SOILS AND THEIR POTENTIAL FOR AGRICULTURAL DEVELOPMENT AT NDOLELA, SONGEA DISTRICT

NATIONAL SOIL SERVICE

TARO-AGRICULTURAL RESEARCH INSTITUTE, MLINGANO

TANGA-TANZANIA

Reconnaissance Soil Survey Report R3

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SUMMARY AND CONCLUSIONS

1. At the request of the Tanganyika Wattle Company Ltd. (TANWAT), the National Soil Service evaluated the soil conditions at Ndolela and assessed the agricultural development potential of the lands for large scale farming.

2. The proposed farm area will cover about 2000 ha and is located west of Mahanje in Songea District, at an average elevation of 1000 m.

3. The rainfall regime at Ndolela is monomodal with a single and long rainy season from November till April and a contrasting dry season from mid-May till November. The mean average rainfall is 1377 mm. The mean annual temperature is around 21°C with mean monthly maximum temperatures of 23 - 29°C and mean monthly minimum temperatures of 12 - 18°C.

4. The landscape of the Ndolela area is characterized by a flat to nearly flat but dissected plain which merges gradually into the gently sloping foot-slope of the Ndolela mountain. The dissection resulted in the formation of large, flat to nearly flat ridges with short, convex slopes towards the valley bottoms.

5. The natural vegetation type is open miombo woodland dominated by Brachystegia spp. with grass undergrowth. At the time of reporting about 400 ha was cleared and prepared for maize cultivation.

6. The soils are very uniform throughout the area, both on the plains as well as on the slopes. They are strongly weathered, well drained and very deep with fine loamy to clayey topsoils over red, clayey subsoils. The physical characteristics of the soils are favourable, but the available soil moisture contents are low. The inherent fertility levels are low to moderate.

7. The fertility of the soils is particularly dependent on the organic matter levels as the contribution of the mineral fraction to the fertility is minimal. To maintain, or possibly to increase organic matter contents incorporation of crop residues and proper crop rotations including legumes, are recommended.

8. The effects of cultivation, especially when heavy farm machinery is used, are a decline in organic matter status and a degradation of the topsoil structure, leading to lower fertility levels, sealing, compaction and increased risks of erosion.

9. The Ndolela lands are only marginally suitable for mechanized maize cultivation because yield levels are far from optimal and may not justify the high levels of inputs.

10. For the cultivation of good quality and high yielding Arabica coffee, the suitability of the lands is limited. The maximum temperatures are too high, the soil conditions are not optimal and irrigation is necessary to overcome the long dry period. The environment is better suited for irrigated Robusta or Arobusta coffee.

11. The lands are not suitable for rainfed tea. For irrigated tea the soil and climatic conditions form constraints for high production of good quality tea.

12. The soils in the Ndolela area are suitable for the production of high quality tobacco, but the climatological conditions are probably marginal.

13. The overall conclusion is that the lands at Ndolela have limited possibilities for large scale agriculture with high levels of inputs. The area is suitable for small scale farming systems based on maize as the main crop and with low to medium input levels.

1 INTRODUCTION

At the request of the Tanzania Wattle Company Ltd (TANWAT), the National Soil Service carried out a study of the soil conditions at Ndolela. The purpose of the study is to investigate the soil conditions of the farm and to characterise the physical and chemical soil properties as a reference base for proper soil and crop management.

The proposed Ndolela farm area will cover about 2000 ha and is located in Songea District, Ruvuma Region (see Fig. 1). The farm will cover the area between the foot of the Ndolela mountain in the northeast and the Ruhuhu river in the south, and west. The geographical location is between $35^{0}10' - 35^{0}13'$ E and $09^{0}53' - 09^{0}56'$ S. The average elevation is about 1000 m above sealevel.

Fieldwork required a period of two weeks in November/December 1986. The field study was carried out by a team consisting of two soil surveyors and one field assistant: Messrs. D.N. Kimaro, A.J. van Kekem and A.E. Kiwelu respectively.

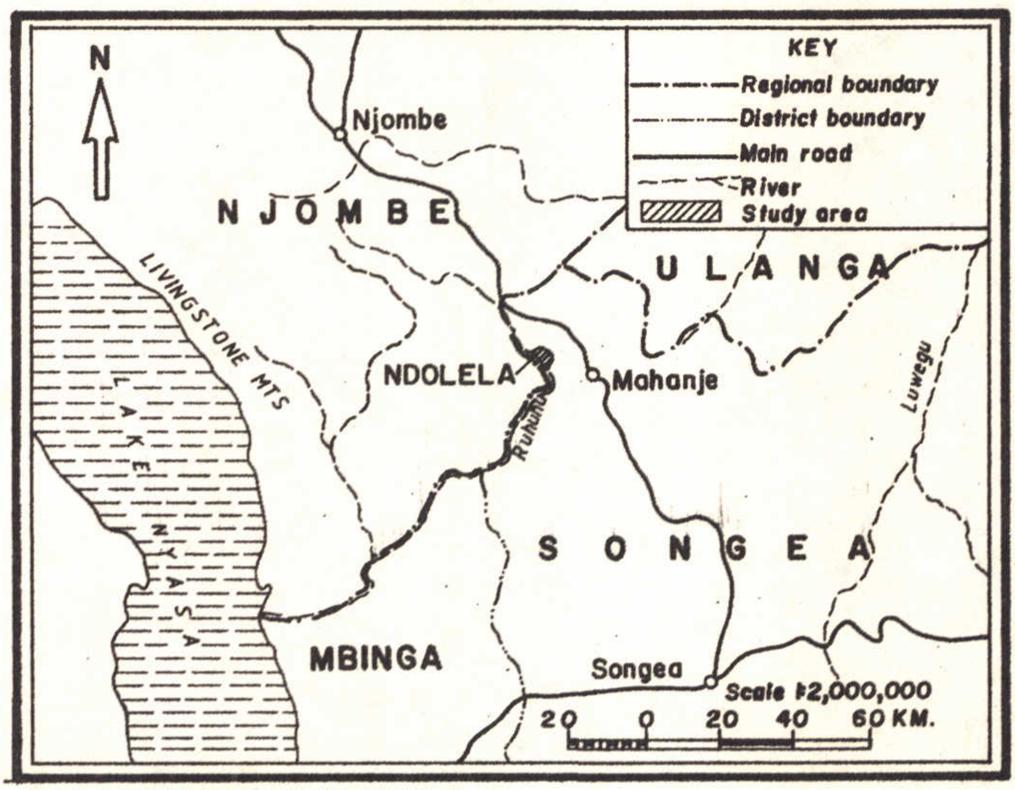

FIG.1. LOCATION OF NDOLELA

The preparation of the map and report was in the hands of D.N. Kimaro and A.J. van Kekem. Final editing of the report was the responsibility of Mr. Van Kekem. Drawing of map and figures was done by Mr. Assenga and typing of the report by Mrs. B. Pasipanodya.
The soil samples collected during the study were analysed by the National Soil Service laboratory at Mlingano.

2 ENVIRONMENT

2.1 CLIMATE

Only few climatological data are available for Ndolela farm as no meteorological station is located in the area. Since 1974, rainfall is recorded at Msigira at the southern end of the proposed farm and at Mahanje mission. Mahanje mission is situated 11 km NE of Ndolela and a similar altitude. At Mahanje, rainfall has been recorded since 1935, covering a much longer period than at Msigira. Comparing the rainfall figures of Msigira with those of Mahanje, the regimes appears to be very similar, both in distribution and in absolute amounts. The data recorded at Mahanje may therefore be considered as being representative for Ndolela.
Temperature data are recorded at Songea airport (elevation 1067 m) and may be regarded as valid for the Ndolela area as well. CCKK (1982) calculated the potential evapotranspiration for Songea airport and these data are also given.

In Table 1 the rainfall, evapotranspiration and temperature data are presented.

The mean annual rainfall in the area is 1377 mm. The rainfall distribution pattern in the area is unimodal with one rainy season which starts around mid-November and lasts till May (see Fig. 2). In November and December the rainfall is not very heavy, but the period January - April is very wet with over 200 mm/month in an average year and about 20 days with rain every month. March is the wettest month with slightly over 300 mm. From December till April, rainfall exceeds largely the potential evapotranspiration (see Fig. 2).
A long dry season starts in May when the rains tail off and continues up to November. From May till December potential evapotranspiration exceeds the rainfall. In particular the period June - October is very dry with an average total rainfall of only 21 mm. This long dry period limits the possibilities for the cultivation of perennial crops, unless irrigated.

