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SUMMARY

Mbulu District Council requested the National Soil Service to carry out a reconnaissance soil survey (at a scale of 1:100.000) of the entire Mbulu District. Within the scope of this study, ten villages were selected of which the soils and agricultural potential had to be characterized in more detail (at a scale of 1:20.000). These 10 villages face severe problems with soil erosion and degradation and therefore need proper land use planning programmes. Kilima Tembo, located in the northern part of Mbulu District, approximately 10 km east of Karatu, on the dissected lower slopes (footridges) of volcanic mountains just north of the district, is one of these villages. The total extent of the village is about 2400 ha.

The northern and highest part of Kilima Tembo village having altitudes ranging from 1550 to 1700 m, receives an average rainfall of 900-1000 mm per year, whereas the lowest southern part, with altitudes of 1400 to 1550 m, receives annually 800-900 mm of rain.

The main crops cultivated are wheat (especially in the northern part), maize, pigeon peas and beans, the latter three mainly intercropped. Nearly all tillage is carried out with tractors or ox-ploughs. The lands that are not used for cultivation are used for extensive grazing.

The distribution of the distinguished soil mapping units, which is closely related to the different landforms, is presented on a soil map with an approximate scale of 1:20.000. This map can be found in the back cover of this report.

Most of the soils in Kilima Tembo village have been developed in situ from undifferentiated volcanic rocks. The soils in the valley bottoms and mbuga are developed in alluvial/colluvial deposits of volcanic origin. The majority of the soils in the area is quite homogeneous in terms of morphological, physical and chemical aspects.

The dominant soils in the study area are very deep, well drained, dark reddish brown to dark red clays; they belong to the most fertile soils in Mbulu District but are extremely erodible. This erodibility is enhanced by several factors, such as: slope, absence or incorrect construction of contour ridges, incorrect tillage methods and grazing in the fields after harvest. A ploughpan, hampering rooting and water infiltration, is mainly present in all soils that are mechanically cultivated for several years with disc ploughs.

Variations in thickness of the topsoils, soil depth and the occurrence of surface stones has led to the differentiation of several mapping units. The variations are closely related to the physiography (i.e. landform and slope).

The thickness of the topsoils is more or less determined by the slope gradient. On slopes less than 4% on relatively broad crests in the northern part of the village, topsoils are very thick (50-80 cm). On slopes over 10%, topsoils are thin (<20 cm). On undulating lands and relatively narrow crests (slopes 2-10%), the thickness of the topsoils varies from 10 to 50 cm; the thickness decreases with increasing slope gradient.

Soil depth is less than 80 cm at the escarpment, on major valley sides and at the upper and middle slopes of the volcanic hills (slopes over 13%).

Surface stones are present in all mapping units with relatively shallow soils as well as on the undulating crests of the lower footridges, close to the Kilima cha Tembo escarpment.

Next to the dominant soil type and its variations, two other soil types have been distinguished: fertile, very deep, moderately well to well drained, stratified, dark reddish brown clays in valley bottoms, and, fertile, very deep, imperfectly to moderately well drained, cracking, (very) dark (greyish) brown clays in mbuga.

The land suitability is assessed for three land utilization types: mechanized cultivation, extensive grazing and afforestation. The assessment has resulted in the following conclusions:

- 46% of the total village area is suitable for mechanized cultivation;
- 20% of the total village area is not suitable for any one of assessed land utilization types; this area has to be fenced in order to enable regrowth of natural vegetation;
- under the assumption that the indicated 46% will be used for mechanized cultivation, 34% remains to be used for extensive grazing and/or afforestation.

In order to conserve the lands of Kilima Tembo, a set of recommendations is proposed which can lead to a sustainable agricultural system. These recommendations are geared to:

- limiting arable farming to areas suitable for mechanized cultivation,
- tillage along the contours on all cultivated lands,
- proper construction and maintenance of contour ridges or permanently vegetated contour strips,
- practice of strip-cropping with frequent crop rotation within the strips,
- regular breaking up of ploughpans with chisel-ploughs,
- soil fertility management (application of nitrogen fertilizers, monitoring of the available phosphorus levels, control of the organic matter contents),
- closing steep and very steep valley sides, escarpments and volcanic hills for grazing and firewood collection with the purpose of regeneration of natural vegetation,
- establishment of a proper afforestation program,
- reconstruction of roads that presently act as waterways,
- livestock management (reduction of herdsize, proper grazing rotations, planting of fodder crops, stimulation of zero-grazing).

1. INTRODUCTION

Within the scope of the 1:100.000 scale reconnaissance soil survey of the entire Mbulu District, the Mbulu District authorities selected ten villages to be mapped in detail, at a 1:20.000 scale. The ten villages are considered to be priority areas for soil conservation and land use planning programmes aimed at sustainable agriculture. Most of these areas have severe soil erosion and land degradation problems, resulting in a serious decline of the agricultural potential.
The objectives of the detailed survey were:

1 to provide a systematic inventory of the land and soil resources at village level, and
2 to provide a physical resource base to develop and execute suitable programmes on land use planning, soil conservation, reafforestation, controlled grazing and other rural and agricultural development projects at village level.

Kilima Tembo is one of the ten villages selected. The village is located in the northern part of Mbulu District, about 10 km east of Karatu, north of the Karatu - Mto wa Mbu road (see figure 1). It is situated on the dissected, lower slopes of the volcanoes in the Ngorongoro Northern Highlands, immediately north of Mbulu District. Kilima Tembo village is bordered in the east by Kambi ya Simba village, also one of the selected villages. The altitude ranges from approximately 1720 m near the forest to about 1420 m in the utmost south. The total extent of the village is approximately 2400 ha.

Maize, mostly intercropped with pigeon peas, is the main crop cultivated in the area. Wheat and beans are predominantly grown in the northern part of the village. Grazing is done in the areas which are not used for mechanized agriculture.

The survey was carried out in the last week of September 1988, by a team of 2 soil surveyors of the National Soil Service ARI-Mlingano, Messrs. Van der Wal and Kiwelu, and one soil conservation officer of the Mbulu District Council, Mr. Mbaga. The report and map were prepared by Mr. F. van der Wal.

Although it was agreed that the NSS should only provide a semi-detailed soil map with an extensive legend, the NSS felt that is was also appropriate to produce an explanatory report with detailed information on physiography, land use, soil fertility, soil erosion, and recommendations for sustainable agriculture.

More background information, especially on climate, carrying capacity and recommended tree and grass species, can be found in the report discussing the soils and the agricultural potential of the entire Mbulu District. This report will be published by the NSS later on. Data on population density, amount of livestock etc. are not included in this report. These data are available for all interested users of this report and can be obtained from the Mbulu District Council.

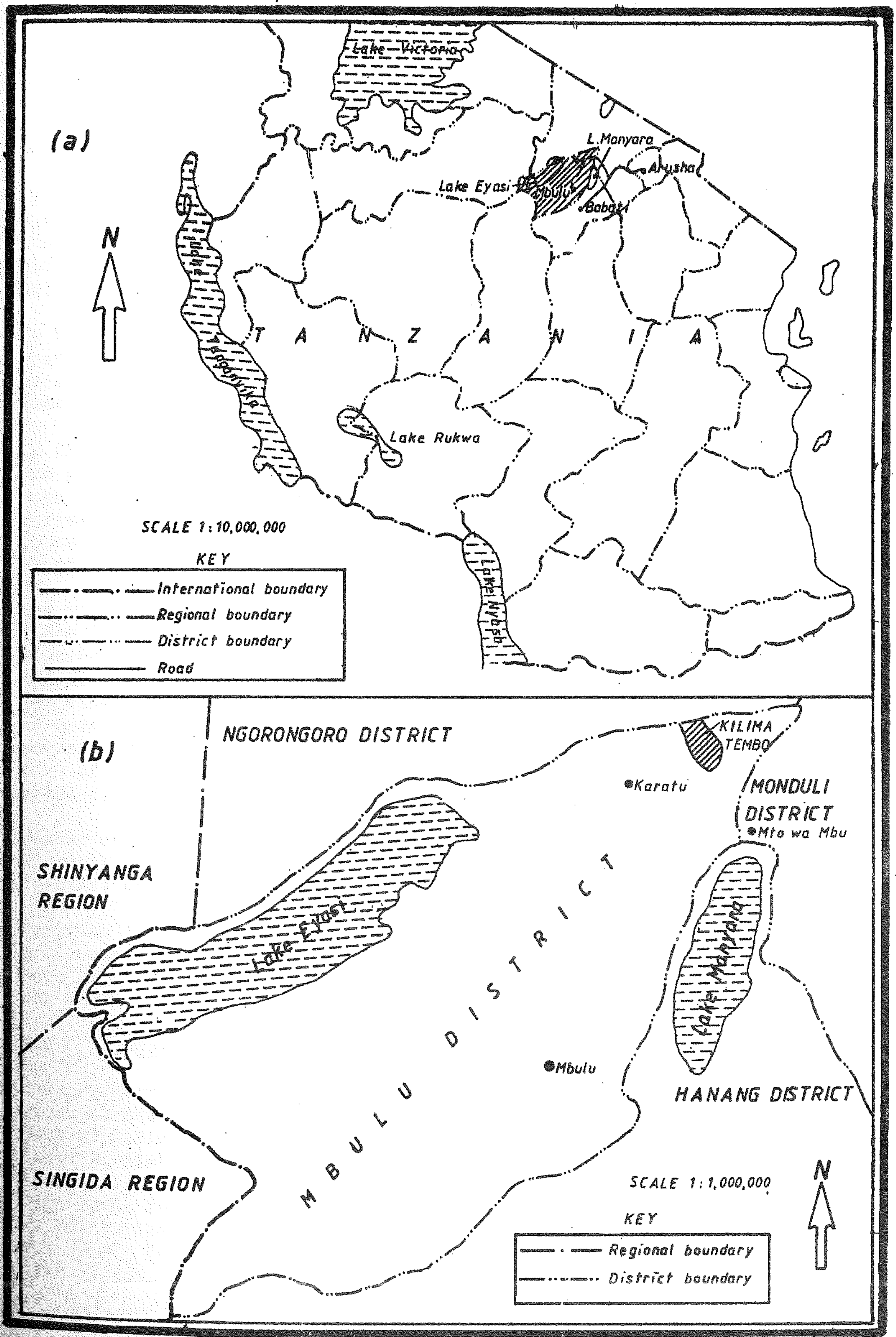


Figure 1a : Location of Mbulu District in Tanzania
1b : Location of Kilima Tembo Village in Mbulu District

2. ENVIRONMENT

2.1 Geology and physiography

Kilima Tembo village is located on the lower slopes of the volcanoes in the Ngorongoro Northern Highlands, just north of Mbulu District (see figure 2). The area is underlain by **rocks of volcanic origin**. Basaltic lavas, pumice, tuffs, scoriae and volcanic ashes are the materials in which the soils of Kilima Tembo have been developed.

In Kilima Tembo the main slope of the volcanoes is dipping to the south-east. The drainage ways on this slope are steeply incised, resulting in parallel ridges with a predominant NW-SE direction (the so-called **volcanic footridges**).

On the lower slopes of the volcanoes, minor volcanic cones or **volcanic hills** are present. Four of such eruption centres are located within the village area. North of the two highest cones the overall dip of the **upper footridges** varies from 6 to 13% (sloping). The so-called **lower footridges**, south of those volcanic hills, have a overall dip that is only 2 to 6% (gently sloping).

The macrorelief on the upper volcanic footridge in the north (altitudes range from 1570 to 1720 m) is very irregular: the highest, relatively broad, flat-topped crest is bordered by (gently) undulating areas (slopes 2-10%) and by moderately steep minor scarps (slopes 10-25%). The crests of the footridges in the southern part of the village (altitudes from 1420 to 1590 m) have a (gently) undulating macrorelief (slopes 2-8%). These crests are bordered by moderately steep or steeper sides of incised **major valleys**. In some of these major valleys, relatively wide, almost flat **valley bottoms** are present.

Saucer-shaped depressions (**mbuga**) with dark, heavy clay soils and no clear drainage ways are located at the heads of most valleys, separating the (gently) undulating lower footridges in the southern part of the village.

Faulting is a very common phenomenon in volcanic areas. In Kilima Tembo a pronounced **escarpment** (approximately 80 m high) forms the south-eastern boundary of the village. This fault-line continues to the north-east and to the south-west.

2.2 Hydrology

Most streams in the area are intermittent and discharge their water via the river Marera into Lake Manyara, via the Manyara National Park. A very small part of Kilima Tembo village drains to the Saata river, at the boundary with Kambi ya Simba village. This is the only river that carries water throughout the year. The Saata river is catching water from the Ngorongoro Northern High-lands Forest Reserve and drains into Lake Manyara after passing the Mto wa Mbu Irrigation Scheme. This Irrigation Scheme, located at the base of the Mto wa Mbu Escarpment at the shores of Lake Manyara, faces severe problems with floods, immediately after heavy rains in the area above the escarpment.

