# SOILS OF THE KWAMTILI ESTATE
# and their
# SUITABILITY FOR CULTIVATION
# of
# COCOA and COCONUT

NATIONAL SOIL SERVICE
TARO-AGRICULTURAL RESEARCH INSTITUTE, MLINGANO
TANGA-TANZANIA

Detailed Soil Survey Report D6

1986

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SUMMARY

This report presents the results of a detailed soil survey and physical land resources evaluation for cocoa and coconut cultivation of the Kwamtili Estate in Tanga Region, as a basis for the Estate's rehabilitation and diversification. The Estate covers 462 ha and is located in an area with a high degree of variability in its environmental features and attributes.

Among the climatic aspects, the annual rainfall shows extremes as low as 830 mm and as high as 2310 mm, with a mean annual value of 1556 mm. The rainfall distribution over the year also shows enormous variations. Dry spells occur frequently in the area. In an average year the rainfall falls short of the potential evapotranspiration during a cumulative period of 8 months, and long dry spells of 110 consecutive days have been recorded. The unpredictability of the rainfall and the occurence of long dry spells in some years are major limitations for crop production in the area.

The topography at the Estate also shows a great deal of variation. The area is strongly dissected and steep slopes are present throughout the estate. Slopes of less than 8% are found on about a third of the Estate lands (= 140 ha), about half the area (= 245 ha) has slopes between 8 - 30%, and the remaining 80 ha is steeper than 30%. The flatter parts are usually small in size.

The soil conditions at the Estate vary considerably over short distances. Most soils of the area are ferruginous deep, sandy clays and clays, moderately acid, but fairly well provided with nutrients. Many soils however are gravelly and/or shallow which are crucial factors for root development and moisture storage. Five different soil series have been recognized, each with a number of phases for slope, effective depth and presence of gravel, occuring in a complex pattern over short distances.

Considering the occurence of long dry spells, the effective depth of gravel free soils should preferably be 150 cm or more. An effective depth of 80 cm has been considered as an absolute minimum

for successful and sustained cultivation of the two crops. About 35% or 170 ha of the estate have soils with a depth less than 80 cm, whereas another 25% or 110 ha have a high gravel content, resulting in only a marginal potential for cultivation.

Deep and very deep soils cover 80 ha and 100 ha of the Estate respectively. Of these lands however, 84 ha have soils with drainage problems or are subject to regular flooding.

The results of the land suitability evaluation are summarized as follows :

Suitability for the cultivation of cocoa

| | | |
|---|---|---|
| Highly suitable land, without major limitations | not present | |
| Suitable land, with only slight limitations | 55 ha | (12%) |
| Moderately suitable land | 90 ha | (19%) |
| Marginally suitable land | 133 ha | (29%) |
| Not suitable land | 184 ha | (40%) |

Suitability for the cultivation of coconut

| | | |
|---|---|---|
| Highly suitable land, without major limitations | 37 ha | ( 8%) |
| Suitable land, with slight limitations | 42 ha | ( 9%) |
| Moderately suitable land | 145 ha | (31%) |
| Marginally suitable land | 21 ha | ( 5%) |
| Not suitable land | 217 ha | (47%) |

The overall results of the land evaluation in terms of the physical suitability indicate that the Kwamtili Estate lands in general have a limited potential for cultivation of cocoa and coconut. Highly to moderately suitable land for cocoa **covers** only approximately 30% of the Estate and approximately 50% for coconut. However the strong variability of the soil conditions over short distances and the consequent complexity of the physical suitability of the Estate lands within each block strongly affects the management of the lands.

# CHAPTER 1 - INTRODUCTION

## 1.1 PURPOSE OF THE SURVEY

The present study on the soils of the Kwamtili Estate has been undertaken to determine the physical land suitability and the development prospects of the area with respect to the cultivation of cocoa and coconut. The results will serve as a necessary basis for the rehabilitation diversification of the Estates.

Although cocoa has been grown on the Estate since 1961, the Estate management has been faced with many problems over the years. New investiments are proposed to consolidate and rehabilitate the area already cultivated with cocoa and to diversify by the introduction of coconut palms. This is to change eventually the product mix and replace the existing mono-culture system.

The National Soil Service has been requested to carry out a soil survey and land evaluation study including the preparation of soil and land suitability maps at a scale of 1:5,000.

## 1.2 LOCATION OF THE SURVEY AREA

The Kwamtili Estate, covering about 460 ha, is located in Tanga Region, Korogwe District, about 50 km west of Tanga town. The Estate is situated between $4^{o}55'$ S and $38^{o}44'$ E, almost at the foot of the Eastern Usambara Mountains, and partly in the valley of the Muzi River, as indicated in Fig. 1.

The western boundary of the Estate is formed by the Muzi river, whereas the Kwamguni Mountain forms the eastern Estate boundary. The elevation is between 140 - 250 m above sealevel.