Table 1. Rainfall, evapotranspiration and temperature data

Period	Rainfall (mm) Mahanje Mission				Songea Airport Met. Station (1957 - 1970)					
	1941-1985		1973-1985		Ep	means temp. °C			extremes temp. °C	
	mean	days	max.	min.	mm	max.	min.	range	highest	lowest
Jan	272.0	18.7	526.0	165.0	112	27.4	18.3	9.1	32.5	15.5
Feb	209.3	16.0	302.2	77.0	106	27.3	18.3	9.0	31.0	16.0
March	304.1	20.1	540.3	84.7	104	26.8	17.9	8.9	34.5	7.0
April	256.9	19.0	500.1	80.7	94	26.1	17.1	9.0	30.5	11.3
May	55.6	6.6	200.6	4.5	83	25.0	14.0	11.0	30.1	8.4
June	5.3	1.5	22.6	0	76	24.0	11.8	12.2	28.8	5.2
July	2.9	0.6	39.0	0	77	23.2	11.2	12.0	27.6	4.4
Aug	1.2	0.5	3.5	0	92	24.6	12.4	12.2	28.9	6.6
Sept	2.7	0.6	15.4	0	120	26.8	14.5	12.3	31.3	10.0
Oct	8.9	1.4	61.8	0	148	28.9	16.6	12.3	33.0	9.3
Nov.	67.5	4.5	182.6	0	139	29.3	18.3	11.0	33.6	14.0
Dec.	190.5	12.7	392.5	85.2	126	27.9	17.8	10.1	33.3	16.3
Year	1377.0	102.2	1782.9	995.2	1277	26.4	15.7	10.7	34.5	4.4

Ep = potential evapotranspiration

Source: E.A. Met. Department, 1975 (Songea), Mahanje Mission and NCCK (1982)

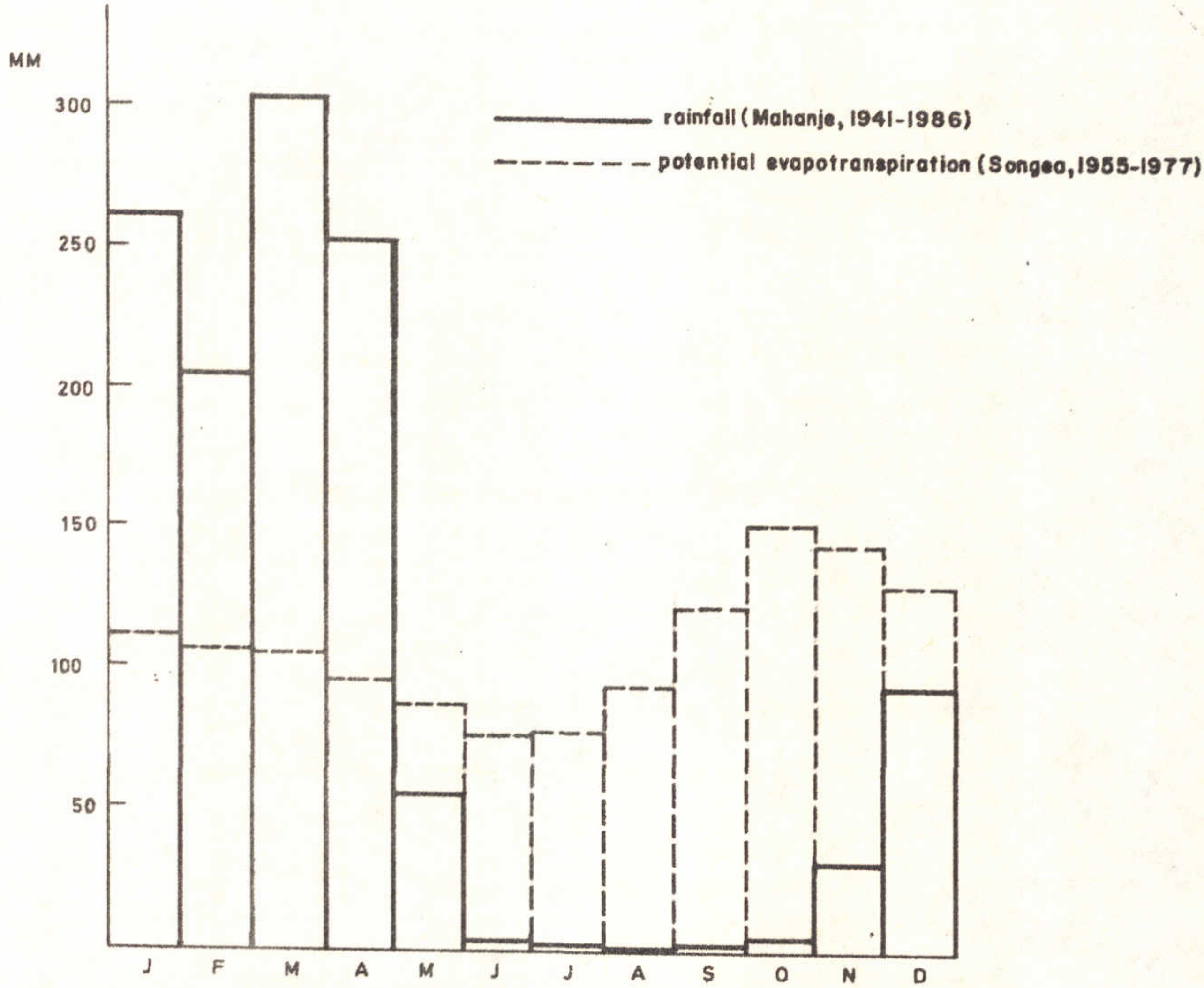

Fig. 2. Mean monthly rainfall and potential evapotranspiration in the Ndolela area

The minimum rainfall recorded in the period 1973 - 1985 is 995 mm and the maximum 1783 mm, inplicating that there is always enough rain for a crop to mature.

The mean annual temperatures are around 21 ^{0}C with little variation throughout the year. The mean monthly maxima range from 23.2^{0}C (in July) to 29.3^{0}C (November). The mean monthly minima range from 11.2^{0}C in July to about 18^{0}C in the period November - February. This temperature regime is favourable for the growth of many crops, including maize.

2.2 GEOLOGY AND PHYSIOGRAPHY

According to the geological map covering the area (Stockley, 1948), the underlying bedrock in the survey area consists of undifferentiated Basement System rocks. CCKK (1982) adds to this that the rocks mainly consist of gneisses.

The Ndolela area is situated just south of a major fault and forms part of the Ruhuhu trough, formed in late Tertiary times. The area consists of a flat to nearly flat but dissected plain, at an average elevation of about 1000 m, extending from the Ruhuhu river to the Ndolela mountain. The mountain rises abrubtly from the plain to an elevation of almost 1500 m. between the mountain and the plain there is a short and gently sloping footslope.
The small streams coming from the mountain have cut into the plain, giving the latter a dissected character. The resulting ridges are several kilometers long and half a kilometer to several kilometers wide. The valleys have short, convex slopes, gently sloping at the upper part and becoming usually steep near the valley bottoms (15 - 30%). The differences in altitude between the plateaus and the valley bottoms range from 15 to 40 m. All streams are perennial and drain into the Ruhuhu river. The valleys have flat, 50 to 200 m wide, bottoms.

The location of the plain in relation to the Ruhuhu river easily gives the impression that the plain is alluvial. The field study, however, made clear that the plain is of a strict denudational origin. The soils of the plain are not developed in alluvial or colluvo-alluvial deposits but are formed in situ in the poor weathering products of the underlying rocks of the basement complex.

2.3 VEGETATION AND LAND USE

At the time of the field study the major part of the area was still under a natural open miombo woodland and wooded grassland type of vegetation. Brachystegia spp. are the most common trees.

The swampy valley bottoms are seasonally flooded and are characterised by a marshy vegetation type.

Clearing operations include the felling of trees, winrowing, burning of the piled up vegetation and levelling of the land. To remove the roots, the land is ripped with heavy chisel ploughs to a depths of about 25 cm. With disc ploughs the land is prepared for cultivation. It is the intention to reduce tilling to a minimum. After harvesting, the crop residues will be chopped up and left on the soil surface as a mulch. This is to protect the soil surface against erosion and to contribute to the maintenance of the soil organic matter levels. By the end of 1986 about 400 ha were cleared and prepared to be planted with maize. The crop is seeded from the beginning of November onwards and harvesting starts about 8 months later.

With planting 150 kg TSP is drilled in along the rows. When the maize is knee high, a topdressing with 250 kg urea is applied. The use of herbicides, fungicides and insecticides are normal farm operations.

3 SOILS

3.1 PREVIOUS WORK

In 1976 King and Hansell prepared a soil map at a scale of 1:25,000 with report which included a suitability evaluation for mechanised agriculture. They describe the general soil pattern as one with deep, well drained, dusky red silty clay soils found on the gently sloping interfluves; they gradually merge into yellowish red, well drained, silty clay to clay loams soils on the valley sides. Locally, moderately well drained soils are reported. The natural fertility is reported to be low and to decline rapidly under permanent cropping systems. The larger part of the area was classified as being highly suitable for mechanised cultivation.

The present study confirms the general soil pattern, but cannot justify the recognition of four different soil types as was done by King and Hansell. The conclusions on the suitability of the soils for large scale maize production also differ.

3.2 STUDY METHODS

Relevant maps and literature on the study area were studied before and during the survey. These include: the topographic map at scale 1:50,000 (sheet 275/3, series Y 742, Survey and Mapping Division, 1975), the geological map (Stockley, 1948) and the soil map and report by King and Hansell (1976).

The aerial photographs only became available after the fieldwork had been completed. They nevertheless were very usefull in the delineation of the map unit boundaries. The aerial photographs at a scale of 1:25,000 were flown by Photomap (K) Ltd., Nairobi, in 1985. The following frames cover the area: Run no 25, frames 5403 - 5407; run 26, frames 5390 - 5396; and run 27, frames 8449 - 8453..

In the field augerhole observations (for general soil characterisations) were made at sites selected according to the physiographic position.

The field work included the descriptions of 26 soil auger borings to a depth of 150 - 200 cm and 6 detailed soil studies in 150 - 200 cm deep soil profile pits. Soil samples, both bulk and undisturbed core samples, were taken from the soil pits for physical and chemical analysis. In addition, 27 topsoil samples from 0 - 25 cm depth were collected from selected sites. Each composite sample is composed of about 10 subsamples from randomly chosen points around the sample site.