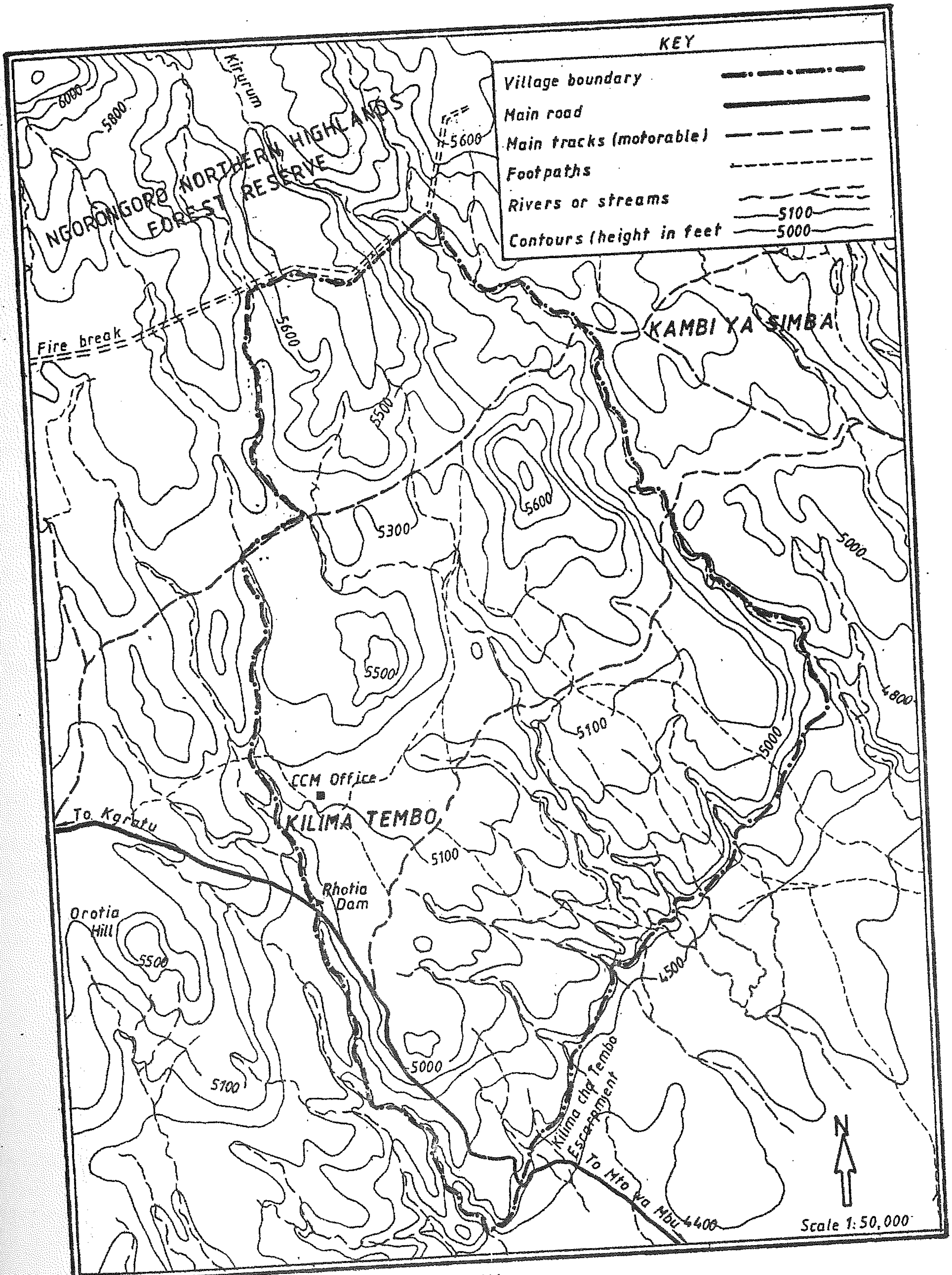


Fig. 2. Topography of Kilima Tembo village

2.3 Climate

The nearest rainfall recording station is Mbulumbulu Station, Kambi ya Simba village, immediately east of Kilima Tembo village. Rainfall data are presented in Table 1.

The mean annual rainfall measured in the Kambi ya Simba village centre, at an altitude of 1550 m, is 922 mm. The rainfall pattern in the study area is slightly bimodal showing peaks during December and April separated by relatively low rainfall in January-February and a dry period with hardly any rainfall from June to October (Figure 3). The data reveal that at least 95% of the average annual rainfall falls between November and May.

According to literature (Schultz, 1967) and field observations, rainfall decreases towards the south. It is estimated that the northern part of the village receives 900-1000 mm of rainfall per year and that the southern part receives 800-900 mm.

Temperature and potential evaporation are not measured in the village or its immediate surroundings. Data are available for the year 1973 only from the meteorological station at Karatu Mission which is located at an altitude of 1485 m and about 12 km west of Kilima Tembo (Stonehouse and Duff, 1977). These data show that maximum temperatures range from 22 to 28 °C and that minimum temperatures are 11 to 16 °C. The highest temperatures are recorded in the months October to April (mean monthly temperatures of 19.8 to 21.2 oC). The monthly pan's evaporation data range from 90.5 mm in June to 288.9 mm in February. The annual total recorded is 2176.5 mm which seems too high. According to Woodhead (1968), the average annual potential evaporation at this altitude should be about 1890 mm.

The temperatures in the study area are related to altitude. The northern part of the village has slightly lower temperatures than the southern part. According to a empirical equation developed by the East African Meteorological Department, average annual temperatures are 19 °C in the northern part of the village and 21 °C in the southern part.

2.4 Vegetation and present land use

Natural vegetation, mostly secondary bush, is only encountered in areas which are too steep or too stony to be used as cropland. The grazing of livestock and the collection of timber/firewood are the main activities practised in those areas. Where the vegetation cover, due to above mentioned activities, has disappeared the lands are very vulnerable to soil erosion.

All non-stony areas with slopes less than 10 or 13% are used for mechanized cultivation. Tractors are commonly used in the village, together with other agricultural implements like disc-ploughs, harrows, combine-harvesters etc. Animal draught power is the other alternative used for cultivating the soils. Chemical fertilizers are used to a limited extent only. The application of farm yard manure is common practice every second or third year.

Wheat is the dominant crop in the northern part of the village, especially

Table 1 : Mean monthly and annual rainfall data recorded over 20 years at Mbulumbulu Station, Kambi ya Simba Village at an altitude of 1550 m

Month	S	O	N	D	J	F	M	A	M	J	J	A
Rainfall (mm)	5	28	89	117	71	81	124	262	127	10	5	3

Source: Stonehouse and Duff, 1977

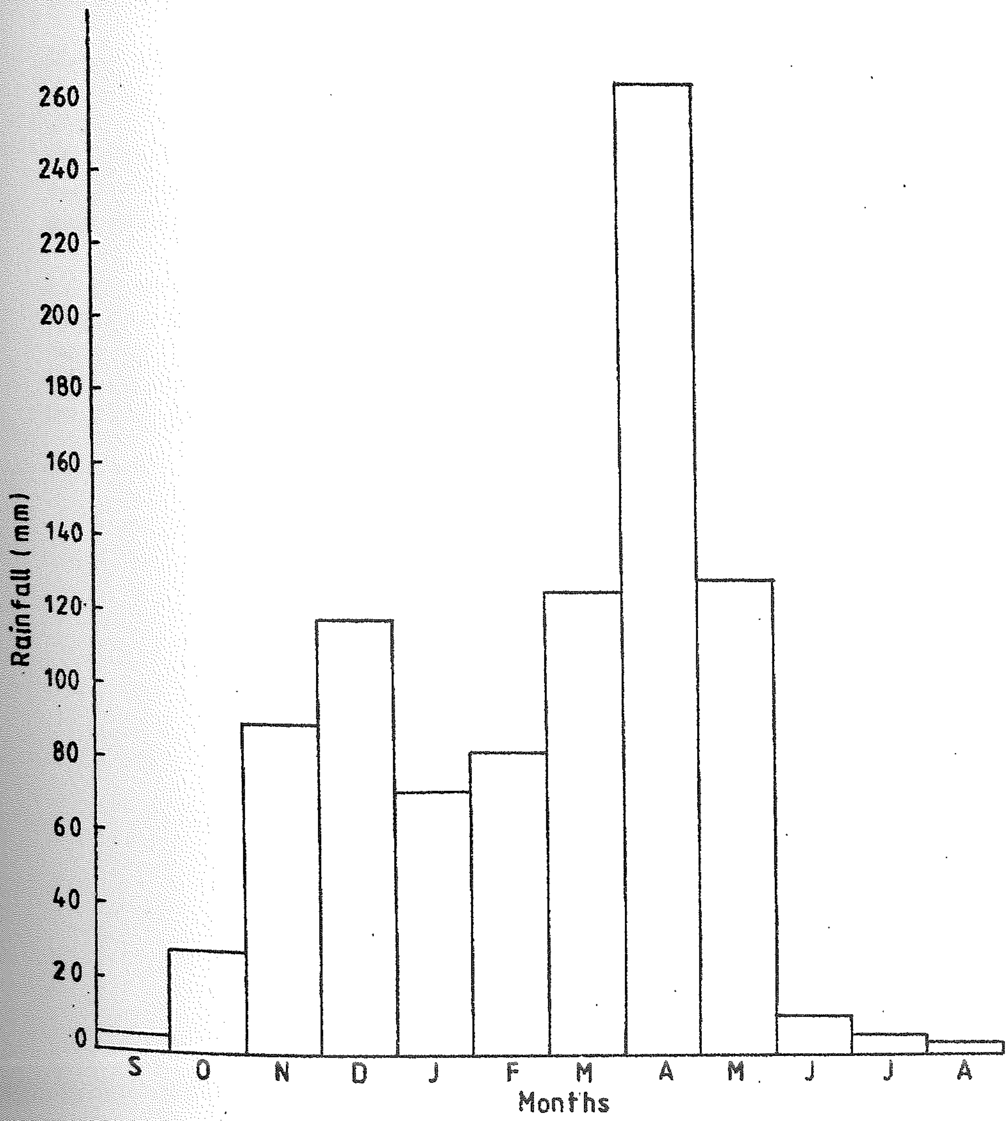


Fig. 3 : Rainfall distribution at Mbulumbulu Station, Kambi ya Simba Village (1550 m)

Source : Stonehouse and Duff, 1977

close to the Ngorongoro Forest Reserve as wheat is less vulnerable to damage by wild animals protruding from these forests, than maize. The average harvests of wheat in the village are in the range of 10 to 15 bags/acre (i.e. 2.2-3.3 tonnes/ha) (pers. comm.).

Beans as a monocrop are grown preceding wheat if good rains start in November. After the harvest the land is ploughed and wheat is sown in April. Farmers complain heavily about the infestation of beans by diseases and pests (black bean fly a.o.).

Maize, which is the dominant crop in the rest of the village area, is mostly intercropped with pigeon peas or beans. The latter is an attractive cash crop that also produces some firewood. Yields of maize grain are roughly in the range of 15 to 25 bags/acre (i.e. 3.3-5.5 t/ha), while 7-10 bags of pigeon peas or beans (i.e. 1.5-2.2 t/ha) can be harvested from the same hectare (pers.comm.).

Trees are only planted around some houses and on some isolated spots at steep slopes. The main tree-species planted are <u>Eucalyptus spp</u>. and the popular <u>Grevillea spp.</u>.

Sheet and rill erosion are observed on most sloping, cultivated lands. Gully erosion is clearly visible on some of the overgrazed hill slopes. Except for some planting of sisal and trees along and in gullies and the construction of some contour ridges, no other measures to control soil erosion are conducted. Most contour ridges do not have a vegetative cover and they are generally ploughed and even used for cultivation.

It is observed that in many places tillage is still carried out along the slopes, whereas, from the viewpoint of erosion control, tillage along the contour is to be preferred. It is also noted that many cultivated fields are grazed by livestock, immediately after harvest. This has a negative effect on soil physical properties and also enhances soil erosion.

3. SOILS

3.1 Study approach

Before starting the actual fieldwork, a physiographic interpretation was made of the aerial photographs of the area, scale 1:20.000, 1988, Photomap Nairobi (frames 6481-6487 of run 4, frames 6460-6465 of run 5 and frames 6496-6498 of run 6). Additionally, the 1:50.000 topographic mapsheets (53/3 and 53/4), and the geological map (quarter degree sheet no. 53, Ngorongoro, scale 1:125.000) were consulted. Furthermore, the report and soilmap (scale 1:50.000) of the Karatu - Oldeani area (Stonehouse and Duff, CIDA, 1977) appeared to be a useful source of information.

In the field auger observations were made at carefully selected sites, to a depth of at least 1.2 m, where soil depth permitted this. These sites were selected according to the preliminary physiographic interpretation map. Many other visual observations helped to distinguish the different soil types present in the area. In 6 pits (standard depth 1.6 m) the soils of the most important mapping units recognized were described in detail. The soils were described according to the guidelines for soil profile descriptions of the FAO (FAO, 1977). Soil classification was done conform the revised legend of the FAO/Unesco Soil Map of the World (Provisional edition of the final text, 1988) and USDA Soil Taxonomy (Soil Survey Staff, 1975). Soil colours (moist) were described according to the Munsell soil colour charts.

Soil samples for physical and chemical analyses were collected from all soil horizons identified in the 6 pits. In order to assess the soil fertility status of the soils, composite samples were collected at 9 representative sites in the most important mapping units.. Each composite sample is composed of about 12 subsamples, from randomly chosen spots within the mapping unit or around a described profile. Composite samples were taken from the top 20 cm and from a depth of 25-50 cm. All soil samples were analysed at the National Soil Service Soils Laboratory in Mlingano, according to internationally accepted methods. These methods are presented in annex 2.

After re-interpretation of the aerial photographs and after studying all collected data, a soil map was compiled which was transferred onto an uncontrolled photomosaic of the Kilima Tembo village area (approximate scale 1:20.000). Soil profile sites and samples sites were plotted on this map. The village boundaries on the map are those which were indicated to the surveyors by the village authorities.

3.2 Soil map and legend

The soil map is presented at an approximate scale of 1:20.000. A brief, tabular description of each mapping unit is given in the legend of this map. The complete description is given in section 3.4. The last columns in the legend give the suitability for mechanized cultivation, extensive grazing and afforestation.

