roots; fauna present (sampled);
- 22 to 36 cm - very dark brown (10YR 2/2) moist, clay loam; moderate fine subangular blocky; sticky, plastic, firm; many fine pores; high permeability; high organic matter; few very fine roots; fauna present (sampled);
- 36 to 48 cm - dark brown (7.5YR 3/2) moist, clay loam; traces of weathered pumice; moderate fine to medium subangular blocky; sticky; plastic, firm, slightly hard; common very fine pores; moderate permeability; moderate organic matter; very few very fine roots (sampled);
- 48 to 127 cm - dark red (2.5YR 3/6) moist, clay; massive, breaking to medium subangular blocky; sticky, plastic, firm; few very fine pores; moderate permeability; low organic matter; very few very fine roots (sampled).

5. Interpreted Characteristics of the Soil

This soil has fairly high fertility. The profile is slightly to medium acid. Good responses can be expected from nitrogen and phosphate fertilizers, as the available phosphorus is low and the C/N ratio is wide. Physically the structure of the soil is weak, and it will break down rapidly if not handled carefully.

Horizon	Depth (cm)	Texture	Moisture	Temperature	pH	Organic Carbon	Nitrogen	C/N ratio	Mechanical analysis
	0	SOL							
	1.31								
	0.54								
	1.89								
	0	SOL							

Profile 6 Analytical Data

Horizon Depth (cm)	0-13	13-22	22-36	36-48	48-127
pH - 1:2.5 water	6.0	6.1	6.1	5.9	5.8
pH - 1:2.5 M/100 CaCl <sub>2</sub>	5.0	5.1	5.1	5.0	5.0
Conductivity - 1:5 micromhos/cm	19.0	22.0	22.0	13.0	13.0
<b>Phosphorus</b>					
0.3N HCl extract - ppm	4.8	2.6	1.8	-	-
Total ppm	700.0	640.0	580.0	-	-
% organic in total	70.0	77.0	79.0	-	-
<b>Exchangeable bases - meq/100 g</b>					
Ca	9.7	9.9	10.0	-	2.2
Mg	1.4	1.5	1.6	-	0.8
Na	0.11	0.12	0.13	-	0.08
K	0.56	0.48	0.32	-	0.8
Mn	0.08	0.06	0.03	-	0.02
Total	11.85	12.06	12.08	-	3.90
Capacity	21.0	-	-	-	5.4
Base saturation %	56.0	-	-	-	60.0
Organic Carbon %	5.80	4.60	2.90	-	-
Nitrogen %	0.43	0.32	-	-	-
C/N ratio	13.5	12.7	-	-	-
<b>Mechanical analysis</b>					
Sand %	63.2	52.1	44.0	47.2	40.0
Silt %	19.4	22.3	28.8	25.2	16.1
Clay %	9.6	21.0	23.9	25.0	42.0
Total	92.2	95.4	96.7	97.4	98.1
Textural class	SL	SCL	L	SCL	C

Soil Profile Number 7

1. Information on the Site

- (a) Profile name: Ikonda;
- (b) Unit number: 7;
- (c) Location: near the water tank and Kitulo grass trial, Ikonda Mission, Njombe District, Tanzania; approximately  $9^{\circ}22'S$ ,  $34^{\circ}14'E$ ;
- (d) Elevation: 1 981 m;
- (e) Land form:
- i) physiographic position: convex midslope;
  - ii) surrounding land form: rolling;
- (f) Slope on which profile is sited: sloping (12 percent);
- (g) Land use: at the time of examination the site was covered with tall to medium Hyparrhenia micrathera and Imperata cylindrica grasses along with Pteridium aquilinum and a few Hagenia abyssinica trees; nearby was a grass trial, a maize field, and the Mission orchard containing grapes, pears, apples, etc.;
- (h) Climate: there are no data available at the site, but Mwakete, approximately 3 km northwest, recorded a two year average rainfall of 1 612.7 mm in the early 1940's; this may be a little high because of the stations proximity to the mountains. June, July and August are very cool months.

2. General Information on the Soil

- (a) Parent material: derived from volcanic pumice and ash over quartz schists;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in the profile: dry throughout;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt and alkali: Class 0, free;
- (h) Human influence: confined to surface horizon.

### 3. Brief Description of the Profile

Dark reddish brown clay loam throughout, with pumice in the third horizon. The profile is well drained, has good structure and has good root distribution.