The soils were described according to the FAO guidelines for soil profile description (FAO, 1977). Colours were determined with the Munsell Colour Chart (Munsell Color, 1975).
Soil classification (see annex) conforms with the legend for the FAO-Unesco soil map of the world (1974) and the revised version of this (FAO, 1985) and with Soil Taxonomy (Soil Survey Staff, 1975).

All bulk soil samples were 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 report M5 (NSS, 1987) of which a brief summary follows:

- particle size analysis: hydrometer method after destruction of the organic matter and using hexametaphosphate as dispersing agent.
- organic carbon: Walkley and Black, wet acid-dichromate digestion and $FeSO_4$ titration.
- total nitrogen: semi-micro Kjeldahl digestion followed by ammonium distillation and titration with sulphuric acid.
- pH: potentiometrically using a combined glass-calomel electrode in a 1:2,5 suspension of H_2O and 1 M KCl.
- exchangeable cations: displacement with 1 M NH_4OAc at pH 7 and determination of K and Na by flamephotometry and Ca and Mg by EDTA titration.
- cation exchange capacity: NH_4 saturation with NH_4OAc at pH 7.
- available phosphorus: Kurz-Bray I; extraction with 0.025 M HCl and 0.03 M NH_4F and colorimetric determination of the extracted P.

- bulk density: determination of the oven dry (105°C) weight of a soil core of known volume.
- water retention: determination of the moisture percentage in undisturbed samples at pressures of 0.1 and 0.25 bar and in disturbed samples at pressures of 5.0 and 15 bar, using soil moisture extractors.

3.3 DESCRIPTION OF THE SOILS

3.3.1 Soil map and legend

The map is presented at a scale of 1:25,000 and has the character of a reconnaissance, physiographic soil map. The base map used to prepare the final map is of a rather poor quality and not exactly to scale, in spite of the fact that it is based on an enlargement of the 1:50.000 topographic map.
A brief description of the mapping units is given in the legend of the map and a complete description is given in the following section.
The technical descriptions of the soil profiles together with the analytical laboratory results of the collected samples are given in Annex 1.
The main differentiating criterion is the physiography; landform type and slopes in particular. Within each landform unit the soils are described in terms of morphological, chemical and physical characteristics.
A code system is used to identify the mapping units. In Table 2 the codes are presented with a brief description of the landform characteristics.

Table 2: Mapping unit codes with description

Code	Description
M	Mountain slopes with angles over 8%, rapidly increasing slope angle with altitude.
F	Gently sloping footslopes of the mountain (2 - 8%)
P	Flat to nearly flat plains with slopes from 0 - 2%
S	Gentle to steep slopes towards the valley bottoms with slopes from 2% at the upper end to over 25% near the valley bottom.
V	Flat valley bottoms (0 - 2%).

3.3.2 General pattern and genesis aspects.

The soils of the survey area are very uniform in their morphological characteristics. The largest part of the area consists of flat to nearly flat plains with very deep, well drained, red, clayey soils with well developed topsoil structures under natural vegetation. The plains merge gradually into the gently sloping footslopes where the soils appear to have coarser textured topsoils (sandy clay loam instead of sandy clay) and have slightly darker red colours. The soils of the relatively short slopes towards the valley bottoms are similar to the soils of the plains. Very locally the soils of the slopes are gravelly. The valley bottoms have poorly drained soils with peaty topsoils over loamy or clayey subsoils.

The coarser topsoil texture of the footslope soils may be the result of more intensive leaching, resulting in a loss of clay particles, both laterally and vertically. There is no evidence of accumulation of coarser colluvial material from the adjacent mountain. (Particle size distribution of the sand fraction is comparable throughout the area). There is also no evidence of alluvial material from the Ruhuhu river being deposited on the plains.

A recent, deeply incised gully on one of the ridges shows a very deep soil formed in situ over weathering bedrock. Moreover, quartz bands coming to the surface locally desintegrate into sharp angled quartz gravel, also indicating the in situ position of this gravel. Only close to the Ruhuhu river, rounded quartz gravel can be found and then only on the soil surface. This rounded gravel could be the remains of the last stage of denudation. After this stage a very intense, deep weathering must have taken place, resulting in the present, deeply weathered and strongly leached soils.

The field observations are in line with the concept of the plain having a denudational origin with soils developed in situ in the weathering products of the underlying bedrock.

3.3.3 Mapping unit descriptions

Mapping unit M

Setting: Unit M represents the steep slopes of Ndolela Mountain. The unit is included in the map only to complete the toposequence as presented by the landform. No observations were made in this unit.

Mapping unit F

Setting: Units F are the gentle footslopes of the Ndolela mountain in the northern part of the area and cover about 300 ha. The slopes range from about 8% at the upper end to 2% in the lower part. The footslopes are incised by streams. The differences in altitude between the gently sloping footslopes and the valley bottoms range between 20 and 40 m. The underlying bedrock consists of various types of gneisses.

Major soil characteristics: The soils of this mapping unit are very deep and well drained. A typical profile has a thin, dusky red to dark reddish brown, sandy clay loamy topsoil over a red, clayey subsoil. The soils have a low to moderately high natural fertility, offer good rooting possibilities but have only limited soil moisture retention capacities. Due to the sloping character of the land, splash and rillwash erosion may occur once the soil surface is bare. The soils of this unit are classified as chromi-haplic Acrisols (FAO, 1985).

Topsoil characteristics: The topsoils are 10 to 15 cm thick with dusky red to dark reddish brown colours and have sandy clay loam textures. Under natural vegetation, the structure is strong, very friable, fine granular and blocky. After clearing and preparation of the land for cultivation the structure becomes moderately well to weakly developed and very fine. The organic matter content ranges from 1.2 to 3.5% with the highest values found under natural vegetation The soil reaction is moderately acid with pH values between 5.4 and 6.0.

Subsoil characteristics: The subsoils have dusky red to dark red colours, are clayey and very friable with moderately well developed, medium to fine, blocky structures. The soil reaction is very acid with pH values of 4.3 - 5.3. The cation exchange capacity of around 4 me/100 g soil is very low.

For the description of a typical profile with analytical data, see Annex 1, profile no 22.

Mapping unit P

Setting: These mapping units form the flat to nearly flat plains and cover about 1350 ha. Slopes range between 0 and 2%. The mean elevation of this unit is about 1000 m. The underlying bedrock consists of various types of gneisses.

Major soil characteristics: The soils are very deep and well drained. A typical profile has a thin, dark reddish brown, sandy clay loam to sandy clay topsoil over a red, clayey subsoil. Under natural conditions the soils have low to moderate fertility levels. Possibilities for root development are good but the soil moisture retention capacities are limited. The erodability of the soils is low, due to the almost flat topography. Most of the soils of this unit are classified as chromi-luvic Acrisols.

Topsoil characteristics: The topsoils vary in thickness between 5 and 20 cm, have dark reddish brown to dusky red colours and sandy clay loam to sandy clay textures. Under natural vegetation the structure is favourable, very friable, fine granular and blocky. The organic matter levels range between 1.1 and 3.6%. The lowest organic matter levels are found on ridge no. 1 (eastern part of the area).
The soil reaction is acid with most pH, values between 5.0 and 5.9.

Subsoil characteristics: The subsoils have yellowish red to dusky red colours and clayey textures. The structures are weak to moderately well developed, fine to medium and blocky. The soil reaction is acid with pH values between 4.8 and 5.6.

For detailed profile descriptions with analytical data of soils of this unit, see Annex 1, profile numbers 4, 12, 16, 24 and 28.

Mapping unit S

Setting: This unit represents the slopes towards the valley bottoms of the tributary streams coming from the mountain and towards the Ruhuhu. The extent of this unit is about 2250 ha. The slopes are typically convex, gently sloping (2 - 8%) at their upper end and becoming steep (up to 30%) near the valley bottoms. The differences in altitude between the flat parts of the plains and the valley bottoms range between 20 and 40 m. The soils are derived from gneiss.

General soil characteristics: The soils are similar to the soils of the plains (unit P). Very locally, these soils are gravelly. Due to the sloping topography, the erodability is high, especially after clearing of the natural vegetation.

Mapping unit V

Setting: Units V are the flat valley bottoms of the tributary streams and the Ruhuhu. Only those valley bottoms which are wider than about 75 m could be indicated on the map at this scale. Together they cover about 550 ha. The parent material consists of loamy and clayey deposits derived from weathering products upstream.

General soil characteristics: The soils are very deep, very poorly drained with about 20 cm thick, black, humiferous topsoils over gray, loamy to clayey subsoils, mottled to about 50 cm depth. The soils are flooded during the major part of the rainy season. The soils of this unit are classified as humic Gleysols.

3.4 SOIL FERTILITY AND FERTILITY MANAGEMENT

Soil fertility is best assessed through the analysis of composite top-soil samples. For this purpose, 27 composite samples were collected from all over the area. The results of the analysis are given in Annex 2.

The soil reaction is strongly to moderately acid, with pH values between 5.0 and 6.0. At site no 2 the pH value was as high as 7, which is difficult to explain.