In the field it appeared that the different soil types present are very well related to their specific physiographic position in the landscape. Consequently **landform** was put at the highest level in the legend.

Seven landform units have been identified in Kilima Tembo village (fig. 4):

- **RU** - Crest of upper volcanic footridge
- **RL** - Crest of lower volcanic footridge
- **H** - Volcanic hill
- **M** - Mbuga
- **V** - Side of major valley
- **A** - Valley bottom
- **E** - Escarpment

If more than one soil type is mapped out within such a physiographic unit, numbers are used to distinguish them (for example: mapping units RU1 and RU2 indicate two different soil types within landform RU). Fourteen mapping units have been distinguished in this way. Figure 5 gives a schematic cross-section from the north to the south. In this figure, the relation between the mapping units and the landscape is clearly shown.

The described soils are the dominant soils within the mapping units. Locally, inclusions of other soil types may be present.

3.3 General soil conditions

Most of the soils in Kilima Tembo village have been developed in situ on undifferentiated volcanic rocks. The soils in the valley bottoms and mbuga are developed in alluvial/colluvial deposits of volcanic origin. The majority of the soils in the area is quite homogeneous in terms of morphological, physical and chemical aspects.

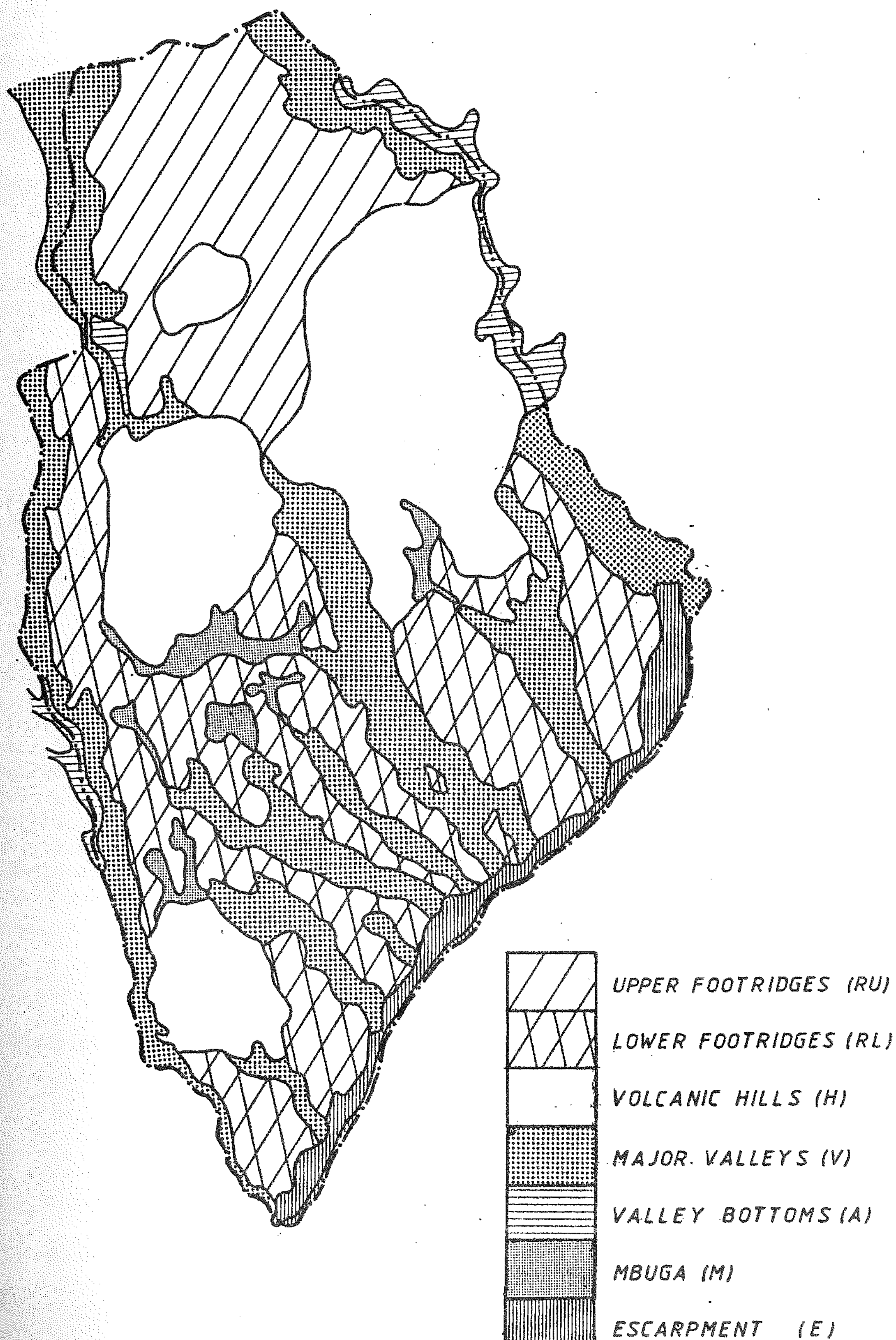
The dominant soils in the study area are fertile, very deep, well drained, dark reddish brown to dark red clays; they belong to the most fertile soils in Mbulu District (see section 3.5).

The structure of the surface layer is well developed, consisting of granular and subangular blocky elements. The soil aggregates though are very fragile: when dry they are easily pulverized by slaking or mechanized action; when wet they disintegrate immediately. Therefore the soils are extremely erodible.

In soils mechanically cultivated for several years a ploughpan is present just below the actual plough layer. This ploughpan is about 10-15 cm thick and has a more strongly developed structure with coarser structural elements than the undisturbed soil. Besides this adverse structure, the soil material is also harder and more compacted than that of the plough layer and thus less permeable for water and roots (see also section 3.6).

The variation in thickness of the topsoils, soil depth and the occurrence of surface stones led to the differentiation of the mapping units. The differences are closely related to the physiography (i.e. landform and slope).

Fig. 4 : LANDFORMS IN KILIMA TEMBO VILLAGE
Scale 1 : 40,000



The thickness of the topsoils is more or less determined by the slope gradient. Where the slopes are less than 4% on relatively broad crests in the northern part of the village, topsoils are very thick (50-80 cm). Where the slopes are over 10%, topsoils are thin (<20 cm). On undulating lands with relatively narrow crests (slopes 2-10%), the thickness of the topsoils varies from 10 to 50 cm; the thickness decreases clearly with increasing slope gradient.

Soil depth is less than 80 cm at the escarpment, on the sides of the major valleys and at the upper and middle slopes of the volcanic hills.

Surface stones are present in the mapping units with relatively shallow soils and on the undulating crests of the lower footridges, close to the Kilima cha Tembo escarpment.

Next to the above mentioned dominant soil type and its variations, two other soil types have been distinguished: fertile, very deep, moderately well to well drained, stratified, dark reddish brown clays in valley bottoms, and, fertile, very deep, imperfectly to moderately well drained, cracking, (very) dark (greyish) brown clays with adverse physical characteristics in mbuga.

3.4 Description of the mapping units

In this section detailed information is given of each mapping unit on setting, general soil characteristics, topsoil and subsoil properties and soil fertility aspects. In other words, this chapter contains all soils data which are necessary to determine the suitability of the lands of Kilima Tembo village.

The legend of the soil and suitability map in the back cover of this report gives a summary of the data mentioned in this chapter.

The following information was used to compile the descriptions of the mapping units:
- augerhole descriptions;
- profile descriptions (see annex 3);
- analytical data of the profiles (see annex 3);
- analytical data of the composite samples (see annex 4);
- NSS classification of analytical data
- soil depth classes:

very shallow	:	< 20 cm
shallow	:	20 - 40 cm
moderately deep	:	40 - 80 cm
deep	:	80 -120 cm
very deep	:	>120 cm.

The descriptions of the mapping units are grouped per landform unit.

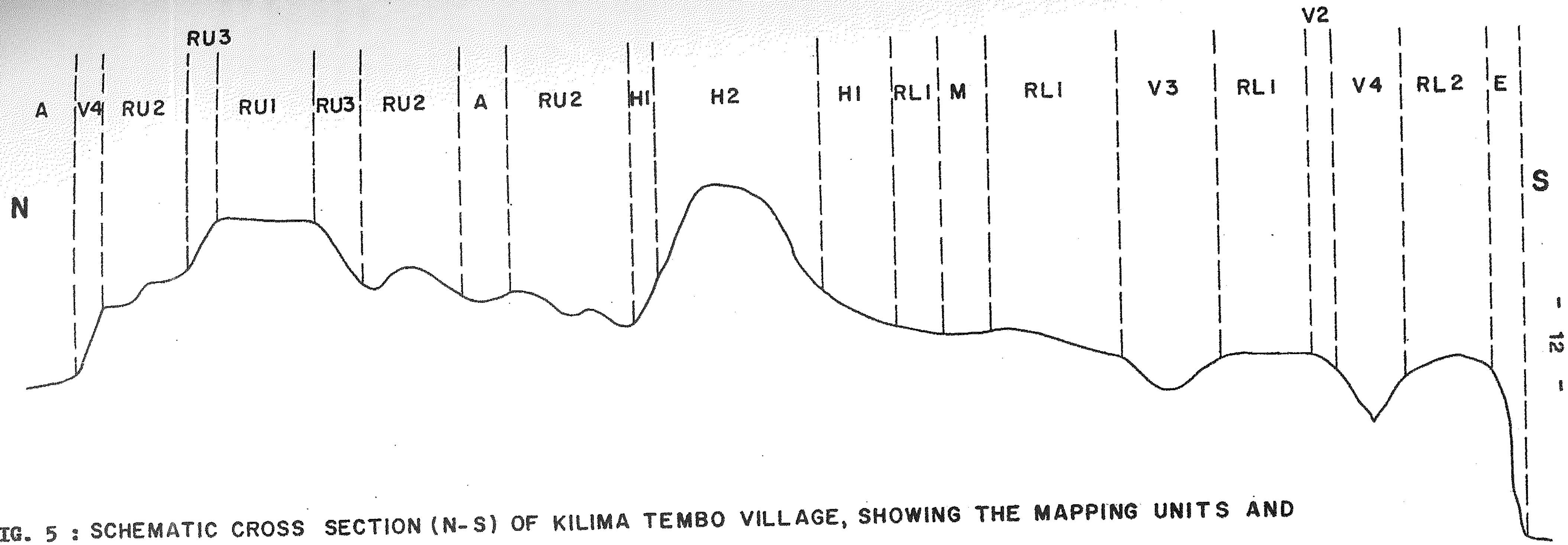


FIG. 5 : SCHEMATIC CROSS SECTION (N-S) OF KILIMA TEMBO VILLAGE, SHOWING THE MAPPING UNITS AND THEIR RELATION WITH THE LANDSCAPE.

UPPER FOOTRIDGES

Mapping unit RU1 (25 ha)

Setting: Unit RU1 is present only in the village shamba, immediately adjacent to the Ngorongoro Forest Reserve, on the highest part of the northern footridge, at an altitude of about 1720 m. This unit occupies the relatively broad, convex upper part of the upper footridge where slopes are not exceeding 4%.
Wheat has been grown for several decades upto present. In years in which the rains are early and sufficient, beans are grown preceding the wheat crop.

General soil characteristics: The soils of unit RU1 are very deep, well drained and clayey having very thick, black to (very) dark brown topsoils over dark reddish brown subsoils. They are very porous and free of stones. Soil erosion is not very significant. The soils of this unit are typified by profile KT/P3.

Topsoil properties: The topsoils are very thick, i.e. at least 50 cm. The texture is silty clay to clay and the colours are black to (very) dark brown. The structure is moderately to strongly developed. In the top layer the structure elements are medium and coarse subangular blocky and granular. At a depth of 10/15 cm a relatively compact, slightly developed, relatively compact ploughpan consists of very coarse subangular blocky elements. This ploughpan is about 15 to 20 cm thick. Deeper down the very coarse structure elements fall apart into medium and coarse blocks. The soil material is slightly hard or hard when dry, very friable or friable when moist and slightly sticky or sticky when wet.
The pH values range from 6.5 to 6.9, the organic matter content from 4.6 to 7.9% and the available phosphorus content from 35 to 38 mg/kg. The CEC values vary from 42.7 to 51.1 meq/100 g soil.

Subsoil properties: The subsoil has a clayey texture and dark reddish brown colours. the structure is weakly developed and consists of medium and coarse subangular blocky elements. The soil material is friable to firm when moist and sticky to slightly sticky and plastic when wet.
The chemical data show a pH of 6.8, a gradually decreasing organic matter content with depth (still 3.8% at 60-90 cm depth), and a rapidly decreasing CEC with depth: 26.1-28.0 meq/100 g soil at depths over 100 cm.

Soil fertility aspects: The organic matter contents of the topsoils are high and locally even very high. The quality is moderate; C/N ratios range from 18 to 21. The soil reaction of the entire profile is neutral. The level of available phosphorus is high. The capacity of the soil to retain nutrients (CEC) is very high in the topsoils and high in the subsoils. The levels of the exchangeable bases calcium and magnesium are high in the topsoils and medium only at depths over 100 cm, whereas the potassium levels are very high throughout the profile. It is found that from a depth of 30 cm onwards exchangeable potassium contents can be higher than those of exchangeable magnesium. This implies an imbalanced magnesium/potassium ratio which is unfavourable for the magnesium uptake of the crops.

Mapping unit RU2 (325 ha)

Setting: Unit RU2 covers most of the upper footridge, north of the two central volcanic hills in Kilima Tembo village. Maximum slopes are about 10%. Relatively narrow, almost flat, convex crests are also included. Altitudes range approximately from 1570 to 1720 m.
Maize is the main crop cultivated on the soils of this unit and is mostly intercropped with pigeon peas and/or beans. Wheat is of a minor importance.