### 4. Detailed Profile Description

- 0 to 18 cm - dark reddish brown (5YR 2/2) moist, clay loam; strong fine subangular blocky; slightly sticky, slightly plastic, loose; many fine pores; high permeability; high organic matter; abundant fine and very fine roots; fauna present (sampled);
- 18 to 36 cm - dark reddish brown (2.5YR 3/4) moist clay loam; strong fine subangular blocky; sticky, plastic, hard; common very fine pores; moderate permeability; moderate organic matter; few fine and very fine roots; fauna present (sampled);
- 36 to 41 cm - yellow (10YR 8/8) moist pumice; structureless, single grained; slightly hard; many medium pores; high permeability; no organic matter; few fine and very fine roots; fauna present;
- 41 to 69 cm - dark red (10YR 3/6) moist, heavy clay loam; massive, breaking to weak fine subangular blocky; sticky, plastic, hard; many very fine pores; moderate permeability; moderate organic matter; few fine and very fine roots; fauna present (sampled);
- 69 to 130 cm - dark red (7.5YR 3/6) moist, clay; massive, breaking to medium subangular blocky; sticky, plastic, hard; common very fine pores; low permeability; low organic matter; very few very fine roots; fauna present (sampled).

### 5. Interpreted Characteristics of the Soil

This soil has poor fertility. The profile is strongly acid. It has a high percentage of inorganic phosphorus but a very low total phosphorus. Nitrogen and other nutrient levels are low. Applications of organic and chemical fertilizers should give good responses. Physically, the structure of this soil is good.

Profile 7 Analytical Data

Horizon Depth (cm)	0-18	18-36	41-69	69-130
pH - 1:2.5 water	5.4	5.0	5.3	5.5
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.3	4.0	4.3	4.4
Conductivity - 1:5 micromhos/cm	11.0	8.0	5.0	8.0
Phosphorus				
0.3N HCl extract - ppm	3.7	2.3	-	-
Total ppm	375.0	215.0	-	-
% organic in total	54.0	57.0	-	-
Exchangeable bases - meq/100 g				
Ca	3.4	1.4	2.0	2.1
Mg	1.2	0.5	0.8	0.7
Na	0.10	0.08	0.04	0.12
K	0.45	0.40	0.32	0.28
Mn	0.30	0.18	0.07	0.05
Total	5.45	2.56	3.23	3.25
Capacity	16.0	-	-	6.0
Base saturation %	34.0	-	-	54.0
Organic Carbon %	4.31	3.38	-	-
Nitrogen %	0.26	0.23	-	-
C/N ratio	16.6	14.7	-	-
Mechanical analysis				
Sand %	48.5	38.8	39.4	31.3
Silt %	21.2	28.4	25.2	16.2
Clay %	25.6	29.6	32.6	50.6
Total %	95.3	96.8	97.2	98.1
Textural class	SCL	CL	CL	C

Soil Profile Number 8

1. Information on the Site

- (a) Profile name: Nkenja;
- (b) Unit number: 1;
- (c) Location: near Kitulo grass trial, approximately 1 km west of Nkenja on the Kitulo road, Njombe District, Tanzania; approximately 9°10'S, 34°04'E;
- (d) Elevation: 2 240 m;
- (e) Land form:
- i) physiographic position: convex midslope;
  - ii) surrounding land form: hilly;
- (f) Slope on which profile is sited: moderately steep (17 percent);
- (g) Land use: at the time of examination the site was under medium Exothea abyssinica grassland, with a grove of Acacia dealbata (silver wattle) nearby; the presence of Helichrysum spp indicated that the site may have been cultivated at some previous time, this soil type is used extensively for growing pyrethrum and other crops;
- (h) Climate: no data are available for the site, but it is estimated to be slightly warmer, with slightly less rainfall, than Kitulo, approximately 16 km to the west at elevation 2 727 m; Kitulo records an annual rainfall of 1 661.1 mm. Average maximum and minimum temperatures are 15.6 and 4.7°C. Frosts are common during the dry season.

2. General Information on the Soil

- (a) Parent material: derived from volcanic ash and pumice;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in the profile: moist throughout;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: moderate sheet erosion where vegetation has been removed;

- (g) Presence of salt and alkali: Class 0, free;
- (h) Human influence: confined to surface horizon.

### 3. Brief Description of the Profile

Deep, well drained, black loams over clay loams that contain traces of pumice. The structure is weak throughout, and the profile has a high concentration of roots in the first horizon.