The organic matter levels of all soils are low (except those of the valley bottoms), ranging between 1.1 and 3.6%. The C/N ratios are around 14 indicating a well decomposed, good quality organic matter. Very low organic matter levels (1.1 - 1.7%) are found at the southern end of ridge no 1 (sites 4, 5 and 6). The organic matter levels in the cultivated fields range between 1.2 and 2.2% (mean 2.2%) whereas the organic matter levels under natural vegetation and of newly cleared land are all above 2% (mean 2.9%), with the exception of the above mentioned sites on ridge no 1.
This is a clear indication that the organic matter levels decrease under cultivation, which is already noticeable after one harvest. Depletion of the organic matter will adversely affect soil structure and natural fertility, including nutrient holding capacity, and will lead to higher risks of surface sealing and lower infiltration rates. In the highly weathered soils of Ndolela, soil fertility is particularly dependent on organic matter as the contribution of the mineral fraction to the fertility is minimal. Maintenance of the soil organic matter is therefore of utmost importance and the incorporation of crop residues and proper crop rotations, including legumes, are basic management practices when the lands are being used for permanent cultivation.

The organic matter levels of the valley bottoms are high (3.8% and higher) with a C/N ratio of 16. (Only one sample was analysed).

The total nitrogen values are low and will decrease further with the decline of the organic matter content. In most cropping systems there will be a clear response to considerable amounts of N fertilizers. Experiments carried out by the National Maize Development

Programme on similar soils in Songea showed economic responses with up to 100 kg/ha of Nitrogen under traditional management levels. (Samki and Harrop, 1984).

The cation exchange capacities, reflecting the possibilities of the soil to retain nutrients, are low in all topsoils. They range between 4.5 and 11.4 me/100 g soil. There is a strong correlation between the organic matter content and the CEC. This indicates that the organic matter is the principal contributor to the CEC. Consequently, a decline in organic matter content will lead to a decline in CEC and to lower fertility levels.
The CEC of the clay fraction is below 10 me/100 g clay. This indicates that low activity clays, probably dominated by kaoline, are the main constituents of the clay fraction. Low activity clays, in combination with low organic matter levels will result in unstable soil structures, especially when the soil biological activity is inhibited by frequent tillage operations and the use of pesticides and insecticides.

The levels of exchangeable Calcium and Magnesium, indicating the availability of these nutrients for the plant, are low (1.1 - 3.8 and 0.5 - 1.9 me/100 g soil resp.). The soils are well supplied with Potassium; exchangeable K levels ranging between 0.2 and 0.5 me/100 g soil.

Available phosphorus varies highly throughout the area and does not show a geographic pattern. Frequency and intensity of bushfires and possibly also differences in vegetation types could offer some explanations. Most levels of available phosphorus are below 25 mg/kg which is reported to be the critical level for maize. At sites 1 and 2, which are located in arable fields, higher levels of available P are found. These high levels are the result of the application of P fertilizers.

The Tropical Soils Analysis Unit, Land Resources Development Centre, Reading in the UK, analyzed selected soil samples on their micronutrient levels. A brief discussion of the results follows hereafter.

The percentage of total sulphur is very low (less than 0.01%). To avoid S deficiencies in sensitive crops, the application of S containing fertilizers is recommended. Possible S source are sulphate of ammonia (SA), single superphosphate and gypsum.

<u>Boron</u> levels (hot water soluble B) in the soils range from 0.2 in the topsoils to 0.1 mg/kg in the subsoils. For most crops, levels of 1.5 - 3 mg/kg are considered satisfactory. (Landon, 1984). Additions of B to the fertilizers or in the form of foliar sprays, are likely to show an economic response in sensitive crops.

<u>Copper</u> levels range between 20 and 70 mg/kg (Perchloric Acid Digestion method). Cu levels above 50 mg/kg are considered sufficient for most crops. For very sensitive crops Cu additions might be necessary.

<u>Manganese</u> is sufficiently supplied by the soils; the levels of total Mn vary between 200 and 1600 mg/kg (Perchloric extractable).

<u>Zinc</u> levels in the topsoils range from low to moderate (between 30 and 40 mg/kg perchloric extractable). Application of Zn is recommended to sensitive crops such as maize.

3.5 SOIL PHYSICAL CHARACTERISTICS

The structure of the soil, especially that of the topsoil, is an important soil property as it is closely related with rooting, permeability and soil aeration. Non-compacted soils with well developed structures, are usually very permeable, well aerated and do not hinder root development.

The topsoils in the area generally have moderate, well developed, fine and medium, subangular blocky and granular structures. With depth, the structures are less well developed, but the soils remain porous and friable throughout.

Tillage practices with disc harrows result in a seedbed with a very fine, granular structure which makes the soil liable to sealing and compaction, especially under continuous mechanised cultivation with heavy machinery. Surface sealing and compaction will result in lower infiltration rates, leading to increased surface runoff and higher risks of erosion.

To maintain a favourable topsoil structure, tillage practices need to be kept to a minimum and the organic matter levels of the soils should be maintained and, if possible, increased. (See also section 3.4).

The soil moisture retention capacity of the soil is a function of soil structure, particularly pore space distribution, and soil texture. The soil water retention characteristics were determined at different tensions and at different depths in three profiles. (see Annex 1, profiles no. 12, 22 and 28 for details).
The highly weathered soils of Ndolela have low available water contents. Although the soils are clayey, they are well aggragated and therefore have relatively many macropores which do not hold much water at field capacity. The water held inside the aggragates is strongly bound at tensions above wilting point.
The for the plant available water is considered to be the difference in soil moisture content at 2.4 bar (field capacity) and 15 bar (permanent wilting point). The available water content ranges between 5 and 10 volume %, but is most commonly around 7%. This means that in 100 cm of soil, only 7 cm of stored soil moisture may be available for the plant. This low available soil moisture content in combination with the long dry season, strongly limits the possibilities for the cultivation of perennial crops, unless irrigated.

4 LAND SUITABILITY

4.1 MAIZE

Maize can be grown in a wide range of environmental conditions, provided it receives a good supply of water, especially during the period of silking. It can not tolerate the slightest degree of waterlogging; it can be killed if it stands in water for as long as a day. Especially during the first few weeks after sowing the soil/air moisture relationship is critical. (Acland, 1971).
The optimum day temperature is 30°C but many maize varieties will grow well at a lower temperature. Minimum temperatures should not be lower than 10°C.
Maize requires well drained, deep soils which are well supplied with plant nutrients. The optimal pH range is 6 - 7, but values as low as pH 5 are tolerated. For mechanized farming, whereby heavy machinery is used, well structured topsoils with stable structures are required.

The temperature regime of the area is well suited for maize growth. Rainfall is abundant during the period December - April, and long maturing varieties can be grown satisfactory under these conditions. The soils in the area are very deep and well drained with a moderate natural fertility status and a pH between 5 and 6. The organic matter levels vary between 1.1 and 3.6%. The topsoil structures under natural conditions are favourable, but the surface is liable to sealing and compaction, especially when heavy farm machinery is used.

For long term mechanized maize cultivation with high levels of inputs the soil conditions at Ndolela are far from optimal. In fact, the lands must be considered as being only marginally suitable for this type of cultivation. The required inputs in terms of fertilizers, to reach acceptable yields, are high. Even in the first year of cultivation, with soils still reasonably well provided with nutrients and well structured, the yield levels were below expectation. It is likely that under continuous cultivation, with a decreasing soil fertility and a detoriation of the physical soil conditions, the yields may decrease even further.

4.2 COFFEE

The optimal environment for Arabica coffee (Coffea arabica) is a temperate, tropical highland climate with contrasting seasons. The optimal amount of rainfall is about 1800 mm, well distributed throughout the year with the exception of a 1.5 - 2.5 month dry period. The dry period is regarded as beneficial: it hardens the wood and gets the tree in a cycle of flowering and bearing. The dry season should preferably not be longer than 3 months.
High temperatures inhibit the growth of coffee; above 25°C the net photosynthesis begins to decrease and stops altogether above 30 - 32°C. Mean annual temperatures above 25°C are therefore not suitable for Arabica coffee and the mean monthly maximum temperature should not exceed 27°C. Absolute minimum temperatures should not be lower than 4 - 5°C. (De Alvim and Kovslovski, 1977).
At Ndolela the maximum temperatures are too high from October to February for good growth of coffee. To temper the negative effects of high temperatures, the application of a light shade may be recommended although the shade trees will compete with the coffee for available soil moisture and nutrients.
The climatological requirements for Robusta coffee (Coffea canephora) are comparable with those of Arabica coffee, but it is usually grown in warmer and wetter areas than the latter as the crop is more resistant to diseases. (Acland, 1971).

In the Ndolela area, the dry season of six months is much too long for optimal coffee growing conditions (drought stress). Mulching and/or irrigation would be possibilities to improve the soil moisture availability. The mulch should however be removed during the rainy season because it increases the risks of diseases. On the other hand, the rainy season, with five months each having close to or over 200 mm of rain, is slightly too wet for coffee. Long periods with too much rain could cause misflowering and increase the risks of coffee berry diseases.

Coffee prefers very deep, well drained, permeable, well aerated soils with high soil moisture reserves and a pH in the range 6 - 7.

Slightly lower pH values are tolerated but may influence optimal yield levels.
The physical properties of the soils in the area are favourable for coffee but the soil moisture availability is limited. The soil pH is invariably below 6 and therefore constitutes a slight limitation for optimal yields.
Coffee, especially Arabica, requires regular applications of Nitrogen to maintain good yields. This is especially valid in the Ndolela area having N deficient soils. Coffee is also sensitive to Boron deficiencies.