General soil characteristics: The soil is very deep, well drained, and clayey with a thin to locally thick, (very) dark brown topsoil over a dark reddish brown to even red subsoil. The soils are very porous and free of stones. Soil erosion is observed (both sheet and rill erosion) and is the main cause of the relatively thin topsoils of this unit when compared with the soils of unit RU1. The soils of this unit are typified by profiles KT/P1 and KT/P2.

Topsoil properties: The thickness of the topsoils varies from 10 to 40 cm. The thickness is closely related to the slope gradient: the thickest topsoils are present on the most gentle slopes. The topsoils are (very) dark brown in colour and have a clayey texture. The structure of the actual ploughlayer (10 to 15 cm deep) is weak and consists of medium, subangular blocky and granular elements. The soil material of this surface layer is slightly hard when dry, very friable when moist and (slightly) sticky, (slightly) plastic when wet. Immediately below this layer a relatively compact ploughpan may have developed with a strongly to moderately developed, very coarse subangular blocky structure. The soil material of this ploughpan is hard when dry and very friable when moist.
The pH values are 6.3 to 6.5. The organic matter contents range from 5.0 to 7.1%. The available phosphorus content is 27-34 mg/kg and the CEC values vary from 26.3 to 40.4 meq/100 g soil.

Subsoil properties: The subsoil has a clayey texture and dark reddish brown to dark red colours. Up to a depth of about 70 to 100 cm the structure is moderately to even strongly developed with very coarse subangular blocky elements. The consistency is hard when dry, friable when moist and (slightly) sticky, slightly plastic when wet. Deeper down in the profile the structure is only weakly developed and consists of coarse angular blocky elements. The soil material is very friable when moist and slightly sticky and slightly plastic when wet.
The pH increases slightly with depth: values range from 6.6 to 6.9. The organic matter content decreases gradually with depth and is 2.9% at a depth of 55-85 cm. The available phosphorus content varies from 13 to 27 mg/kg to a depth of about 80 cm. The CEC values of the better structured subsoils are in the range of 26.6 to 33.6 meq/100 g soil. Deeper down values decrease to values around 21 meq.

Soil fertility aspects: The organic matter contents of the topsoils are dominantly high with C/N ratios of 15 to 22, indicating a reasonably good quality of the organic matter. The soil reaction of the topsoils is slightly acid; the subsoils are invariably neutral. The content of available phosphorus is high in the topsoils but can decrease to a medium level in the upper part of the subsoils. The capacity of the soils to retain nutrients (CEC) is high. Only in the deeper subsoils values can be of a medium level.

The levels of the exchangeable bases calcium and magnesium are high in the topsoils and medium to high in the subsoils. Exchangeable potassium contents are also decreasing with depth but are all of a high or very high level. Mainly in the topsoils, Mg/K ratios can be less than 1 which is not favourable for the magnesium nutrition of the crop.

Mapping unit RU3 **(90 ha)**

Setting: Unit RU3 covers the steepest parts on the crest of the dominantly sloping, upper footridge in the northern part of the village. Slopes are over 10%, locally up to 25%. They are too steep for mechanized cultivation, and are mainly used for grazing or settlements. The altitudes range from 1630 to 1720 m.

General soil characteristics: The soils of this unit are deep to very deep, well to somewhat excessively drained and clayey. Mostly thin, dark reddish brown topsoils overlie the dark reddish brown to dark red subsoil. The soils are porous and generally free of stones; at few places, however, some stones may occur at the surface. Soil erosion is considerable in this unit, especially when the surface is relatively bare due to overgrazing. Both sheet and rill erosion are observed. No further detailed information on soils was collected.

LOWER FOOTRIDGES

Mapping unit RL1 **(515 ha)**

Setting: Unit RL1 covers most of the lower footridges, south of the two hills in the centre of Kilima Tembo village, and is the most extensive one in the village. The area is typically gently undulating to undulating (slopes less than 8%) with a gentle, general dip to the south-east (Kilima cha Tembo Escarpment). The altitude ranges from approximately 1590 m, close to the central hills, to 1440 m near the Kilima cha Tembo escarpment. Maize is the main cultivated crop on the soils of this unit and is mostly intercropped with pigeon peas and/or beans. Wheat is grown to a limited extent.

General soil characteristics: The soils of unit RL1 are deep to very deep, well drained, and clayey with a moderately thick to thick, (very) dark brown topsoil over a dark reddish brown subsoil. They are very porous and generally free of stones. Soil erosion is observed (mainly sheet erosion) but is not very severe. The soils of this unit are typified by profiles KT/P5 and KT/P6.

Topsoil properties: The topsoils are 20-50 cm thick, (very) dark brown in colour and clayey. The structure of the actual ploughlayer (approx. 5-10 cm deep) is moderately developed and consists of mainly granular and fine subangular blocky elements. A relatively compact ploughpan (10-15 cm thick) has developed immediately below this layer and has a moderately strong structure of coarse and very coarse subangular blocky elements. In places the dark coloured topsoil is thicker than those two layers and shows then a moderately developed structure of coarse or very coarse subangular blocks

below the ploughpan. The soil material is slightly hard or hard when dry, friable when moist and sticky and plastic when wet.
The chemical data of the first 15 to 25 cm show a pH of 6.4-6.6, organic matter contents ranging from 4.5 to 6.4%, available phosphorus values of 26 to 35 mg/kg and CEC values that vary between 32.7 and 42.4 meq/100 g soil.

Subsoil properties: The subsoil has a clayey texture and dark reddish brown colours. The development of the structure is moderately strong or moderate but decreases with depth. The structure elements are dominantly coarse subangular blocky, some are angular blocky. The soil material is hard when dry, friable when moist and slightly sticky and plastic when wet.
The pH at depths over 50 cm is 6.6 to 7.1. The organic matter levels are less than 3.4%, the available phosphorus values vary from 16 to 19 mg/kg to a depth of 60 cm and the CEC varies from 27.3 to 37.1 meq/100 g soil.

Soil fertility aspects: The level of the organic matter is predominantly high in the first 15 to 25 cm, with C/N ratios of 14 to 19, indicating a moderate quality of the organic matter. The soil reaction of the topsoils is slightly acid to neutral. In the subsoils the reaction is invariably neutral. The contents of available phosphorus are high in the topsoils but decrease to a medium level at a depth of about 60 cm. The capacity of the soils to retain nutrients (CEC) decreases with depth but is predominantly of a high level throughout the profile. The values of the exchangeable bases calcium, magnesium and potassium decrease slightly with depth: levels are high or very high in the topsoils and high in the subsoils.

Mapping unit RL2 **(70 ha)**

Setting: Unit RL2 covers the gently undulating to undulating crests at the lower ends of the gently sloping, lower volcanic footridges, along the Kilima cha Tembo Escarpment. The slopes are in the range of 2 to 8%. The altitude ranges from 1420 m close to the mainroad Mto wa Mbu - Karatu, to 1520 m near the boundary with Kambi ya Simba. Due to the very stony surface of this unit, the area is not cultivated. Grazing is the main present land use.

General soil characteristics: The soils are comparable to those of unit RL1. The only differences are the stoniness and soil depth. The soils of unit RL2 have a very stony surface, which makes all use of machinery impracticable. In places the soils can be shallow or moderately deep, for instance close to rock outcrops. No detailed information on the soils of this unit has been collected.

VOLCANIC HILLS

Mapping unit H1 **(185 ha)**

Setting: Unit H1 covers most of the lower slopes of the four volcanic hills (cones) in the village area. The unit is typically cultivated. The slope gradients vary between 6 and 13%. The altitudes range between 1650 m, in the north and 1550 m in the south.
Wheat is the main crop on the hill slopes in the north while maize,

intercropped with pigeon peas, is predominantly cultivated on the hill slopes in the southern part of the village.

General soil characteristics: The soils are deep to very deep, well drained, dark reddish brown to dark red and clayey. In places they may have a very thin, black topsoil. They are generally free of stones and porous throughout. Sheet erosion was observed at various locations. The soils of this unit are typified by profile KT/P4.

Topsoil properties: Clear, dark topsoils are mostly not present; the topsoils are dark reddish brown in colour and approximately 15 to 25 cm thick. The texture is invariably clayey. The structure is moderately developed and consists normally of coarse and medium subangular blocky elements. In few places a very thin (less than 10 cm thick), soft, black toplayer is observed. Its structure is moderately developed with fine subangular blocky and granular elements. The soil material is slightly hard when dry, very friable when moist and slightly sticky and plastic when wet. The first 20 to 25 cm have a pH of 6.5 to 6.7, organic matter contents of 4.3 to 6.0% and available phosphorus levels varying between 19 and 31 mg/kg. The CEC values are 27.1 to 39.2 meq/100 g soil.

Subsoil properties: The subsoils are dark reddish brown to dark red in colour and have clayey textures. The structure is moderately strong in the upper subsoil and moderate at depths over approximately 60 to 70 cm. The horizons with the moderately strong structure show coarse and medium subangular blocky elements, while the other horizons have coarse subangular and angular blocky structure elements. The soil material is hard when dry, friable when moist and sticky and plastic when wet.
The pH increases gradually with depth to 7.1. The organic matter contents are below 3.4% and the available phosphorus values are less than 20 mg/kg at depths below 45 cm. The CEC decreases slightly with depth to values of 24.4 to 32.0 meq/100 g soil.

Soil fertility aspects: The organic matter content of the topsoils is of a high level with C/N ratios of 16 or 17, indicating a moderate quality of the organic matter. The soil reaction is slightly acid or neutral in the topsoils but deeper down invariably neutral. The available phosphorus levels are dominantly high in the topsoils and medium in the subsoils. Although the capacity of the soils to retain nutrients (CEC) decreases with depth, the levels are high throughout the profile. The levels of exchangeable calcium are high upto depths of around 50 cm. Below this depth the levels can also be medium. Exchangeable magnesium levels are high or even very high in topsoils but decrease with depth. Exchangeable potassium levels are very high in the topsoils and decrease mostly with depth to medium and high levels.

Mapping unit H2 **(415 ha)**

Setting: Unit H2 covers the major part of the four volcanic hills (cones) in the village. The slopes are dominantly moderately steep to steep (13-55%). The altitudes of the northern and central hills range from 1600 to 1740 m. The southern hill, next to the Mto wa Mbu - Karatu road, has an altitude of 1525 to 1585 m. The unit is not used for cultivation due to the steep slopes and the presence of surface stones. The area is used for grazing, afforestation and collection of timber and/or firewood.

General soil characteristics: The soils do not greatly differ from those of unit H1. The only differences, next to the different slope gradients, are the stoniness and the soil depth. Stoniness varies greatly within the unit: some places have very few stones, others are exceedingly stony. Soil depth varies from shallow to very deep. Soil erosion is in places very severe. Where the hills are bare, gullies are observed on the middle and lower slopes. Rill and sheet erosion are common. No detailed information on the soils of this unit has been collected.

MBUGA

Mapping unit M (55 ha)

Setting: Unit M occurs in saucer-shaped depressions (heads of valleys) on the gently sloping, lower footridges in the southern part of the village, at altitudes of around 1550 m. The slopes are usually less than 2%. The unit is not in use for cultivation due to unfavourable drainage conditions and difficult workability. They are used for grazing and trespassing of cattle.

General soil characteristics: The soils are very deep, imperfectly to moderately well drained, cracking heavy clays. The thin to moderately thick, very dark brown topsoils overlie very dark greyish brown to dark brown subsoils. The soils are relatively compact and form cracks in the dry season. In the rainy season the flattest, lowest parts can be flooded for some days or even weeks. The sloping parts are very vulnerable to gully erosion, especially if the vegetation cover is minimal. The soils are free of stones. Concretions of calcium carbonate are locally present at the surface and in the profile. The soils are known to be chemically rich but have adverse physical characteristics. No further detailed information on these soils was collected.

SIDES OF MAJOR VALLEYS

Mapping unit V1 (35 ha)

Setting: Unit V1 can be present on the transition from the gently undulating to undulating crests of the lower footridges to the steep to very steep, straight sides of the major valleys. These upper slopes are convex and are dominantly in the range of 6-13%. The altitudes range from 1480 to 1570 m. Mainly due to stoniness, the area is not used for cropland but for grazing.

General soil characteristics: The soils are shallow to deep, well drained and clayey. The surface of these soils is stony which makes tillage impracticable. Soil erosion is evident, especially near the steep valley sides. No detailed information on these soils has been collected.

Mapping unit V2 (75 ha)

Setting: Unit V2 occupies the moderately steep sides of the major valley, that forms the western village boundary in the northern part of the village. The slopes are dominantly in the range of 13 to 25%. They tend to become less towards the valley bottoms (concave). The altitude is ranging from 1620 to 1680 m. The area is dominantly used for grazing. The lower concave slopes are used for cultivation.
Wheat, beans, maize and pigeon peas are grown.

General soil characteristics: The soils are moderately deep to very deep, well to somewhat excessively drained and clayey. The topsoils are thin or even absent. Dominant colours are dark reddish brown or dark red. In places few stones cover the surface. Where vegetation cover is absent soil erosion is severe. No detailed information on these soils has been collected.

Mapping unit V3 (100 ha)

Setting: Unit V3 is present at the incised heads of the steeply incised major valleys that divide the gently sloping, lower footridges in the southern part of the village. Almost flat mbuga, situated more upstream, drain into these moderately incised valleys which form unit V3. The dominant slope gradients are in the range of 13 to 25%. The unit occurs at altitudes of 1430 to 1570 m. Due to both stoniness and the steepness of the slopes the area is not used for cultivation. The dominant land use is grazing.