### 4. Detailed Profile Description

- 0 to 13 cm - black (7.5YR 2/0) moist, loam; structureless, single grained; non-sticky, non-plastic, loose, soft; many fine pores; high permeability; high organic matter; abundant fine and very fine roots; fauna present (sampled);
- 13 to 28 cm - black (10YR 2/1) moist, loam; weak crumb; non-sticky, non-plastic, friable, soft; many fine pores; high permeability; high organic matter; many very fine roots; fauna present (sampled);
- 28 to 43 cm - dark yellowish brown (10YR 4/4) moist, clay loam; traces of weathered pumice; weak very fine subangular blocky; slightly sticky, slightly plastic, firm, slightly hard; common very fine pores; high permeability; moderate organic matter; few very fine roots; fauna present (sampled);
- 43 to 74 cm - dark yellowish brown (10YR 3/4) moist, clay loam; moderate fine subangular blocky; slightly sticky, slightly plastic, firm, slightly hard; common very fine pores; high permeability; moderate organic matter; very few very fine roots (sampled);
- 74 to 116 cm - dark brown (10YR 3/3) moist, silty clay loam; moderate fine subangular blocky; slightly hard; few very fine pores; moderate permeability; low organic matter; very few very fine roots (sampled);
- 116 to 130 cm - yellowish brown (10YR 5/6) moist, clay loam; weathered pumice; structureless, single grained; friable, soft; very few very fine pores; moderate permeability; low organic matter; very few very fine roots (sampled);
- 130 to 155 cm - brown (7.5YR 4/4) moist, silty clay loam; massive, breaking to subangular blocky; slightly sticky, slightly plastic; very few very fine pores; low permeability; moderate organic matter; very few very fine roots (sampled).

### 5. Interpreted Characteristics of the Soil

The profile is medium to strongly acid. Though organic matter, nitrogen and available phosphorus are high, the total base exchange is low. The main deficiency appears to be calcium. Even though the fertility of the soil is fairly high, there are likely to be good responses to fertilizers and possibly even to lime. Physically, this soil is weakly structured and very susceptible to erosion.

Profile 8 Analytical Data

Horizon Depth (cm)	0-13	13-28	28-43	43-74	74-116	116-130	130-155
pH - 1:2.5 water	5.5	5.7	5.9	6.0	5.8	5.7	5.3
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.5	4.7	5.0	5.0	4.9	4.7	4.2
Conductivity - 1:5 micromhos/cm	28.0	11.0	10.0	7.0	10.0	7.0	14.0
<b>Phosphorus</b>							
0.3N HCl extract - ppm	5.8	3.0	1.1	-	-	-	-
Total ppm	800.0	680.0	580.0	-	-	-	-
% organic in total	61.0	65.0	69.0	-	-	-	-
<b>Exchangeable bases - meq/100 g</b>							
Ca	2.2	1.4	1.2	1.0	0.8	-	0.8
Mg	1.0	0.8	0.6	0.4	0.2	-	0.1
Na	0.13	0.11	0.10	0.11	0.15	-	0.50
K	0.64	0.28	0.24	0.20	0.28	-	1.92
Mn	0.42	0.16	0.13	0.08	0.07	-	0.02
Total	4.39	2.75	2.27	1.79	1.50	-	3.34
Capacity	30.5	-	-	-	-	-	10.1
Base saturation %	14.0	-	-	-	-	-	33.0
Organic Carbon %	11.3	6.46	4.08	-	-	-	-
Nitrogen %	0.78	0.47	-	-	-	-	-
C/N ratio	14.5	13.7	-	-	-	-	-
<b>Mechanical analysis</b>							
Sand %	67.2	75.2	70.0	68.0	75.0	51.4	60.8
Silt %	10.8	9.3	13.4	13.8	10.0	17.2	15.0
Clay %	7.8	6.7	10.6	15.2	9.8	26.7	22.6
Total %	85.8	91.0	94.0	97.0	94.8	95.3	98.4
Textural class	LS	LS	SL	SL	LS	SCL	SCL

Soil Profile Number 9

1. Information on the Site

- (a) Profile name: Kitulo hillcrest;
- (b) Unit number: 1;
- (c) Location: crest of hill, approximately 1 km west of Kitulo Sheep Raising Project buildings, Njombe District, Tanzania; approximately 9°05'S, 33°54'E;
- (d) Elevation: 2 805 m;
- (e) Land form:
- i) physiographic position: convex crest;
  - ii) surrounding land form: rolling to hilly;
- (f) Slope on which profile is sited: almost flat (1 percent);
- (g) Land use: at the time of examination the site was under natural medium Koeleria-Festuca grassland, and was being grazed by cattle and sheep;
- (h) Climate: Kitulo records an average annual rainfall of 1 661.1 mm, falling in 174 days from November to May. The maximum rainfall is in March. The mean maximum and minimum temperatures are 15.6 and 4.7°C. The average air temperature is 12.2°C. Frost is common during the dry season.