Comparing the environmental requirements of Arabica coffee with the actual conditions at Ndolela, the suitability of the Ndolela lands for this crop **is** limited. The altitude is too low with maximum temperatures too high, especially in the period October - February. For rainfed coffee, the dry season is too long and the soil moisture storage capacities too limited. Irrigation would solve the dry season limitation, but this practice may not be economic considering the not optimal temperature regime and the rather low yield potentials of the soils. The lands are better suited for the cultivation of Rubusta or Arobusta coffee varieties.

4.3 TEA

Tea (Camellia sinensis) requires a constant supply of soil moisture in order to give a continuous flush growth. Dry spells are only tolerated when there is enough soil moisture available. The actual evapotranspiration of a mature tea bush is very close to the potential evapotranspiration. The meteorological drought in the Ndolela area starts in May and lasts till November (see Fig. 2). At the beginning of the dry season the available soil moisture reserve in 150 cm of soil, being the assumed depth to which tea can effectively use the soil moisture, is calculated as 105 mm. The meteorological moisture deficit (potential evapotranspiration minus rainfall) in May is 27 mm and in June 71 mm, together 98 mm. The stored soil moisture will enable the tea to grow till the beginning of July. From then onwards till November serious moisture stress will occur, unless supplementary irrigation is provided.

Optimal mean monthly temperatures for tea are in the range of 16 - 21°C and the mean monthly minimum should not be below 8.5°C (see also Report R1, Table 3, NSS, 1986). Mean minimum temperatures in the Ndolela area are favourable (around 15.7°C), but the mean maximum temperatures (around 26.4°C) are too high for the production of high quality tea.

Tea needs acid soils, preferrably with a pH between 5.0 and 5.5. Slightly higher values are tolerated, but pH values over 6 make proper establishment of the crop difficult. The soils need to be rich in organic matter with values of over 5% considered as being optimal.
The soils in the Ndolela area have for tea favourable pH values, being between 5.0 and 6.0 in the topsoils and around 5.5 in the subsoils. Organic matter levels are generally below 3%, causing slight limitations for optimal yields.

Considering the very long period with moisture stress, the Ndolela area is not suitable for rainfed tea cultivation. If irrigated, the lands will be suitable for tea but the relatively high temperatures and the low soil organic matter levels still constitute limiting factors for the production of high quality tea.

4.4 TOBACCO

The Southern Highlands is an important area for the production of tobacco (*Nicotiana tabacum*). Dark fire-cured tobacco is grown in Songea District and flue-cured tobacco is being cultivated around Iringa. Although the characteristics of the crops vary and the product also varies in quality from year to year, the Southern Highlands are able to produce good and well bodied leaves.

Flue-cured tobacco is a low-nitrogen containing product. Nitrogen uptake must be low during the latter part of the growing season. During early growth, however, adequate nitrogen supplies are essential. The soils in which the crop is grown should have good physical properties, be well drained and have reasonable high water retention capacities.

Dark fire-cured tobacco aims for a dark, oily type of leaf and requires a more fertile type of soil. This type does not require the critical timing of the nitrogen availability. For both types of tobacco cultivation a soil pH between 5.5 and 6.5 is preferred, but in practice good tobacco soils show considerable variations in soil pH.(Akehurst, 1981)

Considering the above soil requirements, the soils at Ndolela are suitable for tobacco. They are well drained, friable and porous and on the nearly flat to flat plains the risks of erosion are limited, providing careful soil management. The soils also have the right pH range and the low organic matter levels will help to reach the delicate balance in the nitrogen levels of the soils required for the good quality of flue-cured tobacco leaf.

Planting on ridges is recommended, as the rains can be heavy during the rainy season. To avoid erosion the ridges need to follow the contours very closely.

The crop should preferably not be cultivated on the same land for more than a few years in succession, in spite of fumigation practices. At Ndolela possible crop rotations include tobacco-maize, tobacco-green manure (e.g. Crotolaris spp), tobacco-groundnut and tobacco-grasses (e.g. Rhodes grass).

For proper tobacco cultivation, the climatic conditions at Ndolela are more limiting than the soil conditions.
The major limitation is the length of the rainy season, more than six months, which is far too long for tobacco, as the crop has a growing season of only 100-120 days. Evidence of research trials carried out suggest considerable productivity benefits from establishing crops in the field a week or two before the rains commence. But the advantage of dry planting may easily be eliminated by the fact that the crop then will have to be harvested during the rainy period. The temperature regime at Ndolela is well suited for tobacco, particularly for the fire-cured tobacco type which grows best in warm conditions and produces good quality leaf under higher temperature regimes.

Summarizing, it may be concluded that the climatological conditions at Ndolela are probably marginal for the cultivation of high yielding and good quality tobacco.

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Annex 1: Soil profile descriptions with analytical data

Profile No. 4

General information on site and soil

Location: Tanwat-Ndolela, ridge No. 1. Parent material: Gneisses. Land form and Relief: Nearly flat, but dissected plain with steepest slopes between 15% and 20% to valleys. Vegetation: Brachestegia woodland. Slope of site: The profile is located on a nearly flat plain with 1% slope towards south. Elevation of site: 975 m

Soil: Very deep, well drained with dark reddish brown, fine loamy topsoil over a red clayey subsoil. The soil has a well developed blocky structure.

Description: The profile was described on 19-11-1986 by A.J. van Kekem and D.N. Kimaro.

Soil profile description:

Ah 0 - 8/13 cm	dark brown (7.5YR 3/2, moist); sandy clay loam; strong fine and medium, subangular blocky; very friable when moist, sticky and slightly plastic when wet; many pores; many fine and very fine, few common, roots; clear and irregular to
BA 8/13 - 26 cm	yellowish red (3.5YR 4/6, moist); sandy clay; moderate, fine, subangular blocky; very friable, when moist, sticky and slightly plastic when wet; many pores and channels filled with topsoil material; very few, small and medium, hard and soft, Fe nodules; many, very fine and fine, pores; many, fine and very fine, few medium, roots; gradual and smooth to
Bt1 26 - 64 cm	red (3.5YR 4/6, moist); clay; moderate, fine, irregular angular blocky; very friable when moist, sticky and plastic when wet; some large (2-5 cm) crotovinas filled with topsoil material; many, very fine fine and fine, pores; broken, continuous thick cutans; many, fine and very fine, few medium, roots; diffuse and smooth to
Bt2 64 - 120 cm	red (2.5Yr 4/6, moist); clay; weak, medium to fine, irregular angular blocky; hard when dry, very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; broken, thick cutans; few, fine roots; diffuse and smooth to
Bws 120 - 160^{+}cm	red (2.5YR 4/6, moist); clay; weak, medium to fine, irregular angular blocky; slightly hard when dry, very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; very patchy, thin cutans; very few fine roots.

Analytical data

Horizon	Ah	BA	Bt1	Bt2	Bws
Depth (cm)	0-10	15-25	40-60	80-100	120-140
Texture:					
clay %	27	44	59	64	60
fine silt %	4	4	3	2	4
coarse silt %	9	4	2	3	3
very fine sand %	6	6	5	5	6
fine sand %	17	15	11	10	10
medium sand %	23	16	12	9	9
coarse sand %	14	10	7	6	7
very coarse s. %	0	1	1	1	1
Textural class	s.c.l	s.clay	clay	clay	clay
pH water (1:2.5)	5.5	5.2	5.6	5.6	5.6
pH KCl (1:2.5)	4.1	4.2	4.7	5.1	5.4
Organic Carbon %	1.35	0.63	0.40	0.40	0.34
Av. P, Bray I, mg/kg	25.0	22.2	9.0	1.9	0.7
CEC NH_4OAc me/100 g	4.6	4.2	4.2	3.5	5.1
exch. Ca "	1.3	1.2	1.5	1.4	1.5
exch. Mg "	0.8	0.6	0.8	0.7	0.8
exch. K "	0.2	0.1	0.2	0.1	0.1
exch. Na "	0.1	0.1	0.1	0.1	0.1
Base saturation %	52	48	62	66	45

Soil classification:

FAO - Unesco : chromic Lixisol (formerly chromic Luvisol)

Soil Taxonomy : oxic Haplustalf

Profile No. 12

General information on site and soil

Location: Tanwat - Ndolela, ridge No. 2. Parent material: Gneisses. Landform and Relief: Nearly flat, but dissected plain with moderate to steep slopes towards valleys. Vegetation: Brachestegia woodland. Slope of site: The profile is located on a nearly flat plain with 1%slope towards the E. Elevation of site: 980 m.

Soil: Very deep, well drained with clayey, very dusky red topsoil having a well developed structure over dark reddish brown, clayey subsoil.

Description: The profile was described on 18-11-1986 by A.J. van Kekem and D.N. Kimaro.