General soil characteristics: The soils are shallow to deep, well to somewhat excessively drained and clayey. Dominant colours are dark brown and dark reddish brown. The surface is in most places stony or even very stony, to make nearly all use of machinery impracticable. Where the vegetation cover is minimal or absent soil erosion is severe. No detailed information on these soils has been collected.

Mapping unit V4 (400 ha)

Setting: The unit covers the steep to very steep, straight sides of the major valleys which divide the several footridges. Slopes are dominantly over 25% (up to over 55%). The altitude ranges from 1600 m in the north to 1400 m near the Kilima Tembo Escarpment. The area is too steep and too stony/rocky to be used for either cropland or grazing. Collection of timber/firewood is locally practised.

General soil characteristics: The soils are shallow or moderately deep, (somewhat) excessively drained and clayey. Rock outcrops are abundant and the surfaces of the soils are exceedingly stony. Where the vegetation cover is minimal or absent, soil erosion is very severe. No detailed information on the soils of this unit has been collected.

VALLEY BOTTOMS

Mapping unit A (45 ha)

Setting: Unit A covers the relatively wide, alluvial flats and the concave, lower slopes along the major streams. Slopes are generally less than 4%. They are generally found at altitudes of around 1500-1550 m. Wheat, maize, pigeon peas and beans are the dominant crops grown.

General soil characteristics: The soils are very deep, moderately well to well drained, stratified and clayey. The topsoils are mostly very thick and (very) dark brown in colour; they overlie dark reddish brown subsoils. The soils are developed in alluvial and/or colluvial sediments of volcanic origin. After heavy downpours, the area is sometimes subject to flooding for some days. The soils are porous and free of stones. Deposition of soil material is a common process.
The data from the composite samples show in the first 50 cm a pH of 6.4 to 6.5 (slightly acid), very high organic matter contents of 6.4 to 6.7% with C/N ratios of 19 or 20, indicating a moderate quality of the organic matter. The available phosphorus content is high (31 mg/kg) and the CEC is high or very high (35.4-42.5 meq/100 g soil). The exchangeable calcium and magnesium show high levels whereas exchangeable potassium levels are very high.

ESCARPMENT

Mapping unit E (80 ha)

Setting: The unit comprises the very steep, natural south-eastern boundary of the village, the Kilima Tembo Escarpment, approximately 80 m high. Slopes are in general over 55%. Near the boundary with Kambi ya Simba, the upper altitude of the escarpment is approximately 1550 m; close to the mainroad Mto wa Mbu - Karatu this is 1420 m. The area is too steep and too stony/rocky to be used for either cropland or grazing. Collection of timber/firewood is locally practised.

General soil characteristics: Rock outcrops and stones dominate the area, leaving few patches with some soil. The area is classified as rubble land, which means that over 90% of the surface is paved with stones or boulders.

3.5 Soil fertility status

The soils of Kilima Tembo village are all well supplied with the basic plant nutrients. Especially if soils are non-eroded, nutrient levels are very high. This high fertility status is largely attributed to the relatively low rainfall and the volcanic character of the relatively young parent rock in which the soils have developed.

Organic matter contents are high in all topsoils. The topsoils of units RU1 and A have even very high values. Apart from supplying nutrients, the organic matter can contribute to the water retention capacity of the soils. High organic matter contents favour biological activity and therefore the porosity and infiltration rate of the soil.

Organic matter contents in the topsoils (0-20 cm) decrease with altitude. The highest values are found in the north whereas the topsoils in the southern part of the village have slightly lower values. Most likely, this trend can be explained by the differences in climate within the village: relatively more organic matter is produced and less is decomposed in the cooler and moister, northern part of the village.

The high organic matter contents favour the **nitrogen** supply. Reasonable amounts of nitrogen are expected to mineralize as the quality of the organic matter is not too bad.

Available phosphorus levels are high in nearly all soils. Some upper subsoils, mostly from a depth of 40 cm onwards, however, show values of a medium level.

The soil reaction (**pH**) of the topsoils is slightly acid to neutral. All subsoils are invariably neutral. This reaction is favourable for all crops cultivated in the village.

The capacity of the soils to retain nutrients (**CEC**) is high to very high in most soils. With depth, however, the CEC levels decrease to even medium levels.

Also the levels of the **exchangeable bases** calcium, magnesium and potassium are dominantly high or very high. Imbalances, however, between these exchangeable bases exist in the soils on the northern upper footridge. Here magnesium/potassium ratios are less than 1, which may result in a poor magnesium supply to the crops (the very high amounts of potassium reduce the availability of magnesium). Crops may suffer from magnesium deficiency.

Although all soils have a high soil fertility status, differences in contents exist which are mainly caused by soil erosion. For instance, if the soil analytical data of the top 20 cm of units RU1 and RU2, with identical climatic conditions but with different slopes (less than 4% and 2-10%, respectively), are compared, it is seen that the values of organic matter, available phosphorus, pH and CEC are all lower in the topsoils of the eroded soils of unit RU2. A similar trend is also observed in the neighbouring Kambi ya Simba village

3.6 Soil erosion and soil degradation

Although soil erosion is not as serious as in other parts of Mbulu District (f.e. Bashay) it is still evident and a matter of serious concern.

Sheet erosion is common throughout the whole village area, especially on sloping cropland with maize as the major crop. If slopes are approaching a gradient of 10% and no erosion control measures are conducted, even **rills** are seen.

Land under maize is more vulnerable to erosion than land under wheat as the latter protects the soil surface earlier and better by its denser stand. Only if slopes are less than 4%, sheet erosion is not significant and topsoils are thick to very thick.

The slope gradient is not the only reason for the occurrence of sheet and rill erosion. Soil erosion is certainly enhanced by the presence of a ploughpan in most of the arable soils in Kilima Tembo village. This ploughpan is a somewhat compacted horizon, 10-15 cm thick, immediately below the plough layer (5-15 cm deep) and occurs in fields which have been ploughed for several years with disc-ploughs only. Due to the relatively high silt content and the clay mineralogy of the volcanic soils, soils become very smeary just below the disc, giving rise to the development of a relatively dense, layer with very coarse subangular blocky structure elements. Ploughpans are relatively less permeable for rainwater and difficult to penetrate by roots. This gives rise to a less efficient water utilization and nutrient uptake and to an enhanced run-off and hence an increased risk of soil erosion.

Other factors responsible for the observed soil erosion are the absence, bad maintenance or incorrect construction of contour ridges, the practice of ploughing up and down the slopes instead of ploughing along the contours, and the grazing of animals in fields that have just been harvested.

Gullies occur mainly on the sparsely vegetated, middle and lower slopes of some volcanic hills (unit H2). They steadily increase in depth and extend headward after each heavy downpour. Gullies are also present along some roads within the village that run along the slope, instead of traversing it. In this way these roads act as drainage ways. Minor gullies are formed in the overgrazed, relatively sloping parts of mbuga (unit M), mostly around spring levels at the fringes.

The steep and very steep, stony and rocky areas (units V4 and E) are relatively well protected against serious soil erosion. This is due to the relatively good natural vegetation cover and the rough surface of the terrain.

Most of the cultivated topsoils show a tendency to seal after rain showers on the bare surface. After tillage operations the soil particles are small in size and a slightly cemented crust with a thickness of a few millimeters, may form at the surface. This crust enhances again the run-off and may also give rise to problems during germination of the seeds. Apparently the soils do not have a very high structure stability.

4. LAND SUITABILITY

In this chapter the physical suitability of all recognized mapping units is assessed for three land utilization types: mechanized cultivation, extensive grazing and afforestation. The limiting factors which affect the suitability are assessed (Table 2). The approach adopted follows the framework for land evaluation (FAO,1976).

Mechanized cultivation is defined as the cultivation of several crops (wheat, maize, beans, pigeon peas) in which the use of tractor or animal draught power is common practice.
Extensive grazing is defined as free grazing of livestock.
Afforestation is defined as planting of trees for several purposes, i.e. for firewood, building materials, fodder and soil erosion control.

The suitability of certain lands or mapping units is determined by comparing the characteristics , described in section 3.4, with the requirements of each of the assessed land utilization types.

Mechanized cultivation is only possible on well-drained, non-stony soils with slopes less than 10%. Extensive grazing is well possible on lands with slopes not exceeding 25%, with soils that are not too stony. Afforestation can be practised on lands which have even steeper slopes.

In table 2, suitability classes are given for all distinguished mapping units. The limiting factors of the lands and soils are listed as well. The suitability classes are defined below:

Highly suitable land : Land having no significant limitations; no special management or improvements are required; land able to produce high yields with relatively low inputs.

Suitable land : Land having minor limitations that may require some simple management practices or minor land improvements which can be implemented easily.

Moderately suitable land : Land with limitations which, as a whole, are moderate. The limitations may effect productivity or require major inputs and/or improvements.

Marginally suitable land : Land with limitations which, as a whole, are severe and which seriously reduce productivity or require major corrections or inputs which are only marginally justified.

Not suitable land : Land with limitations which cannot be corrected economically or with existing knowledge and which preclude its successful and/or sustained use.

Table 2 : Land suitability and limiting factors for mechanized cultivation, extensive grazing and afforestation

Mapping unit	Approx. extent (ha)	Actual suitability			Limiting factors
		Mechanized cultivation	Extensive grazing	Afforestation	
RU1	25	Suitable	Highly suitable	Highly suitable	Ploughpan
RU2	325	Suitable	Suitable	Highly suitable	Ploughpan
RU3	90	Marginally to not suitable	Moderately suitable	Suitable	Slope
RL1	515	Suitable	Highly suitable to suitable	Highly suitable	Ploughpan
RL2	70	Marginally suitable	Moderately suitable	Suitable to moderately suitable	Stoniness
H1	185	Suitable to moderately suitable	Suitable	Suitable	Ploughpan
H2	415	Not suitable	Moderately suitable	Not suitable	Slope, stoniness, soil depth
M	55	Not suitable	Moderately suitable	Not suitable	Workability, drainage
V1	35	Marginally suitable	Moderately suitable	Moderately suitable	Stoniness, soil depth
V2	75	Not suitable	Marginally suitable	Suitable to moderately suitable	Slope, stoniness, soil depth
V3	100	Not suitable	Marginally suitable	Moderately suitable	Slope, stoniness, soil depth
V4	400	Not suitable	Not suitable	Not suitable	Slope, stoniness, rockiness, soil depth
A	45	Suitable	Suitable	Suitable	Occasional flooding
E	80	Not suitable	Not suitable	Not suitable	Slope, stoniness, rockiness, soil depth

From Table 2 the following conclusions can be drawn:

Nearly half of the village area (1095 ha or 46%) is suitable for mechanized cultivation. These are the non-stony lands on slopes less than 10%. These lands are also (highly) suitable for extensive grazing and afforestation. The remaining 1320 of the total 2405 ha are marginally or not suitable for mechanized cultivation, due to surface stoniness or rockiness, slopes which are too steep, limited soil depth or difficult workability.

One fifth (480 ha or 20%) of the village area is not suitable at all for any one of the assessed land utilization types. These are the very stony, rocky or rubble lands with slopes over 25%.

Under the assumption that cultivation of crops has a greater priority than extensive grazing or afforestation, it seems logical that all lands suitable for mechanized cultivation will be used for this purpose. This means that one third (34%) of the village area can be used for extensive grazing or afforestation.

For extensive grazing, 325 of the 840 ha are moderately suitable. These are the well-drained lands on slopes less than 25%; 515 ha are marginally or not suitable for extensive grazing.

The lands in the mbuga are the only areas which are not suitable for afforestation. The rest of the 840 ha are suitable or moderately suitable for this purpose, except for the steepest and most stony or rocky areas on the volcanic hills which are marginally suitable.

If planners decide that extensive grazing is a sustainable land use in the village and that it has to be practised to a maximum extent, a possible land use plan could be:

1095 ha for mechanized cultivation	(units RU1, RU2, RL1, H1, A)
325 ha for extensive grazing	(units RU3, RL2, M, V1, V2)
515 ha for afforestation	(units H2, V3)
480 ha should remain under natural vegetation	(units V4, E)

The planners may also decide, however, that afforestation is more important than extensive grazing. In that case the above data show that up to 735 ha can be used for afforestation which means that only 55 ha remain for extensive grazing. This can also be attained if farmers are motivated to shift from extensive grazing to zero-grazing.

Planners have always to bear in mind that both extensive grazing and afforestation can be practised on the same lands: livestock can graze between rows of trees.

5 CONCLUSIONS AND RECOMMENDATIONS

From the previous chapters it is clear that the agricultural potential of the village is quite high: nearly half of the village area is well suited for mechanized cultivation, about 30% is suitable for extensive grazing and/or afforestation, while only 20% is not suitable for either one of these land uses.

In this chapter recommendations are given which can lead to a more sustainable use of the lands of Kilima Tembo. Most of the recommendations are related to the use as cropland.

5.1 Soil tillage practices and soil and water conservation management

It is recommended that all soil tillage should be done across the slope (i.e. along the contours) instead of up and down the slope, as is still seen at several places. It is necessary to do this with immediate effect. Contour tillage alone, however, is mostly insufficient to protect the soil against soil erosion. There are several possibilities for additional measures:

The construction of contour ridges, low earthen banks with often a channel at the upslope side of the bank, is often mentioned as the first and rather simple measure. Contour ridges, however, are only effective in erosion control if they are constructed properly and if they are well maintained. Clear examples of correctly constructed and maintained contour ridges can be seen in some fields in the neighbouring Rhotia village.