2. General Information on the Soil

- (a) Parent material: derived from volcanic ash and pumice;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in profile: moist throughout;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: very slight, confined to grazing and, probably, previous burning.

### 3. Brief Description of the Profile

Moderately deep, well drained, black loam over pale brown pumice. The organic content of the surface horizon is high. Roots penetrate to a depth of 142 cm.

### 4. Detailed Profile Description

- 0 to 48 cm - black (7.5YR 2/0) moist, loam; weak, fine, subangular, blocky; slightly sticky, slightly plastic, friable, loose; many fine and very fine pores; high permeability; high organic matter; abundant fine and very fine roots; fauna present (sampled);
- 48 to 74 cm - very pale brown (10YR 7/4) moist, pumice; many fine pores; high permeability; very little organic matter; few fine and very fine roots;
- 74 to 97 cm - very dark brown (10YR 2/2) moist, clay loam; strong, fine, subangular blocky; sticky, plastic; many very fine pores; high permeability; high organic matter; very few very fine roots (sampled);
- 97 to 142 cm - yellow (10YR 7/8) moist, coarse pumice; many fine and medium pores; high permeability; very little organic matter; very few medium roots;
- 142 + cm - dark reddish grey (5YR 4/2) moist, clay loam; massive, structureless; sticky, plastic; common very fine and micro pores; moderate permeability; moderate organic matter.

### 5. Interpreted Characteristics of the Soil

This soil has fairly high fertility. The profile is slightly acid. The low available phosphorus and the wide C/N ratio indicate that responses to nitrogen and phosphate fertilizers are likely. Physically these soils are loose and friable and require packing to provide a good seed bed. Cover crops or trash cover are required to reduce wind and water erosion.

Profile 9 Analytical Data

Horizon Depth (cm)	0-48	74-97
pH - 1:2.5 water	6.0	6.3
pH - 1:2.5 M/100 CaCl <sub>2</sub>	5.0	5.4
Conductivity - 1:5 micromhos/cm	14.0	18.0
Phosphorus		
0.3N HCl extract - ppm	3.6	1.3
Total ppm	850.0	530.0
% organic in total	70.0	74.0
Exchangeable bases - meq/100 g		
Ca	6.7	5.6
Mg	1.3	2.8
Na	0.22	0.56
K	0.56	2.24
Mn	0.08	0.13
Total	8.86	11.33
Capacity	26.4	-
Base saturation %	34.0	-
Organic Carbon %	6.70	4.18
Nitrogen %	0.48	-
C/N ratio	14.0	-
Mechanical analysis		
Sand %	62.6	64.2
Silt %	17.6	16.8
Clay %	12.8	13.7
Total %	93.0	94.7
Textural class	SL	SL

Soil Profile Number 10

1. Information on the Site

- (a) Profile name: Kitulo hillside;
- (b) Unit number: 1;
- (c) Location: hillside, approximately 1 km west of Kitulo Sheep Raising Project buildings, Njombe District, Tanzania; approximately 9°05'S, 33°54'E;
- (d) Elevation: 2 773 m;
- (e) Land form:
- i) physiographic position: mid-convex slope;
  - ii) surrounding land form: rolling to hilly;
- (f) Slope on which profile is sited: moderately steep (21 percent);
- (g) Land use: at the time of examination the site was under natural medium Koeleria-Festuca grassland, and was being grazed by cattle and sheep;
- (h) Climate: Kitulo records an average annual rainfall of 1 661.1 mm, falling in 174 days from November to May. The maximum rainfall is in March. The mean maximum and minimum temperatures are 15.6 and 4.7°C. The average air temperature is 12.2°C. Frost is common during the dry season.

2. General Information on the Soil

- (a) Parent material: derived from volcanic ash and pumice;
- (b) Drainage: Class 4, well drained;
- (c) Moisture conditions in the profile: moist throughout;
- (d) Depth of groundwater table: unknown;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: very slight, confined to grazing and, probably, previous burning.