Soil profile description:

Ah 0 - 9 cm	very dusky red (2.5YR 2.5/2, moist); sandy clay; strong, fine granular and subangular blocky; very friable when moist, sticky and slightly plastic when wet; small charcoal fragments; many pores; very many, fine and very fine, roots; clear and smooth to
AB 9 - 24 cm	very dusky red (2.5YR 2.5/4, moist); sandy clay; strong, fine and medium, subangular blocky; very friable when moist, sticky and plastic when wet; small charcoal fragments; many, fine and very fine, pores; very many, fine and very fine, roots; gradual and smooth to
Bws 24 - 50 cm	dark reddish brown (2.5YR 3/4, moist); sandy clay, moderate, fine and medium, subangular blocky; very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; many, fine and very fine, roots; gradual and smooth.to
Bt1 50 - 165 cm	dark reddish brown (2.5YR 3/4, moist); clay; moderate, medium, irregular angular blocky; slightly hard when dry, very friable when wet; many, very fine and fine, pores; broken, very thick cutans; many very fine roots; diffuse and smooth to
Bt2 165 - 180$^+$cm	dark red (2.5YR 3/6, moist); clay; weak to moderate, medium, irregular angular blocky; very friable when moist, sticky and slightly plastic when wet; many, very fine and fine, pores; patchy, very thick cutans, common, very fine roots

Remark: Below 100 cm depth semi-hard clay concentrations (durinodes) occur.

Analytical data

Horizon	Ah	AB	Bws	Bt1	Bt2
Depth (cm)	0-9	10-24	25-45	60-80	120-140
Texture:					
clay %	41	44	46	62	59
fine silt %	6	6	5	5	4
coarse silt %	2	3	3	0	1
very fine sand %	5	6	5	5	4
fine sand %	13	15	15	12	13
m sium sand %	19	16	15	11	11
coarse sand %	13	9	10	5	7
very coarse sand %	1	1	1	0	0
Textural class	s.clay	s.clay	s.clay	clay	clay
pH water (1:2.5)	5.8	4.9	5.2	5.4	5.4
pH KCl (1:2.5)	4.5	4.2	4.2	4.2	4.3
Organic Carbon %	2.1	1.5	0.9	0.3	0.1
Av. P, Bray I, mg/kg	18.6	2.9	2.1	1.3	0.7
CEC NH_4OAc me/100 g	10.2	8.7	6.6	7.5	5.0
exch. Ca "	2.5	0.5	0.5	0.5	0.6
exch. Mg "	1.2	0.3	0.2	0.2	0.2
exch. K "	0.4	0.1	0.1	0.0	0.0
exch. Na "	0.1	0.1	0.1	0.1	0.1
Base saturation %	41	11	13	11	18
Bulk density (g/cm^3)		1.16	1.25	1.25	
Soil moisture retention (Vol %) at					
pF 2.0		33.1	24.6	25.4	
pF 2.4		25.5	21.9	23.0	
pF 3.0		17.8	17.9	21.2	
pF 4.2		15.3	15.1	18.2	

Soil classification:

FAO - Unesco : chromi-haplic Acrisol

Soil Taxonomy : typic Rhodustult

Profile No. 16

General information on site and soil:

Location: Tanwat - Ndolela, ridge No. 3. Parent material: Gneisses. Landform and Relief: Nearly flat, but dissected plain, with moderate to steep convex slopes towards valleys (2-30%). Vegetation: Cleared woodland, not yet levelled. Slope of site: The profile is located on nearly flat plain with 0-2% slope. Elevation: 975 m.

Soil: Very deep, well drained soil with dark reddish brown, clayey topsoil with well developed structure over a yellowish red clayey subsoil. The soil has a high biological activity.

Description: The profile was described on 19-11-1986 by A.J. van Kekem, D.N. Kimaro and A.E. Kiwelu.

Soil profile description:

Ah 0 - 13 cm	dark reddish brown (2.5YR 2.5/1.5, moist); sandy clay; strong, fine, granular; very friable when moist, sticky and plastic when wet; many pores; small charcoal fragments; many, very fine and fine, roots; clear and smooth to
AB 13 - 28 cm	dark reddish brown (5YR 3/3, moist); sandy clay; strong, fine and very fine, granular and subangular blocky; very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; few charcoal fragments; many, very fine and fine, few medium, roots; clear and smooth to
BA 28 - 47 cm	reddish brown (5YR 4/4, moist); sandy clay, moderate, fine, subangular blocky; very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; few charcoal fragments; many, very fine and fine, roots; clear and smooth to
Bws1 47 - 105 cm	yellowish red (5YR 4/6, moist); clay; moderate, medium, irregular subangular blocky; slightly hard when dry, very friable when moist, sticky and plastic when wet; many very fine, common fine, pores; few charcoal fragments; few, medium, slightly hard, clay nodules with MnO_2; common very fine, few fine and medium, roots; diffuse and smooth to
Bws2 105 - 175$^+$cm	yellowish red (5YR 4/8, moist); clay; very weak, fine, subangular blocky; very friable when moist, sticky and plastic when wet; many very fine, few, fine and medium, roots;

Analytical data

Horizon	Ah	AB	BA	Bws1	Bws2
Depth (cm)	0-13	15-25	30-45	60-80	130-150
Texture :					
clay %	39	39	44	49	45
fine silt %	6	5	5	6	14
coarse silt %	4	4	3	3	2
very fine sand %	5	5	5	5	6
fine sand %	15	15	15	14	14
medium sand %	20	20	18	15	12
coarse sand %	10	11	9	7	6
very coarse sand %	1	1	1	1	1
Textural class	s.clay	s.clay	s.clay	clay	clay
pH water (1:2.5)	6.4	5.5	5.2	5.2	5.4
pH KCl (1:2.5)	5.2	4.3	4.2	4.5	4.8
Organic Carbon %	1.3	0.8	0.4	0.4	0.2
Av. P. Bray I. mg/kg	12.0	2.0	1.2	0.7	0.7
CEC NH_4OAc me/100 g	13.2	7.2	3.9	4.9	9.8
exch. Ca "	4.3	2.0	0.6	0.8	0.6
exch. Mg "	2.8	1.3	0.3	0.3	0.3
exch. K "	0.3	0.2	0.1	0.0	-
exch. Na "	0.1	0.1	0.1	0.1	0.1
Base saturation %	57	50	28	24	10

Soil classification:

FAO - Unesco : haplic Ferralsol

Soil Tazonomy : typic Haplustox

Profile No. 22

General information on site and soil:

Location: Tanwat - Ndolela, ridge No. 2. Parent material: Gneisses. Landform: Footslopes of mountain. Relief: Gently sloping (2-8%). Vegetation/Land use: Cleared woodland, prepared to plant the first crop. Slope of site: The profile is located on a middle slope of 5% towards the SW. Elevation of site: 980 m.

Soil: Very deep, well drained; with fine loamy dusky red topsoil over dark reddish brown subsoil. The soil profile has a moderately well developed structure.

Description: The profile was described on 18-11-1986 by A.J. van Kekem and D.N. Kimaro.

Soil profile description:

Ap 0 - 13 cm	very dusky red (2.5YR 2.5/2, moist); sandy clay loam; moderate, fine, granular and subangular blocky; very friable when moist, sticky and plastic when wet; many pores; many, fine and very fine, roots; clear and wavy to
BA 13 - 35 cm	dark reddish brown (2.5YR 3/4, moist); sandy clay; moderate, medium, subangular blocky to angular blocky; very friable when moist, many, very fine and fine, pores; sticky and plastic when wet; many, very fine roots; diffuse and smooth to
Bt1 35 - 70 cm	dusky red (10R 3/4, moist); sandy clay, moderate, medium and fine, subangular blocky; very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; few clay concentrations; broken, moderately thick cutans; many, very fine and fine, roots; diffuse and smooth to
Bt2 70 - 170+cm	dark reddish brown (2.5YR 3/4, moist); clay; weak to moderate, medium and fine, subangular blocky; slightly hard when dry, very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; patchy, moderately thick to thick cutans, few very fine roots.

Analytical data

Horizon	Ap	BA	Bt1	Bt21	Bt22
Depth (cm)	0-10	15-30	40-60	100-120	140-160
Texture:					
clay %	24	35	46	41	51
fine silt %	2	6	6	7	5
coarse silt %	14	6	5	12	6
very fine sand %	7	7	7	7	7
fine sand %	21	20	15	15	13
medium sand %	24	20	16	13	13
coarse sand %	8	5	5	5	5
very coarse sand %	0	1	0	0	0
Textural class	s.c.l	s.clay	s.clay	clay	clay
pH water (1:2.5)	6.0	4.7	4.3	4.8	5.3
pH KCl (1:2.5)	5.1	4.4	4.2	4.4	4.0
Organic Carbon %	2.1	1.3	0.6	0.3	0.3
Av. P, Bray I, mg/kg	5.4	2.0	1.0	0.8	0.6
CEC NH_4OAc me/100 g	7.4	5.6	4.1	5.7	3.0
exch. Ca "	2.6	1.2	0.7	0.8	0.8
exch. Mg "	2.2	0.3	0.2	0.4	0.3
exch. K "	0.4	0.2	0.2	0.1	0.1
exch. Na "	0.1	0.1	0.1	0.1	0.1
Base saturation %	72	32	29	25	43
Bulk density (g/cm^3)		1.36	1.36	1.28	
Soil moisture retention (vol %)					
pF 2.0		19.7	21.8	24.9	
2.4		17.6	19.4	21.6	
3.0		13.3	15.8	15.9	
4.2		11.1	14.2	13.5	

Soil classification:

FAO - Unesco : chromi-haplic Acrisol

Soil Taxonomy : typic Rhodustult

Profile No. 24

General information on site and soil:

Location: Tanwat - Ndolela, ridge No. 3 Parent material: Gneisses. Landform and Relief: Nearly flat, but dissected plain with moderate to steep convex slopes (2-30%) towards valleys. Vegetation: Open woodland (*Brachestegia spp*) and wooded grassland. Slope of site: The profile is located on a nearly flat plain, slopes of 0 - 2% towards SW. Elevation of site: 980 m.