Some farmers in Kilima Tembo have constructed contour ridges but it has been observed that the ridges are not as effective as they should be. In spite of the contours, several rills are seen. In most cases this is due to the poor maintenance of the constructed ridges or it is caused by poor construction, especially at the ends. These contour ridges, which are meant to be kept under a permanently vegetation cover, are mostly ploughed as well when preparing the fields and sometimes even sown with maize or wheat. This weakens the strength of the contour ridges considerably and increases the risk that the ridges break when the run-off water accumulates behind the ridge. This can cause severe erosion down the slope and is even more destructive than having no contour ridges at all.

Another practical limitation of the use of contour ridges is the fact that one has to ensure that the water collected in the channel is conveyed to waterways. If the ridges are not properly designed, the water may run into neighbouring fields and cause damage there. The construction of ridges and channels is laborious and requires a considerable tractor input.

It must be clear that a system of properly established contour ridges is not a simple erosion control measure. It requires an optimal coordination and cooperation of all farmers. The ridges are only effective if they are properly constructed, grassed, not cultivated and continuous from one waterway to the other.

Another possibility is the establishment of permanently vegetated contour strips. In this system a permanent grass is planted along the contours, at specific intervals, depending on the slope.
The grass root divisions (slips) can be planted in a single ploughed furrow. This disturbs only little soil and relatively less tractor input is required. With time, the grass tillers up through soil material that is filtered out of the run-off water, forming gradually a natural terrace. The speed of the water is slowed down by the grass hedges, thus reducing erosion and there is no risk of water being concentrated in any area downslope, as is the case if a contour ridge breaks through.

Vegetated contour strips are most probably the safest and most feasible measure to control erosion. An extra advantage is the fact that the farmer now also is obliged to cultivate his lands along the contours. It is not necessary with this system that the vegetative hedges continue on all individual fields. The latter is essential with contour ridges but not with vegetated contour strips.

In most places the establishment of a dense hedge will take 2 or 3 growing seasons. Maintenance has to be done during establishment. Care has to be taken that the vegetative system forms a continuous hedge row in order to be effective; gap filling has to be done wherever and whenever necessary. The hedges have to be accurately planted along the contour.

Some help will be necessary from qualified persons, e.g. the land use planners of the Mbulu Council. They may teach a small group of people in the village on how to measure the contours. It is also necessary to show farmers how to divide and properly treat the clumps of grass, before they can be planted. A nursery will have to be established in the village.

The grass to be grown on contour strips may be either an unpalatable one or a fodder grass. The advantage of having an unpalatable grass is that it will not be damaged by free grazing animals. In case of a fodder crop, care must be taken that no animals enter the fields and destroy the hedges. The fodder must be cut and brought to the animals (zero-grazing). In this case leguminous crops may be included as they can fix nitrogen from the air and thus may add to the soil fertility.

Whatever measure is taken, it will always imply a more complicated way of agriculture than the present one. But, there is no way of avoiding an active role of the population in soil conservation. Soil conservation should become just as much part of farm management as tillage, planting and harvesting.

As discussed in section 3.6, the presence of a ploughpan in most of the cultivated soils in Kilima Tembo, results also in an increased run-off and therefore more erosion. Farmers are advised to stop using disc ploughs only. As explained in section 3.6, soils in the area become very smeary just below the disc. In addition to this it is mentioned that penetration by disc ploughs is limited in heavy soils. Such penetration can be achieved only by heavy weights which can cause compaction of furrow bottoms.

The use of mouldboard ploughs is a better alternative but it will never prevent completely the formation of a ploughpan. Deep ploughing by mouldboard ploughs is achieved by special mechanisms and suitable shares. In general when using a disc plough, the soil is tilled less intensively and with less inversion than with a mouldboard plough.

The use of chisel ploughs is necessary for breaking the ploughpan. This practice has to be repeated every 2 or 3 years. The chisel plough accomplishes deep tillage and can thus serve as an alternative to ploughing. It assists in loosening hard dry soils before ploughing and breaks up the hard layers below the normal ploughing depth.

It is recommended that ploughing be done when the soils are neither too dry nor too wet. This is due to the fact that the greater the soil moisture content, the easier a ploughpan will develop in the described volcanic soils. If the soil is too dry ploughing depth will be very limited. Ploughing should be done not immediately after heavy rains.

Another recommendation which may help to reduce the run-off and therefore soil erosion is the practice of strip-cropping. Strip-cropping is an agricultural practice in which different crops (e.g. wheat and maize) are cultivated in relatively narrow strips (20-40 m broad) along the contours within one field. It is important that these crops are regularly rotated, preferably every growing season.

As a conclusion, it can be said that a package with proper tillage (i.e. along the contours with chisel- and mouldboard-ploughs), proper planting (strip-cropping) and the construction of permanently vegetated contour strips can control most of the sheet and rill erosion which is presently observed on sloping cropland in Kilima Tembo village.

5.2 Soil fertility management

As discussed in section 3.5, the actual soil fertility of all cultivated lands is high. This does not mean, however, that no attention should be paid to soil fertility management. As yields are high, vast amounts of nutrients are removed with each harvest. As the applied amounts of farm yard manure are not enough to satisfy the crop nutrient requirements, use of chemical fertilizers has to be considered. Especially nitrogen-containing fertilizers (e.g. urea, sulphate of ammonia) could be of interest.

Levels of available phosphorus are presently high enough but monitoring of the phosphorus-status by regularly soil-sampling is recommended in order to detect a further decrease in those levels. If levels will drop below about 10 mg/kg, application of phosphatic fertilizer (e.g. triple super phosphate, TSP) is recommended. Application of Minjingu rock phosphate is not recommended as the pH and exchangeable calcium values are too high. The phosphorus will not become available under these circumstances.

On lands at the upper footridge in the northern part of the village, application of magnesium fertilizer (e.g. kieserite) may be necessary in order to prevent potassium-induced magnesium deficiency. Simple trials have to be carried out in order to confirm this recommendation.

Organic matter levels have to be maintained by ploughing in all plant residues as much as possible. Fields should not be allowed to be grazed after harvest. Stubble and other plant residues should be left on the fields and ploughed in when preparing the fields for the next growing season. This does not only contribute to the organic matter content of the soils but also helps to protect the soil against erosion in the period that the soils are bare.

5.3 Land management

All lands rated as suitable for mechanized cultivation can be used for this purpose in a sustainable way if the above mentioned recommendations are carried out.

About one fifth of the village area has to be closed for all assessed land uses in order to allow regeneration of natural vegetation. This refers to steep and very steep rocky and stony sides of the deeply incised major valleys and the escarpments. A good vegetation cover on these sites throughout the year is absolutely necessary to minimize soil erosion. This vegetation cover can only be achieved if grazing and collection of firewood, fodder or building materials are minimized and strictly controlled. The best and most simple way is closing the area for any use. Planting of sisal on the upper slopes of the valley sides and escarpments can help to fence the area. Natural vegetation can then regenerate; bare spots have to be planted where possible with trees or shrubs. The construction of contour ridges, built up with stones collected from the surface, will also help to reduce run-off. In this way, the rate of regrowth of natural vegetation can be increased as eroded soil material will silt up behind the stone ridges (natural terracing effect). Afforestation geared on production of firewood or other products, however, will never be sustainable.

The remaining lands in the village, i.e. the dominantly moderately steep lands which are marginally or not suitable for cultivation, can be used for grazing and/or afforestation. If zero-grazing is going to be widely accepted, more land can be used for afforestation purposes. Extension of the existing village nursery will certainly be necessary. Species which supply fodder, firewood and building materials should be propagated. It must be clear that these tree seedlings need as much attention as any agricultural crop. They should be planted in the beginning of the rainy season, manure has to be applied during planting, weeding has to be carried out during establishment and livestock should be prevented from entering the planted areas. It is advised that a specially nominated team of villagers, guided by a forester, carries out all these tasks.

It has to be tried to control existing and active rills and gullies. Rills should be filled immediately after developing, or at least immediately after each harvest. Gullies should be controlled by check structures such as heaps of stones and small dams and by planting quick growing grasses in the waterways.

Some roads have to be reconstructed in such a way that they do not serve anymore as a drainage way. All roads need frequent and clean drains to lead the water off the road.

5.4 Livestock management

Although the number of cattle, goats and sheep is not extremely high in the village area, if compared with other areas in Mbulu District, the number still has to be rationalized, to accord more closely with the carrying capacity of the area. A reliable indication of the carrying capacity can not be given unless detailed studies on this are carried out. The only information available is from Rorke Bryan who mentions a carrying capacity of approximately 5 ha/livestock unit for the Basodowesh area, based on climatic and soils conditions of that area and on carrying capacity data from comparable areas elsewhere. As soil and climatological conditions are more favourable in Kilima Tembo than in the Basodowesh area, a slightly higher carrying capacity seems quite applicable. This means that in Kilima Tembo village the maximum number of free grazing livestock units is roughly in the range of 75 to 100, which is far under the actual number. Improving the natural grazing areas by intersowing more nutritious (leguminous) species can increase the optimal number of livestock which can graze per hectare.

Apart from herdsize regulations there should be proper grazing rotations. On top of this, there must be a proper separation of the land into land designated for cultivation and land designated for grazing. This study can help to decide which lands should or should not be grazed. Cultivated fields will have to be protected against free grazing animals by fencing them off, especially when cattle tracks are near. Livestock should never be allowed to enter the cultivated fields, even not after harvest.

Zero-grazing with improved cattle, i.e. cultivated fodder crops are cut and taken to dairy cows, may be a good alternative. The poor availability of water and veterinary drugs for these improved breeds, however, is a severely limiting factor to the development of this system. If the supply of both water and drugs can be assured, zero-grazing is certainly recommended. Fodder crops can then be grown on contours, on fenced plots and they can be collected from specially planted (leguminous) trees.

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GLOSSARY

Alluvium: Unconsolidated sediments deposited by water along stream channels and in low parts of bottomlands which are subject to flooding.

Basaltic lava: fine-grained, locally glassy basic, igneous rock which has been extruded by a volcano (i.e. the most common rock present in the north of Mbulu District).

CEC: Cation exchange capacity or the capacity of the soil to retain nutrients and provide them to the plants. This capacity is mainly determined by the clay mineralogy of the soil and by the organic matter content. The CEC is expressed in milli-equivalents per 100 g soil.

Colluvium: Deposit of rock fragments and soil material accumulated at the base of a steep slope originating from higher slopes due to gravitational action and sheet erosion.

Escarpment: very steep slopes separating surfaces of different elevation.

Pumice: hardened volcanic materials which have been blown into the atmosphere by explosive activity. They are generally produced from volcanoes whose lava is of a viscous type. The material contains very many empty cavities.

Scoriae: volcanic rock with many empty cavities (volcanic bombs).

Soil horizon: A layer of soil, usually approximately parallel to the soil surface, with distinct characteristics produced by soil-forming processes.

Subsoil: Soil below the topsoil.

Topsoil: The relatively dark coloured toplayer of a soil that contains the highest amounts of organic matter, available phosphorus and nitrogen. It is generally the layer which is disturbed by tillage operations (i.e. the actual ploughlayer and, when present, the ploughpan.

Tuff: comparable with pumice but generally less porous.

Volcanic ashes: recent non-hardened volcanic materials which have been blown into the atmosphere by explosive activity of volcanoes.

NSS routine soil analytical procedures

The soil samples are air-dried, crushed in a mortar and passed through a 2 mm sieve. Determinations are performed on the fine earth fraction and results are reported on that basis.

The analytical methods are described in detail in report M7 of the National Soil Service (1989) of which a brief summary follows:

- particle size analysis according to the pipette method (**texture**): After destruction of the organic matter and other cementing substances with hydrogen peroxide and hydrochloric acid respectively, the soil is chemically dispersed after addition of sodium hexametaphosphate. Fractions larger than 50 microns (sand) are separated by using USDA standard sieves and fractions smaller than 50 microns are determined using a pipette.

- **pH-H_2O**: Measured potentiometrically in a 1:2.5 soil-water suspension.

- **pH-KCl**: Measured potentiometrically in a 1:2.5 soil-1 M potassium chloride suspension.

- **Electrical conductivity (EC)**: Measured in a 1:2.5 soil-water suspension.

- **Organic carbon**: Determined according to Walkley and Black. Wet-acid digestion with an excess of potassium dichromate. The excess is titrated with ferrous-ammoniumsulphate.

- **Total nitrogen**: Determined according to Kjeldahl. Acid digestion with selenium as a catalyst. The produced ammonium is distilled and determined titrimetrically.

- **Available phosphorus**: Determined according to Bray and Kurz I in soils with a pH-H_2O <7. Extraction with 0.025 M hydrochloric acid and 0.03 M ammonium fluoride. The extracted phosphate is determined spectrophotometrically.

- **Cation exchange capacity (CEC) and exchangeable cations**: For soils with a pH-H_2O <7.5, subsequent percolation with 1 M ammoniumacetate at pH 7.0, ethanol and acidified 1 M potassium chloride. In the first percolate the exchangeable cations calcium and magnesium are determined with an atomic absorption spectro-photometer. Sodium and potassium are determined with a flame-photometer. The CEC is determined in the last percolate by distillation and titration. In soils with an EC >0.5 mS/cm the soil is washed with ethanol prior to percolation.

Profile no. KT/P1 Mapping unit RU2

General information on site and soil:

Location: On top of ridge, west of central volcanic hill. Landform: Gently undulating surface on top of sloping volcanic footridge. Slope of site: 2%. Parent material: Undifferentiated volcanic rocks. Land use: Cropland maize, intercropped with pigeon peas. Erosion: very slight sheet erosion. Elevation: 1640 m

Soil: Very deep, well drained, very dark grayish brown to dark reddish brown clay; with slight ploughpan formation which does not impede rooting severely, roots go through peds.