3. Brief Description of the Profile

Moderately deep, well drained, black loam underlain by pale yellow pumice. The organic content of the surface horizon is high. Roots are confined to the top 53 cm.

4. Detailed Profile Description

- 0 to 53 cm - black (2.5YR 2/0) moist, loam; moderately, fine, subangular blocky; non-sticky, non-plastic, friable, loose; many fine and very fine pores; high permeability; high organic matter; abundant fine and very fine roots; fauna present (sampled);
- 53 to 84 cm - pale yellow (2.5YR 7/4) moist, pumice;
- 84 to 124 cm - black (10YR 2/1) moist, clay loam; traces of weathered pumice; massive, breaking to weak very fine subangular blocky; sticky, plastic; many very fine and micro pores; moderate permeability; high organic matter (sampled);
- 124 to 142 cm - dark brown (7.5YR 3/2) moist, clay loam; yellowish red (5YR 5/8) moist pumice; massive breaking to weak fine subangular blocky; sticky, plastic; moderate permeability; moderate organic matter;
- 142 + cm - yellow (10YR 7/6) moist, coarse pumice.

5. Interpreted Characteristics of the Soil

This soil has fairly high fertility. The profile is slightly to medium acid. Though the potassium level is borderline and may be deficient, the Kitulo Project has received no response to potassium fertilizers. The low available phosphorus and the wide C/N ratio indicate that responses to nitrogen and phosphate fertilizers are likely. Physically, this soil is loose and friable and requires packing to make a good seed bed. Cover crops or trash cover are required to reduce wind and water erosion.

2. General Information on the Soil

- (a) Parent material: derived from volcanic ash and pumice;
- (b) Drainage: well drained;
- (c) Moisture conditions in profile: moist throughout;
- (d) Depth of groundwater table: unknown;
- (e) Presence of stones, rock outcrops: Class 0, none;

## Profile 10 Analytical Data

Horizon Depth (cm)	0-53	84-124
pH - 1:2.5 water	5.9	6.3
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.8	5.3
Conductivity - 1:5 micromhos/cm	12.0	17.0
Phosphorus		
0.3N HCl extract - ppm	4.1	1.0
Total ppm	1 400.0	420.0
% organic in total	76.0	74.0
Exchangeable bases - meq/100 g		
Ca	4.5	7.0
Mg	2.3	2.6
Na	0.11	0.44
K	0.32	2.12
Mn	0.13	0.12
Total	7.36	12.28
Capacity	28.8	-
Base saturation %	26.0	-
Organic Carbon %	8.50	3.96
Nitrogen %	0.62	-
C/N ratio	13.7	-
Mechanical analysis		
Sand %	77.8	65.2
Silt %	7.8	14.8
Clay %	5.0	14.7
Total %	90.6	94.7
Textural class	LS	SL

Soil Profile Number 111. Information on the Site(a) Profile name: Kitulo;(b) Unit number: 1;(c) Location: Paddock 11, approximately 1 km east of the dairy, Kitulo  
Sheep Raising Project, Njombe District, Tanzania;  
approximately 9°05'S, 33°54'E;(d) Elevation: 2 727 m;(e) Land form:

i) physiographic position: convex crest;

ii) surrounding land form: undulating;

(f) Slope on which profile is sited: almost flat (2 percent);(g) Land use: at the time of examination the site was under three year old planted pasture that is regularly grazed by the dairy herd; the pasture grasses are Festuca arundinacea, Dactylis glomerata, Trifolium repens var lousiappa and Trifolium subterranean var bacchus marsh; in 1966 this pasture received 112 kg/ha each of lime and single super phosphate; it was top dressed with 112 kg/ha single superphosphate in 1967, 1968 and twice in 1969, the last application being just prior to taking the soil sample;(h) Climate: Kitulo records an average annual rainfall of 1 661.1 mm, falling in 174 days from November to May. The maximum rainfall is in March. The mean maximum and minimum temperatures are 15.6 and 4.7°C. The average air temperature is 12.2°C. Frost is common during the dry season.2. General Information on the Soil(a) Parent material: derived from volcanic ash and pumice;(b) Drainage: Class 4, well drained;(c) Moisture conditions in profile: moist throughout;(d) Depth of groundwater table: unknown;(e) Presence of surface stones, rock outcrops: Class 0, none;

- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: confined to surface horizon, cultivation, application of fertilizers, and introduced plants.