Soil: Very deep, well drained, with fine loamy dusky red topsoil over clayey, dark red subsoil. The soil has a moderately to weakly developed structure.

Description: The profile was described on 19-11-1986 by A.J. van Kekem and D.N. Kimaro.

Soil profile description:

Ah 0 - 16 cm	very dusky red (2.5YR 2.5/2, moist); sandy clay loam; moderate, fine and very fine, granular and subangular blocky; very friable when moist, sticky and plastic when wet; many pores; many, very fine and fine, roots; clear and smooth to
BA 16 - 36 cm	dark reddish brown (2.5YR 2.5/4, moist); sandy loam; moderate, fine subangular blocky; very friable when moist, sticky and plastic when wet; many, very fine and fine, pores; many very fine, few, fine and medium, roots; clear and smooth to
Bt1 36 - 90 cm	dark red (2.5YR 3/6, moist); sandy clay; weak, fine, subangular blocky; very friable when moist, sticky and plastic when wet; many very fine, few fine, pores; few soft, clay nodules; broken moderately thick cutans; common, fine and very fine, roots; gradual and smooth to
Bt2 90 - 125 cm	dark red (2.5YR 3/6, moist); sandy clay; weak, fine subangular blocky; slightly hard when dry, very friable when moist, sticky and slightly plastic when wet; many, fine and very fine, pores; few clay nodules; patchy, moderately thick cutans; few, few, fine and very fine, roots; gradual and smooth to
Bt3 125 - 175^{+}cm	dark red (2.5YR 3/6, moist); sandy clay; very weak, fine, subangular blocky; very friable when moist, sticky and slightly plastic when wet; many very fine, few fine, pores; few clay nodules; very patchy, thin cutans; few, fine and very fine, roots.

Analytical data

Horizon		Ah	BA	Bt1	Bt2	Bt3
Depth (cm)		0-15	20-35	50-70	90-110	140-160
Texture:						
clay	%	27	14	48	42	46
fine silt	%	5	17	4	4	3
coarse silt	%	10	4	4	7	5
very fine sand	%	8	9	7	8	9
fine sand	%	22	24	16	18	17
medium sand	%	22	26	15	15	14
coarse sand	%	6	6	5	5	5
very coarse sand	%	0	0	1	1	1
Textural class		s.c.l	s.loam	s.clay	s.clay	s.clay
pH water (1:2.5)		5.8	5.1	5.2	5.5	5.7
pH KCl (1:2.5)		4.4	4.1	4.1	4.3	4.3
Organic Carbon	%	1.3	1.1	0.3	0.2	0.3
Av. P, Bray I, mg/kg		24.5	3.2	1.9	1.0	0.6
CEC NH_4OAc	me/100 g	6.9	4.6	4.0	4.6	4.2
exch. Ca	"	1.5	1.1	1.1	0.9	0.5
exch. Mg	"	1.0	0.4	0.6	0.4	0.4
exch. K	"	0.2	0.1	0.1	0.1	0.1
exch. Na	"	0.1	0.1	0.1	0.1	0.1
Base saturation	%	41	36	48	33	26

Soil classification:

FAO - Unesco : chromi haplic Acrisol

Soil Taxonomy : typic Rhodustult

Profile No. 28

General information on site and soil:

Location: Tanwat - Ndolela, 200 m S of office. Parent material: Gneisses. Landform and Relief: Nearly flat, but dissected plain with moderate to steep (2-30%) slopes towards valleys. Land use: Maize land, experimental area. Slope of site: The profile is located on nearly flat plain with 1.5% slope towards S. Elevation of site: 1000 m.

Soil: Very deep, well drained with a moderately well developed structure, with fine loamy dusky red topsoil over clayey dusky red subsoil.

Description: The profile was described on 20-11-1986 by A.J. van Kekem and D.N. Kimaro.

Soil profile description:

Ap
0 - 24 cm
dusky red (2.5YR 3/2, moist); sandy clay loam; moderate, fine, granular and subangular blocky; very friable when moist, sticky and plastic when wet; many pores; many, very fine and fine, roots; clear and smooth to

Bt1
24 - 45 cm
dusky red (1YR 3/4, moist); sandy clay loam; moderate, fine and medium, irregular angular blocky; very friable when wet; many, fine and very fine, few medium, pores; few medium, clay concentrations; very patchy, moderately thick cutans; few, very fine roots; gradual and smooth to

Bt2
45 - 109 cm
dusky red (10R 3/4, moist); clay; moderate, fine and medium, irregular angular blocky; hard when dry; very friable when moist, sticky and plastic when wet; many, fine and very fine, pores; frequent, medium (2-10 mm) clay concentrations with some MnO_2 cover, hard when dry, friable when moist; almost continuous, thick cutans; few very fine roots; diffuse and smooth to

Bt3
109 - 200$^+$cm
dusky red (10R 3/4, moist); clay; weak, fine, subangular blocky; very friable when moist, sticky and slightly plastic when wet; many, very fine and fine, pores; few, medium and large (3-15 mm), soft clay nodules; patchy, moderately thick cutans; no roots.

Analytical data

Horizon	Ap	Bt1	Bt2	Bt31	Bt32
Depth (cm)	0-20	25-45	65-85	120-140	160-180
Texture:					
clay %	35	31	57	52	56
fine silt %	4	9	3	4	4
coarse silt %	7	13	2	3	3
very fine sand %	9	8	6	8	8
fine sand %	24	19	15	16	14
medium sand %	17	15	12	11	10
coarse sand %	4	5	4	5	4
very coarse sand %	0	0	1	1	1
Textural class	s.c.l	s.c.	clay	clay	clay
pH water (1:2.5)	4.7	4.9	5.1	4.8	5.6
pH KCl (1:2.5)	4.0	4.0	4.4	4.2	4.1
Organic Carbon %	1.3	0.8	0.4	0.5	0.2
Av. P, Bray I, mg/kg	46.4	2.2	1.6	0.7	0.7
CEC NH_4OAc me/100 g	7.0	6.6	5.6	4.6	3.6
exch. Ca "	1.5	1.1	1.6	0.6	0.4
exch. Mg "	0.5	0.3	0.6	0.4	0.6
exch. K "	0.1	0.1	0.0	0.0	0.0
exch. Na "	0.1	0.1	0.1	0.1	0.1
Base saturation %	31	24	41	24	31
Bulk density (g/cm^3)		1.40	1.29		
Soil moisture retention (vol %) at					
pF 2.0		21.8	24.9		
2.4		19.1	21.0		
3.0		15.5	17.3		
4.2		13.8	16.0		

Soil classification:

FAO - Unesco : chromi-haplic Acrisol

Soil Taxonomy : typic Rhodustult

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Annex 2. Chemical soil fertility data of composite topsoil samples (0 - 25 cm)

Mapping unit*)	Site No.	pH H20	pH KCl	organic matter%	Total N%	CEC me/100g	Exch. Cations(me/100g) Ca	Mg	K	Na	KCl Exch.H me/100g	KCl Exch.Al me/100g	Avail.P mg/kg	Site characteristics
P	1	5.2	4.2	2.0	0.10	6.1	1.4	1.1	0.3	0.1	0.2	0.4	30.6	one harvest
	2	7.4	7.0	1.6	0.06	3.8	6.0	2.0	0.5	0.1			72.6	one harvest
	3	6.2	5.0	3.2	0.10	8.1	3.5	1.9	0.5	0.1			13.0	woodland
	4	5.6	4.3	1.1	0.07	5.0	1.1	0.9	0.2	0.1			19.7	woodland
	10	5.8	4.5	2.4	0.08	5.9	1.5	1.2	0.3	0.1			4.4	newly cleared
	11	5.5	4.4	3.3	0.08	9.9	1.6	1.3	0.2	0.1			4.6	trees cleared
	12	5.4	4.2	2.6	0.07	6.8	1.5	0.9	0.3	0.1	0.3	0.3	3.7	open woodland
	14	5.1	4.1	3.1	0.10	9.1	1.0	0.6	0.2	0.1	0.4	0.6	3.8	woodland
	15	5.3	4.2	3.3	0.11	6.1	1.7	1.2	0.2	0.1	0.4	0.6	4.6	woodland
	16	5.9	4.7	3.0	0.10	7.6	1.8	1.5	0.2	1.1			11.0	trees cleared
	20	5.9	4.7	2.9	0.09	9.1	2.0	1.0	0.2	0.1			6.9	wooded grassland
	23	5.6	4.5	1.8	0.09	4.5	1.6	0.9	0.2	0.1			11.1	poor arable
	24	5.9	4.7	2.4	0.12	8.2	1.7	1.5	0.2	0.1			33.7	wooded grassland
	28	5.0	4.1	2.2	0.06	7.0	1.5	1.3	0.2	0.1	0.4	0.5	19.3	experimental side
	30	5.7	4.5	3.6	0.18	11.4	1.6	1.3	0.3	0.1			4.0	woodland
S	5	6.1	5.0	1.7	0.11	5.6	1.9	1.4	0.3	0.1			1.7	woodland
	6	5.5	4.2	1.7	0.10	6.5	1.1	0.9	0.2	0.1			3.5	woodland
	18	5.6	4.4	2.0	0.05	6.3	1.3	1.0	0.2	0.1			4.6	wooded grassland
	21	5.7	4.4	2.7	0.09	8.2	2.6	1.0	0.2	0.1			26.1	wooded grassland
	29	5.6	4.4	3.6	0.11	9.3	1.6	1.3	0.3	0.1			5.8	woodland
F	7	5.4	4.3	1.2	0.08	4.8	1.5	1.2	0.2	0.1	0.4	0.0	12.5	one harvest
	8	5.5	4.2	2.5	0.06	6.9	1.4	0.6	0.3	0.1			4.8	newly cleared
	9	5.4	4.3	3.1	0.09	10.1	1.8	0.9	0.3	0.1	0.3	0.3	10.2	newly cleared
	22	5.8	4.7	2.4	0.10	7.4	2.0	1.5	0.3	0.1			4.8	newly cleared
V	27	5.9	4.8	6.5	0.23	8.1	3.3	1.1	0.2	0.1			3.1	valley bottom