Date and authors: The profile was described on 29/9/88 by J.P. Magoggo and F. van der Wal.

Soil profile description:

Ap1 0-15 cm	very dark brown (10YR 2/2 moist); clay; weak, medium, subangular blocky and granular structure; porous; slightly hard when dry, very friable when moist, sticky and plastic when wet; many very fine and common medium roots; abrupt and wavy boundary to:
Ap2 15-25 cm	black (10YR 2/1 moist); clay; strong, very coarse, subangular blocky structure; hard when dry, very friable when moist, sticky and plastic when wet; porous; common very fine roots; gradual and smooth boundary to:
BA 25-48 cm	dark brown (7.5YR 3/2 moist); clay; strong, coarse and very coarse, subangular blocky structure; friable when moist, sticky and plastic when wet; broken, moderately thick cutans; clay nodules; porous; few very fine roots; gradual and smooth boundary to:
Bt1 48-69 cm	dark reddish brown (5YR 3/2 moist); clay; moderate, very coarse, subangular blocky structure; friable when moist, slightly sticky and plastic when wet; broken, thin cutans; few clay nodules; porous; few very fine roots; gradual and smooth boundary to:
Bt2 69-102 cm	dark reddish brown (5YR 3/3 moist); clay; weak, coarse, angular blocky structure; friable when moist slightly plastic when wet; patchy, thin cutans; porous; few very fine roots; gradual and smooth boundary to:
BC 102-165 cm+	dark reddish brown (5YR 3/4 moist); clay; friable when moist, slightly sticky and slightly plastic when wet; weak, coarse, angular blocky structure; very patchy, very thin, cutans; porous; very few, very fine roots

Profile number: KT/P1 Mapping unit: RU2

Horizon	COMP	Ap1	Ap2	BA	Bt1	Bt2	BC	BC
Depth (cm)	0-20	0-15	15-25	30-45	55-65	75-65	110-130	140-160
Texture: clay %	56	52	54	62	67	68	66	73
fine silt %	13	26	26	26	12	9	10	7
coarse silt %	12	15	13	8	17	20	20	17
very fine sand %		3	4	2	2	2	2	2
fine sand %		3	2	1	1	1	1	1
medium sand %	20	1	1	1	1	0	1	1
coarse sand %		0	0	0	0	0	0	0
very coarse sand %		0	0	0	0	0	0	0
Textural class	C	C	C	C	C	C	C	C
pH water (1:2.5)	6.4	6.3	6.5	6.6	6.7	6.7	6.9	6.9
pH KCl (1:2.5)	5.1	5.1	5.1	5.1	5.2	5.5	5.9	5.9
EC mS/cm (1:2.5)	0.06	0.09	0.05	0.03	0.03	0.04	0.03	0.03
Organic Carbon %	3.7	4.1	3.8	2.6	1.8	1.3		
Total N %	0.20	0.19	0.19	0.12	0.11	0.10		
C/N	19	22	20	22	16	13		
Available P (Bray I) mg/kg	34	33	32	29	25			
CEC NH_4OAc me/100 g	40.0	38.4	40.4	33.6	32.7	25.0	22.9	21.0
exch. Ca me/100 g	19.2	17.9	18.1	13.2	11.0	8.9	6.9	6.6
exch. Mg me/100 g	4.4	4.8	4.6	3.6	3.3	1.9	2.5	2.6
exch. K me/100 g	2.70	5.02	5.02	3.34	2.24	2.36	2.47	2.36
exch. Na me/100 g	0.26	0.20	0.24	0.15	0.15	0.18	0.19	0.19
Base saturation %	69	73	69	60	51	53	53	56

Soil classification:

FAO-Unesco (1988) : Chromic Luvisol

USDA : Udic Paleustalf

Profile no. KT/P2 Mapping unit RU2

General information on site and soil:

Location: Along road from Rhotia to Kambi ya Simba between village shamba and central hills. Landform: Convex, upper part of undulating surface on sloping footridge. Slope of site: 2%. Parent material: Undifferentiated volcanic rocks. Landuse: Cropland; cultivation of wheat and maize intercropped with pigeon peas. Erosion: Very slight sheet erosion. Elevation: 1620 m.

Soil: Very deep, well drained, dark brown to dark red clay with ploughpan; high biological activity.

Date and authors: The profile was described on 29/9/89 by J.P. Magoggo and F. van der Wal.

Soil profile description:

Ap 1 0-9 cm	dark brown (7.5YR 3/2 moist); clay; weak, medium subangular blocky and granular structure; slightly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; porous; many very fine roots; abrupt and smooth boundary to:
Ap2 9-17 cm	dark reddish brown (5YR 3/2 moist); clay; moderate, very coarse, subangular blocky and granular structure; hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; porous; many very fine roots; clear and smooth boundary to:
Bt1 17-49 cm	dark reddish brown (5YR 3/3 moist); clay; strong, very coarse prisms falling apart in coarse subangular blocks; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; broken, thin cutans; porous; common very fine roots; some 2-3 mm wide cracks; gradual and smooth boundary to:
Bt2 49-94 cm	dark reddish brown (5YR 3/4 moist); clay; moderately strong, very coarse subangular blocky structure; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; patchy to broken, thin cutans; porous; common very fine roots;some 2-3 mm wide cracks; gradual and smooth boundary to:
Bt3 94-128 cm	dark reddish brown (2.5YR 3/4 moist); clay; weak, coarse, angular blocky structure; very friable when moist, slightly sticky and slightly plastic when wet; patchy, very thin cutans; porous; no roots; relatively compacted; gradual and smooth boundary to:
BC 128-180+ cm	dark red (2.5YR 3/6 moist); clay; very friable when moist slightly sticky and slightly plastic when wet; weak, coarse angular blocky structure; very patchy, very thin cutans; no roots; porous, relatively not compacted

Profile number: KT/P2 Mapping unit: RU2

Horizon	COMP	Ap1	Ap2	Bt1	Bt2	Bt3	BC
Depth (cm)	0-20	0-9	9-17	20-45	55-85	100-120	140-170
Texture: clay %	58	42	65	69	71	67	68
fine silt %	15	12	14	10	7	11	6
coarse silt %	6	44	14	18	19	20	24
very fine sand %		1	3	2	2	1	1
fine sand %		1	2	1	1	1	1
medium sand %	21	0	1	0	0	0	0
coarse sand %		0	1	0	0	0	0
very coarse sand %		0	0	0	0	0	0
Textural class	C	C	C	C	C	C	C
pH water (1:2.5)	6.5	6.5	6.5	6.6	6.9	6.9	6.9
pH KCl (1:2.5)	5.1	5.1	5.1	5.2	5.5	5.8	6.0
EC mS/cm (1:2.5)	0.07	0.07	0.08	0.06	0.03	0.02	0.03
Organic Carbon %	3.2	2.9	3.2	2.5	1.7		
Total N %	0.20	0.19	0.19	0.13	0.10		
C/N	16	15	17	19	17		
Available P (Bray I) mg/kg	28	28	27	19	15		
CEC NH_4OAc me/100 g	34.0	37.2	35.1	32.1	30.3	22.2	20.3
exch. Na me/100 g	17.2	18.1	15.0	11.0	8.6	6.7	6.2
exch. Mg me/100 g	4.3	4.2	4.2	2.9	2.5	2.3	2.4
exch. K me/100 g	2.81	4.45	4.40	2.37	1.98	2.33	2.23
exch. Na me/100 g	0.26	9.19	0.20	0.11	0.11	0.14	0.14
Base saturation %	72	73	68	51	44	52	54

Soil classification:

FAO-Unesco (1988) : Haplic Alisol/Chromic Luvisol

USDA : Udic Paleustalf

Profile no. KT/P3 Mapping unit RU1

General information on site and soil:

Location: In village shamba, close to Ngorongoro Forest Reserve.
Landform: Relatively flat and broad surface on sloping footridge.
Slope of site: 2%. Parent material: Undifferentiated volcanic rocks.
Land use: Crop land, cultivation of wheat. Erosion: Not significant.
Elevation: 1720 m.

Soil: Very deep, well drained clay with a thick, black topsoil over a dark reddish brown subsoil. Very high biological activity (viz. many krotovinas, subsoil material in topsoil). A plough-pan exists.

Date and authors: The profile was described on 29/9/88 by J.P. Magoggo and F. van der Wal.

Soil profile description:

Ap1 0-10/15 cm	black (10YR 2/1 moist); clay; moderate, medium and coarse, subangular blocky and granular structure; slightly hard when dry, very friable when moist, slightly sticky and plastic when wet; porous; very many, very fine roots; abrupt and wavy boundary to:
Ap2 10/15-27 cm	black (10YR 2/1-2 moist); clay; moderate, very coarse subangular blocky structure; friable when moist, slightly sticky and plastic when wet; porous; common very fine roots; clear and smooth boundary to:
Ah 27-56 cm	very dark brown (10YR 2/2 moist); clay; weak, very coarse prisms falling apart into a strong, medium and coarse subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; patchy, thin, bio-cutans; porous; many very fine roots; includes material from the deeper subsoil; gradual and smooth boundary to:
BA 56-96 cm	dark brown (7.5YR 3/2 moist); clay; weak, coarse, subangular blocky structure; friable to firm when moist, sticky and plastic when wet; broken, thin, cutans; porous; many very fine roots, clear and smooth boundary to:
Bt 96-150 cm+	dark reddish brown (5YR 3/4 moist) clay; weak, medium and coarse, subangular blocky structure; friable when moist, slightly sticky and plastic when wet; patchy to broken, thin cutans; very few, small, hard, rounded manganese nodules; porous; few, very fine roots

Profile number: KT/P3 Mapping unit: RU1

Horizon	COMP	Ap1	Ap2	Ah	BA	Bt	Bt
Depth (cm)	0-20	0-10	15-27	30-50	60-90	100-120	130-150
Texture: clay %	46	43	53	68	69	66	63
fine silt %	11	26	24	21	12	12	11
coarse silt %	19	17	14	15	18	18	20
very fine sand %		6	4	3	2	2	3
fine sand %		5	3	2	2	2	2
medium sand %	24	2	1	1	0	0	1
coarse sand %		1	1	0	0	0	0
very coarse sand %		0	0	0	0	0	0
Textural class	C	C	C	C	C	C	C
pH water (1:2.5)	6.5	6.6	6.9	6.9	6.8	6.8	6.8
pH KCl (1:2.5)	5.1	5.1	5.6	5.5	5.3	5.5	5.6
EC mS/cm (1:2.5)	0.07	0.10	0.05	0.05	0.03	0.03	0.03
Organic Carbon %	3.8	4.6	3.9	2.7	2.2		
Total N %	0.20	0.19	0.19	0.13	0.10		
C/N	18	18	21	18	18		
Available P (Bray I) mg/kg	35	38	37	36			
CEC NH_4OAc me/100 g	42.2	51.1	48.8	42.7	38.9	28.0	26.1
exch. Ca me/100 g	20.3	26.5	23.2	18.5	13.6	7.6	7.5
exch. Mg me/100 g	4.4	5.8	5.4	4.9	3.9	2.4	2.6
exch. K me/100 g	2.69	5.98	5.78	6.01	6.29	4.13	3.48
exch. Na me/100 g	0.26	0.27	0.24	0.29	0.29	0.21	0.20
Base saturation %	64	75	71	70	62	51	53

Soil classification:

FAO-Unesco (1988) : Luvic Phaeozem

USDA : Pachic Paleustalf

General information on site and soil:

Location: On the northern slope of the volcanic hill along the main road Mto wa Mbu-Karatu. **Landform:** On mid to lower straight slope of volcanic hill. **Parent material:** Undifferentiated volcanic rocks. **Slope of site:** 12%. **Land use:** Crop land, pigeon peas. **Erosion:** Slight sheet erosion. **Elevation:** 1550 m.

Soil: Very deep, well drained clay with a black to very dusky red topsoil over a rather compact dark reddish brown to (dark) red subsoil. No clear designation in horizons from 3rd horizon onwards. A ploughpan exists.

Date and authors: The profile was described on 30/9/88 by A.J.M. Brom and J.M. Shaka.