## 1.3 ORGANIZATION AND IMPLEMENTATION OF THE SURVEY

The survey has been carried out between January and May 1985. The Kwamtili area has been studied by a team consisting of two survey parties, each with two senior and one assistant soil surveyor.

Map compilation, analyses of the soil samples and report writing took place after the survey team returned from the field.

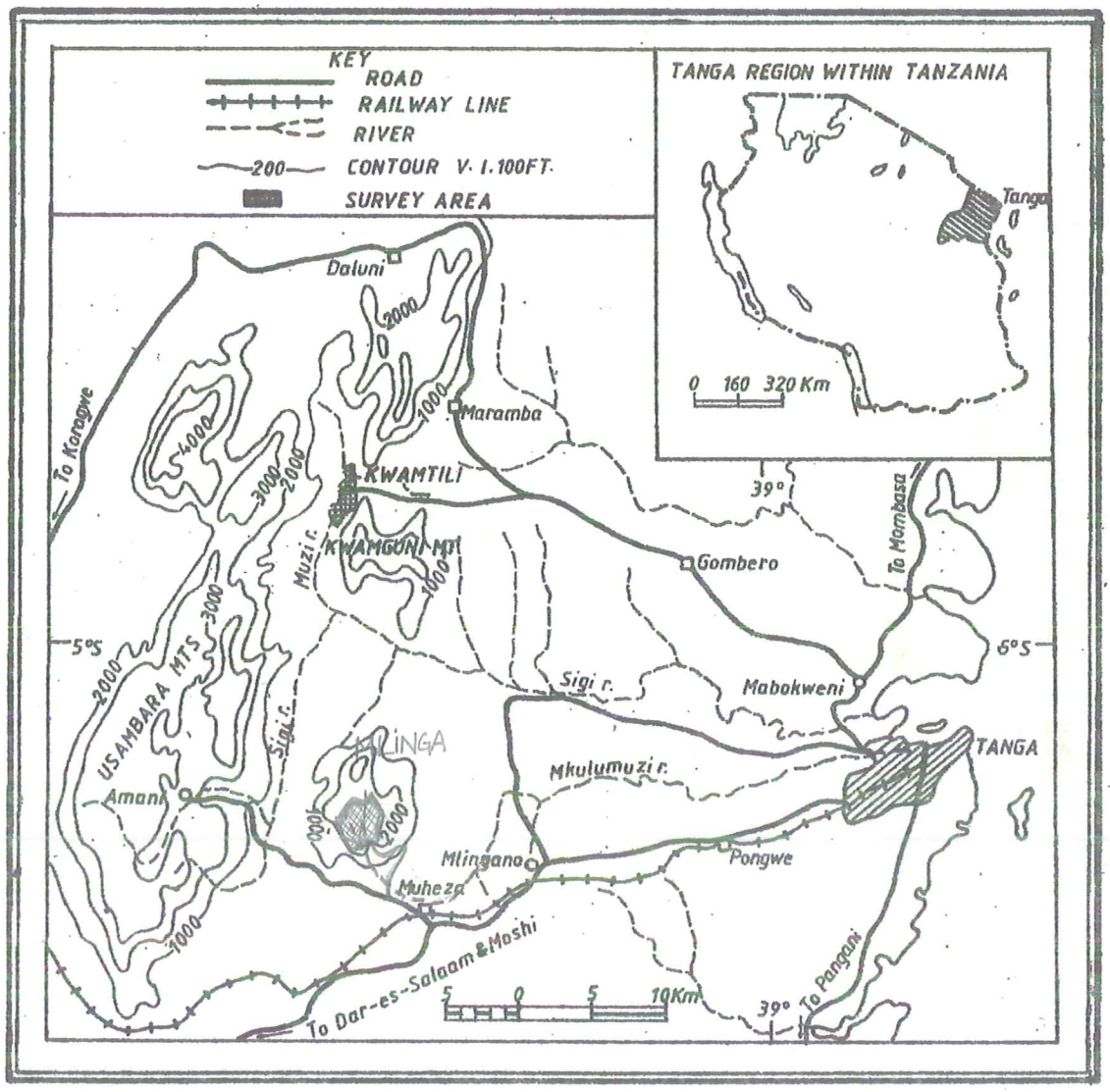


Fig.1:- Location of Kwamtili Estate (Tanga Region)

The following staff of the NSS participated in the survey :

Mr. S.E. Mugogo, Scientific officer
Mr. S. Nzabayanga, Scientific officer
Mr. Z.A. Mmari, Agricultural field officer
Mr. R.K. Kimaro, Agricultural field officer
Mr. D.A. Kingalu, Agricultural field assistant
Mr. J.K.W. Niemeyer, Soil survey technical advisor

Map and report preparation was in the hands of Mr. J.K.W. Niemeyer. Mr. G.W. van Barneveld assisted in the editing of the chapter on Land Suitability Evaluation. Useful comments on the draft text were received from Mr. K.L. Haule, Mr. J.F. Harrop and Mr. A.J. van Kekem of the National Soil Service.