*) See map in back cover

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NATIONAL SOIL SERVICE
TARO MLINGANO

TANZANIA WATTLE COMPANY

PHYSIOGRAPHY AND SOILS

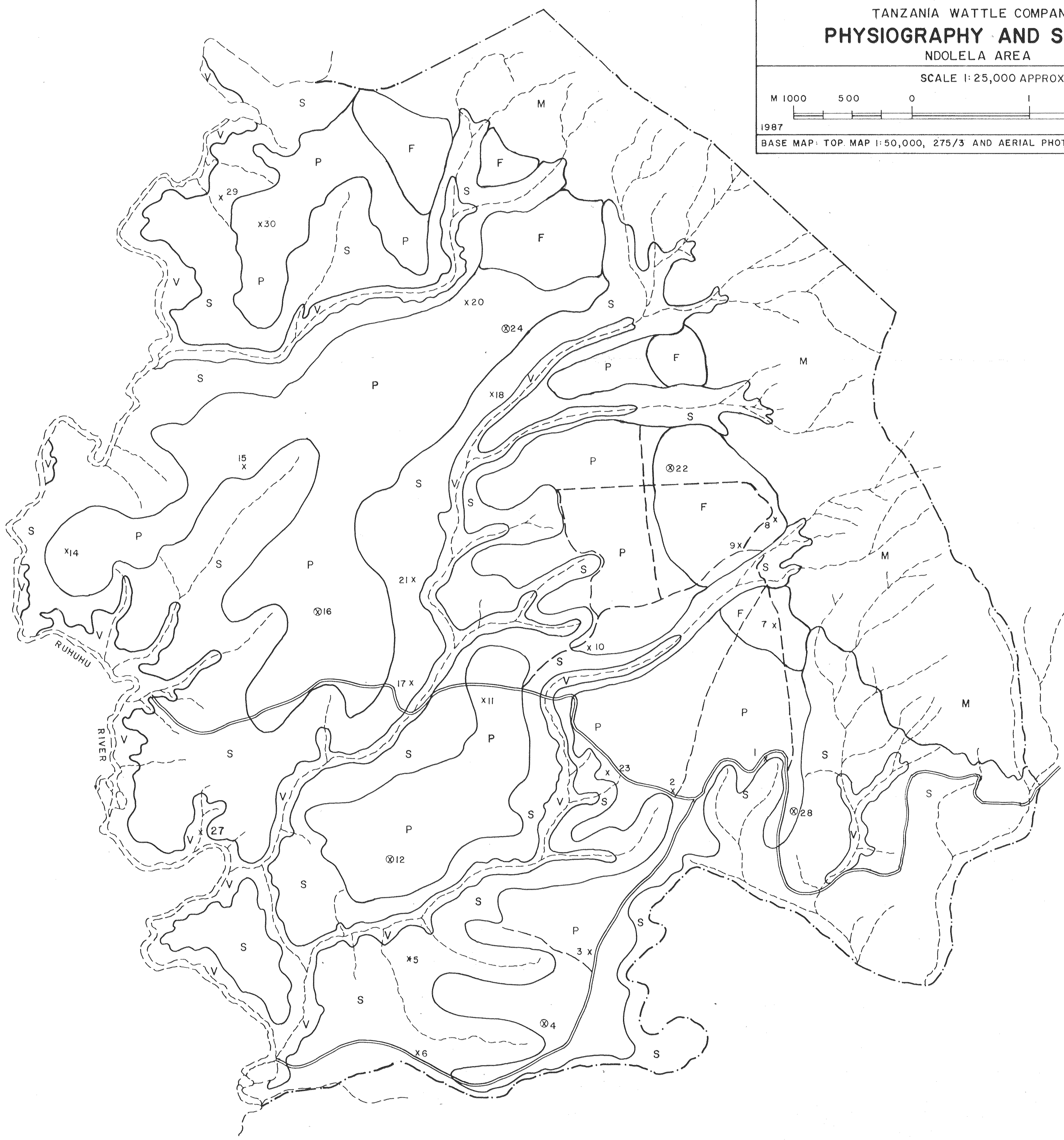
NDOLELA AREA

SCALE 1: 25,000 APPROX.

M 1000 500 0 1 2 Km.

1987 REPORT R3

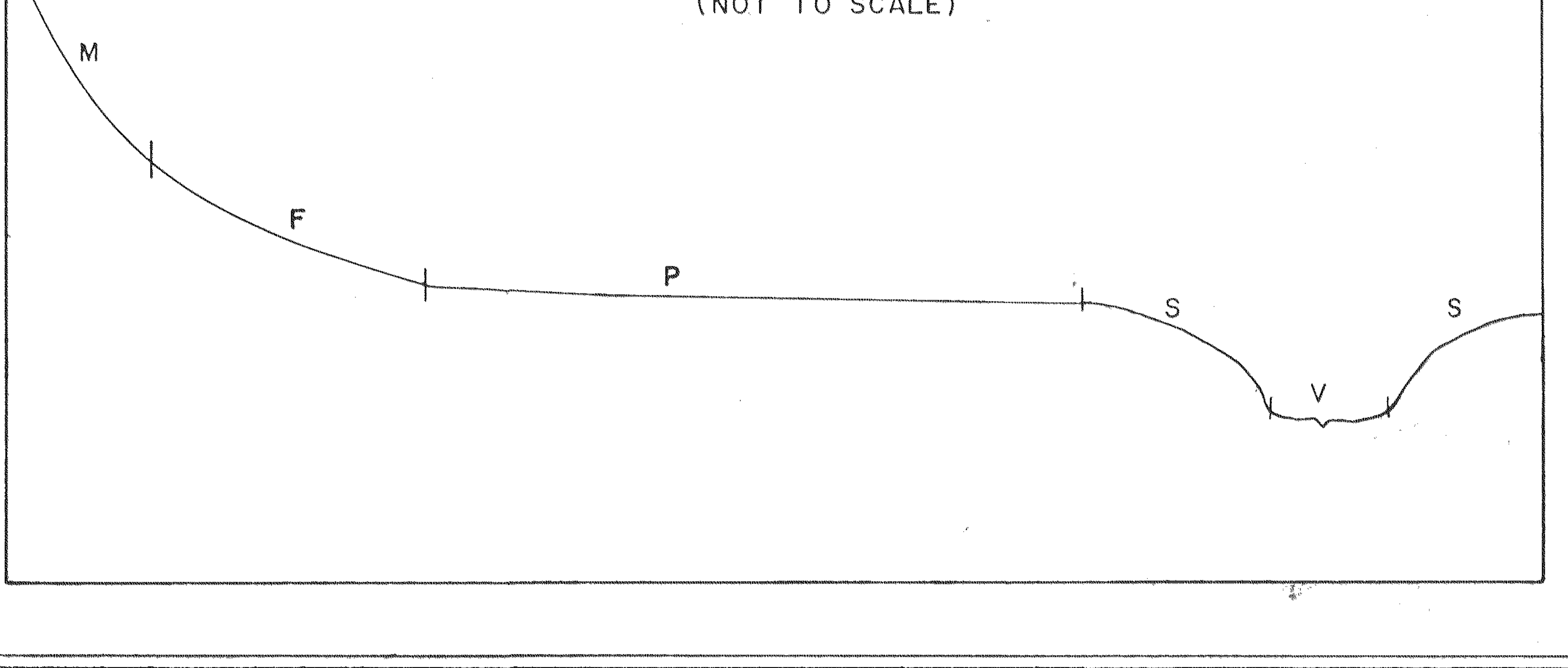
BASE MAP: TOP. MAP 1:50,000, 275/3 AND AERIAL PHOTOGRAPHS 1:25,000



LEGEND

MAP CODE	LANDFORM CHARACTERISTICS	SOIL CHARACTERISTICS
M	mountain slopes (over 8%)	no data
F	gently sloping footslopes (2-8%)	very deep, well drained soils with thin sandy clay loam topsoils, over dusky red to dark red clayey subsoils
P	flat to nearly flat plains (0-2%)	very deep, well drained soils with thin sandy clay topsoils, over red clayey subsoils.
S	gentle to steep slopes towards valley bottoms (2 to over 25%)	very deep, well drained soils, with very thin sandy clay loam topsoils, over red clayey subsoils, locally gravelly.
V	flat valley bottoms (0-2%)	very deep, very poorly drained soils with humiferous topsoils over loamy to clayey subsoils, mottled to about 50cm depth

SCHEMATIC CROSS SECTION
(NOT TO SCALE)



KEY

— · — · —	survey area boundary
———	mapping unit boundary
⊗22	soil pit
x6	composite topsoil sample
═══	major track
— — —	minor track
- - - -	stream
1sq.cm	6·25 ha

N