3. Brief Description of the Profile

Well drained, highly organic, black loams over pumice. Root distribution is normal.

4. Detailed Profile Description

- 0 to 20 cm - black (5YR 2/1) moist, loam; weak, fine, subangular blocky; non-sticky, non-plastic; many fine and very fine pores; high permeability; high organic matter; abundant fine and very fine roots; fauna present (sampled);
- 20 to 35 cm - very dark brown (10YR 2/2) moist, loam; weak, fine, subangular blocky; non-sticky, non-plastic; many fine pores; high permeability; high organic matter; abundant fine and very fine roots; fauna present;
- 35 to 86 cm - brownish yellow (10YR 6/6) moist, pumice; medium textured; many fine pores; high permeability; very little organic matter; few fine and very fine roots;
- 86 to 112 cm - very dark greyish brown (10YR 3/2) moist, clay loam; strong, fine, subangular blocky; many very fine pores; moderate permeability; high organic matter; very few very fine roots;
- 112 + cm - reddish yellow (7.5YR 6/8) moist, clay loam; coarse pumice fragments.

5. Interpreted Characteristics of the Soils

This soil has fairly high fertility, though some of the data may be higher due to applications of fertilizers and planted legumes. The profile is medium acid. Magnesium appears to be marginal but the Mg/K ratio is fairly wide. Physically, the soil has good structure and has a good grass-legume covering. Packing was required to provide a good seed bed, and a cover crop was used to prevent erosion during pasture establishment.

3. Brief Description of the Profile

A waterlogged profile with black peaty loam underlain by loamy sand.

Profile 11 Analytical Data

Horizon Depth (cm)	Information on the Site
pH - 1:2.5 water	5.6
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.7
Conductivity - 1:5 micromhos/cm	87.0
Phosphorus	
0.3N HCl extract - ppm	4.8
Total ppm	1 000.0
% organic in total	67.0
Exchangeable bases - meq/100 g	
Ca	6.4
Mg	0.8
Na	0.27
K	0.60
Mn	0.29
Total	8.36
Capacity	25.5
Base saturation %	33.0
Organic Carbon %	8.70
Nitrogen %	0.63
C/N ratio	13.8
Mechanical analysis	
Sand %	60.0
Silt %	21.1
Clay %	8.8
Total %	89.9
Textural class	SL

Soil Profile Number 121. Information on the Site

- (a) Profile name: Kitulo depression;
- (b) Unit number: 1;
- (c) Location: approximately 1 km west of the Kitulo Sheep Raising Project buildings, Njombe District, Tanzania; approximately 9°05'S, 33°54'E;
- (d) Elevation: 2 720 m;
- (e) Land form:
- i) physiographic position: concave lower slope;
  - ii) surrounding land form: undulating;
- (f) Slope on which profile is sited: gently sloping (3 percent);
- (g) Land use: the area is under natural short Andropogon flabellifer seasonally flooded grassland;
- (h) Climate: Kitulo records an average annual rainfall of 1 661.1 mm, falling in 174 days from November to May. The mean maximum and minimum temperatures are 15.6 and 4.7°C. The air temperature is 12.2°C. Frost is common during the dry season.

2. General Information on the Soil

- (a) Parent material: derived from alluvium of volcanic origin;
- (b) Drainage: Class 0, very poorly drained;
- (c) Moisture conditions in profile: wet throughout;
- (d) Depth of groundwater table: at the surface;
- (e) Presence of surface stones, rock outcrops: Class 0, none;
- (f) Evidence of erosion: none;
- (g) Presence of salt or alkali: Class 0, free;
- (h) Human influence: none.



## Profile 12 Analytical Data

Horizon Depth (cm)	0-79
pH - 1:2.5 water	6.0
pH - 1:2.5 M/100 CaCl <sub>2</sub>	4.8
Conductivity - 1:5 micromhos/cm	50.0
Phosphorus	
0.3N HCl extract - ppm	6.1
Total ppm	680.0
% organic in total	71.0
Exchangeable bases - meq/100 g	
Ca	4.9
Mg	1.0
Na	0.37
K	1.00
Mn	1.02
Total	8.29
Capacity	26.9
Base saturation %	31.0
Organic Carbon %	10.9
Nitrogen %	0.80
C/N ratio	13.6
Mechanical analysis	
Sand %	45.2
Silt %	30.7
Clay %	10.6
Total %	86.5
Textural class	Org. L

Appendix 2

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