Soil profile description:

Ap1 0-8 cm	black to very dusky red (2.5YR 2.5/1 moist); clay; moderate, fine, subangular blocky and granular structure; soft when dry, very friable when moist, slightly sticky and plastic when wet; porous; many very fine and common fine roots; clear and smooth boundary to:
Ap2 8-27 cm	very dusky red (2.5YR 2.5/2 moist); clay; moderate, coarse and medium, subangular blocky structure; slightly hard when dry, very friable when moist, sticky and plastic when wet; porous; many very fine and common fine and medium roots; clear and smooth boundary to :
BA 27-44 cm	very dusky red (2.5YR 2.5/2 moist); clay; moderately strong coarse and medium subangular blocky structure; hard when dry, friable when moist, slightly sticky and plastic when wet; patchy, thin, cutans; clay nodules; porous; many very fine roots; clear and smooth boundary to :
Bt1 44-62 cm	dark reddish brown, (2.5YR 2.5/4 moist) clay; moderately strong, coarse and medium subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; patchy to broken, thin cutans; clay nodules; porous; few fine and very fine roots; diffuse and smooth boundary to :
Bt2 62-98 cm	dark reddish brown to dark red (2.5YR 3/5 moist); clay; moderate, coarse, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; patchy, thin, cutans; clay nodules; porous; few very fine and fine roots; diffuse and smooth boundary to :
BC 98-150 cm+	dark red to red (2.5YR 3-4/6 moist); clay; moderate, coarse, subangular and angular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; clay nodules; porous; few fine and very fine roots

Horizon		COMP	Ap1	Ap2	BA	Bt1	Bt2	BC
Depth (cm)		0-20	0-8	10-25	30-40	45-60	65-95	115-135
Texture:	clay %	52	59	53	66	67	72	77
	fine silt %	15	23	24	18	12	9	6
	coarse silt %	7	12	16	12	18	17	15
	very fine sand %		3	3	3	1	1	1
	fine sand %		2	2	1	1	1	1
	medium sand %	26	1	1	0	1	0	0
	coarse sand %		0	1	0	0	0	0
	very coarse sand %		0	0	0	0	0	0
Textural class		C	C	C	C	C	C	C
pH water	(1:2.5)	6.5	6.5	6.7	6.6	6.7	6.8	7.1
pH KCl	(1:2.5)	5.3	5.4	5.3	5.2	5.3	5.5	5.9
EC mS/cm	(1:2.5)	0.10	0.15	0.06	0.05	0.03	0.04	0.03
Organic Carbon %		3.1	3.5	3.2	2.5	2.0	1.6	
Total N %		0.19	0.21	0.20	0.16	0.13	0.11	
C/N		16	17	16	16	15	15	
Available P (Bray I) mg/kg		30	31	28	22	19		
CEC NH_4OAc	me/100 g	36.7	35.3	39.2	36.1	32.0	25.7	24.4
exch. Ca	me/100 g	18.5	18.2	18.1	14.8	11.5	9.7	8.1
exch. Mg	me/100 g	5.5	6.3	6.4	5.5	4.3	5.0	3.6
exch. K	me/100 g	3.06	5.97	4.99	3.07	2.22	2.62	1.30
exch. Na	me/100 g	0.27	0.28	0.27	0.19	0.22	0.26	0.28
Base saturation %		81	87	76	65	57	68	54

Soil classification:

FAO-Unesco (1988) : Chromic Luvisol

USDA : Rhodic Paleustalf

Profile no. KT/P5 Mapping unit RL1

General information on site and soil:

Location: West of the road which goes from the mainroad (Mto wa Mbu-Karatu) to the CCM office. Landform: Upper convex slope on undulating surface of gently sloping footridge. Slope of site: 2%. Parent material: Undifferentiated volcanic rocks. Land use: Cropland, maize intercropped with pigeon peas. Erosion: Not significant Elevation: 1555 m

Soil: Deep, well drained, clay with a black topsoil over a dark yellowish brown, subsoil over weathered volcanic rock. A ploughpan exists.

Date and authors: The profile was described on 30/9/88 by A.J.M. Brom and J.M. Shaka.

Soil profile description:

Ap1 0-5 cm	black (10YR 2/1 moist); clay; moderate, fine, subangular blocky and granular structure; hard when dry, friable when moist, sticky and plastic when wet; porous; many very fine and fine roots; clear and smooth boundary to :
Ap2 10-14 cm	black (10YR 2/1 moist); clay; moderately strong, coarse subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; many very fine and fine, common medium roots; clear and smooth boundary to :
BA 14-32 cm	very dark gray to very dark grayish brown (10YR 3/1-2 moist); clay; moderate, very coarse, subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; very patchy, thin, cutans; porous; common fine and very fine roots; clear and smooth boundary to :
Bt 32-71 cm	dark brown (7.5YR 3/3-10YR 3/3 moist); clay; moderately strong, coarse and very coarse subangular blocky structure; hard when dry friable when moist, sticky and plastic when wet; patchy, thin, cutans; very few, small and medium, hard, round, iron and especially manganese nodules; porous; few very fine roots; clear and smooth boundary to:
BC 71-115 cm	dark yellowish brown, (10YR 3/4 moist) clay; moderate, coarse and very coarse, subangular blocky and angular blocky structure; slightly hard when dry, friable when moist, slightly sticky and plastic when wet; very patchy, thin cutans; compact; few small and medium, hard, round, Fe and Mn nodules; porous few very fine roots; some small cracks; abrupt and smooth boundary to:
CR 115-165 cm+	Weathered volcanic rock, few, very fine roots

Profile number: KT/P5 Mapping unit: RL1

Horizon		COMP	Ap1	Ap2	BA	Bt	BC
Depth (cm)		0-20	0-5	5-14	15-30	40-60	80-105
Texture:	clay %	58	59	57	56	65	61
	fine silt %	9	11	15	13	9	8
	coarse silt %	8	17	14	14	16	15
	very fine sand %		3	3	3	2	3
	fine sand %		3	3	3	3	3
	medium sand %	25	4	4	4	2	4
	coarse sand %		4	3	4	2	4
	very coarse sand %		2	1	3	1	2
Textural class		C	C	C	C	C	C
pH water	(1:2.5)	6.4	6.6	6.5	6.6	6.8	6.8
pH KCl	(1:2.5)	5.2	5.1	5.1	5.0	5.2	5.5
EC mS/cm	(1:2.5)	0.07	0.06	0.06	0.03	0.02	0.03
Organic Carbon %		2.6	2.6	2.7	2.2	1.8	1.1
Total N %		0.14	0.14	0.15	0.14	0.11	0.07
C/N		19	19	18	16	16	16
Available P (Bray I) mg/kg		30	26	27	25	16	
CEC NH_4OAc	me/100 g	32.7	39.8	36.9	39.9	29.8	22.7
exch. Ca	me/100 g	17.9	15.1	16.4	16.9	11.7	10.7
exch. Mg	me/100 g	5.8	5.4	4.4	5.0	3.8	3.9
exch. K	me/100 g	3.05	2.76	2.58	2.12	1.48	1.32
exch. Na	me/100 g	0.29	0.26	0.25	0.23	0.20	0.24
Base saturation %		83	59	64	61	58	71

Soil classification:

FAO-Unesco (1988) : Haplic Luvisol

USDA : Udic Paleustalf

General information on site and soil:

Location: East of road which goes from the mainroad (Mto wa Mbu-Karatu) to the central watering reservoir). **Landform:** Upper convex slope on undulating surface of gently sloping footridge. **Slope of site** 1-3%. **Parent material:** Undifferentiated volcanic rocks. **Land use:** Crop land, maize intercropped with pigeon peas. **Erosion:** Not significant **Elevation:** 1550 m

Soil: Very deep, well drained clay with a dark brown topsoil over a dark reddish brown subsoil.

Date and authors: The profile was described on 30/9/89 by A.J.M. Brom and J. Shaka.

Soil profile description:

Ap1 0-12 cm	very dark gray to dark brown (7.5YR 3/1 moist); clay moderate, fine, subangular blocky and granular structure; slightly hard when dry, very friable when moist, sticky and plastic when wet; porous; clear and smooth boundary to :
Ap2 12-28 cm	dark brown (7.5YR 3/2 moist); clay moderately strong, fine, medium and coarse, subangular blocky and granular structure; slightly hard when dry, friable when moist, sticky and plastic when wet; porous; clear and wavy boundary to:
AB 28-47 cm	dark reddish brown (5YR 3/2 moist); clay; moderate, coarse, subangular blocky structure; hard when dry friable when moist, sticky and plastic when wet; porous; clear and smooth boundary to:
Bt1 47-60 cm	dark reddish brown (5YR 3/2 moist); clay, moderately strong, medium and coarse, subangular blocky structure; hard when dry, friable when moist, slightly sticky and plastic when wet; patchy, thin cutans; clay nodules; porous; clear and smooth boundary to :
Bt2 60-87 cm	dark reddish brown, (5YR 3/3 moist); clay, moderately strong, coarse and very coarse subangular blocky structure; hard when dry, friable when moist, slightly sticky and plastic when wet; patchy, thin, cutans; clay nodules and very few, small, hard, rounded iron and manganese nodules; porous; gradual and smooth boundary to:
Bt3 87-123 cm	dark reddish brown (5YR 3/3-4 moist); clay; moderate, medium and coarse, subangular and angular blocky structure; hard when dry, friable when moist, slightly sticky and plastic when wet; patchy, thin, cutans very few, very few very small, hard, rounded iron nodules; porous; gradual and smooth boundary to:
Bt4 123-165 cm+	yellowish red (5YR 4/6 moist); clay; moderately weak, coarse, subangular and angular blocky structure; friable when moist, slightly sticky and plastic when wet; patchy thin cutans; very few, very small, hard, rounded Fe nodules; porous

Profile number: KT/P6 **Mapping unit:** RL1

Horizon		COMP	Ap1	Ap2	AB	Bt1	Bt2	Bt3	Bt4
Depth (cm)		0-20	0-10	15-25	30-45	47-60	60-87	95-115	135-150
Texture: clay %		52	59	58	61	69	68	68	69
fine silt %		16	20	20	18	15	10	9	8
coarse silt %		7	13	14	13	12	18	19	19
very fine sand %			3	4	3	2	2	2	2
fine sand %			2	2	2	1	1	1	1
medium sand %		25	1	1	1	1	1	1	1
coarse sand %			1	1	1	0	0	0	0
very coarse sand %			1	0	0	0	0	0	0
Textural class		C	C	C	C	C	C	C	C
pH water	(1:2.5)	6.6	6.5	6.5	6.6	6.6	6.7	7.0	7.1
pH KCl	(1:2.5)	5.2	5.3	5.2	5.1	5.0	5.2	5.6	5.7
EC mS/cm	(1:2.5)	0.07	0.14	0.08	0.04	0.03	0.02	0.02	0.03
Oranic Carbon %		2.8	3.2	2.7	2.7	2.0	1.5		
Total N %		0.16	0.20	0.19	0.16	0.13	0.10		
C/N		18	16	14	17	15	15		
Available P (Bray I) mg/kg		30	31	34	29	19			
CEC NH_4OAc	me/100 g	-	34.3	42.4	39.2	37.1	35.4	27.3	29.5
exch. Ca	me/100 g	19.7	18.8	18.8	16.3	13.4	10.9	9.9	10.1
exch. Mg	me/100 g	6.5	6.2	5.9	5.3	4.0	3.8	4.0	4.6
exch. K	me/100 g	3.35	4.91	3.66	2.20	1.41	1.25	1.5	1.64
exch. Na	me/100 g	0.32	0.34	0.31	0.25	0.19	0.20	0.28	0.35
Base saturation %		-	88	68	61	51	46	57	57

Soil classification:

FAO-Unesco (1988) : Haplic Alisol/Chromic Luvisol

USDA : Udic Paleustalf

NATIONAL SOIL SERVICE

ANALYTICAL RESULTS OF COMPOSITE SOIL SAMPLES

ORIGIN OF SAMPLES: KILIMA TEMBO VILLAGE, MBULU DISTRICT

SAMPLE IDENT.	MAPPING UNIT	PARTICLE SIZE ANALYSIS <2 µm	2-20 µm	20-50 µm	50-2000 µm	pH 1:2.5 H_2O	KCl	ORG. C %	TOTAL N %	C/N	AVAILABLE P BRAY I mg/kg	OLSEN mg/kg	CEC me/100g	EXCHANGEABLE BASES Ca me/100g	Mg me/100g	K me/100g	Na me/100g	B.S. %
C1-1	RL1	56	17	6	21	6.5	5.2	3.1	0.15	20	35		41.1	20.9	5.6	2.44	0.26	71
-2		61	14	10	15	6.7	5.1	1.7	0.13	13	35		42.0	19.5	5.5	1.83	0.28	65
C2-1	RU2	54	15	8	23	6.4	5.3	3.7	0.20	19	28		36.2	18.3	4.2	2.40	0.22	69
-2		58	15	8	19	6.7	5.5	2.5	0.15	17	23		29.2	14.1	3.3	1.34	0.20	65
C3-1	RU2	60	11	6	23	6.5	5.3	3.3	0.20	17	27		26.3	15.4	3.7	2.52	0.21	83
-2		66	9	6	19	6.8	5.4	2.4	0.13	18	24		26.6	11.4	2.6	1.59	0.21	59
C4-1	RU2	55	17	7	21	6.5	5.3	3.4	0.20	17	31		34.7	19.7	4.4	2.08	0.22	76
-2		60	14	9	17	6.8	5.5	2.2	0.13	18	20		33.4	16.1	3.3	1.05	0.20	62
C5-1	H1	60	15	9	16	6.6	5.4	2.7	0.16	17	19		27.1	14.0	3.8	1.95	0.25	74
-2		59	14	4	23	6.7	5.5	2.2	0.12	18	17		19.1	10.4	2.9	0.90	0.16	75
C6-1	A	49	14	3	34	6.4	5.3	4.1	0.20	21	31		35.4	17.4	4.5	3.20	0.27	72
-2		41	18	7	34	6.5	5.1	3.7	0.19	19	31		42.5	19.4	4.6	2.10	0.23	62
C7-1	RL1	54	13	7	26	6.6	5.3	3.3	0.18	18	31		39.8	20.8	6.3	3.66	0.32	78
-2		55	17	6	21	6.7	5.3	2.4	0.14	17	27		32.4	14.2	4.5	2.02	0.25	66
C8-1	RL1	59	18	8	15	6.4	5.2	3.2	0.18	18	29		38.4	16.5	4.7	2.39	0.25	62
-2		63	15	5	17	6.6	5.1	1.8	0.11	18	24		26.4	13.4	3.7	1.50	0.19	71
C9-1	RL1	68	17	10	15	6.5	5.1	2.8	0.17	16	23		36.5	15.4	5.2	2.79	0.30	65
-2		62	15	7	16	6.4	5.2	1.7	0.10	17	21		26.6	10.1	3.5	1.47	0.19	57

-1 : composite sample at depth of 0-20 cm

-2 ; composite sample at depth of 25-50 cm

NATIONAL SOIL SERVICE

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