Chemical and physical analyses of the samples collected during the field work have been carried out under the direction of Messrs. F. Kiango and B. Kiwambo of the NSS laboratory in Mlingano. The drawing of the final maps was done by Mr. S.V. Assenga, cartographic draughtsman. Typing of the report was carried out by Mrs. B. Pasipanodya.

# CHAPTER 2 - ENVIRONMENT

## 2.1 CLIMATE

### 2.1.1 General

The climate in the Kwamtili area is predominantly governed by the atmospheric circulation of the intertropical convergence zone, a low pressure zone with adjacent high pressure belts to its north and its south. These three pressure zones oscillate north and south annually resulting in a monsoon climate with a bi-modal rainfall regime.

According to Köppen the climate can be classified as Aw"i, i.e. a tropical bi-modal savannah climate with a difference of less than 5°C between the mean monthly temperatures of the warmest and the coldest month.

Table 1 : Temperature, rainfall and potential evapotranspiration data of the Kwamtili Estate area
(sources: Agrar- und Hydrotechnik, 1976a; Kwamtili Estate records; Agrar- und Hydrotechnik, 1975)

| | temperature (°C) | | | rainfall (mm) | | | potential evapotranspiration (mm) |
|---|---|---|---|---|---|---|---|
| | max. | min. | mean | mean | standard deviation | 80% probability | |
| Jan | 32.4 | 21.7 | 27.1 | 79 | 70 | 20 | 173 |
| Feb. | 33.3 | 21.7 | 27.5 | 47 | 35 | 18 | 168 |
| Mar. | 32.8 | 21.9 | 27.4 | 147 | 99 | 64 | 166 |
| Apr. | 30.6 | 21.8 | 26.2 | 202 | 117 | 104 | 139 |
| May | 28.6 | 20.9 | 24.8 | 190 | 115 | 93 | 123 |
| June | 28.2 | 19.5 | 23.9 | 73 | 44 | 36 | 117 |
| July | 27.7 | 18.7 | 23.2 | 78 | 41 | 44 | 115 |
| Aug. | 27.9 | 18.4 | 23.2 | 74 | 46 | 35 | 123 |
| Sep. | 28.5 | 18.7 | 23.6 | 111 | 94 | 32 | 138 |
| Oct. | 29.5 | 19.6 | 24.6 | 178 | 137 | 63 | 153 |
| Nov. | 30.8 | 20.7 | 25.8 | 216 | 139 | 99 | 152 |
| Dec. | 31.5 | 21.7 | 26.8 | 162 | 87 | 88 | 164 |
| Year | 30.1 | 20.4 | 25.3 | 1556 | 450 | 1178 | 1731 |

At the Kwamtili Estate only rainfall is recorded and these data have been used for the computation of the monthly rainfall figures indicated in Table 1. In this table the temperature data are the ones at the Mlingano Agricultural Research Institute, being the nearest place (about 30 km southeast of Kwamtili) with sufficient and representative temperature data. The potential evapotranspiration data are also based on information of Mlingano.

### 2.1.2 Characteristics of the main weather seasons

In the Kwamtili area four main weather seasons can be distinguished, distributed through the annual cycle as follows :

- the long rainy season, from late March to the end of May
- the intermediate season, from early June to early October
- the short rainy season, from mid-October to mid-December
- the main dry season, from late December to mid-March.

#### a) the long rainy season

On average this main rainy season starts during the last week of March and continues till the end of May. The onset of the rains, however can be as early as mid-February or as late as the last week of April. The end of the season is not very predictable either and fluctuates considerably from year to year. The rains may already cease by the end of April but they may also continue till late July.

The average length of the season is 85 days, with a mean seasonal rainfall of 590 mm. The length of the season can vary between 20 days and 140 days, with a variation in precipitation between 115 mm and 1290 mm. Rainfall usually exceeds evapotranspiration during this season. Periods of one or two weeks with dry weather may occur, but are not very common. The rainfall is mainly of the convectional type with some orographic rain at the end of the season.

The mean temperature during the long rainy season is 25.5°C, with mean minimum temperatures between 21 - 22°C and mean maximum temperatures between 29 - 31°C.

b) the intermediate season

Once the long rains cease an intermediate season starts (between the long rains and the short rains), characterized by changeable weather with dry periods and rainy periods succeeding each other. Mean temperatures are about 23 - 24°C with mean minima. of 18 - 19°C and mean maxima of around 28°C.

This season starts on average in early June and continues till mid-October. Also this season however, is very variable. It can already begin in early May or only by late July. It ends with the onset of the short rains which can be as early as mid-August or as late as the end of November. During its average length of 120 days the seasonal rainfall is 225 mm. The variation of the length over the years is between 40 days and 190 days, whereas the precipitation can vary between 70 mm and 360 mm.

The rainfall during this season is almost entirely of the orographic type, resulting from moisture-laden air that is forced to rise over the Usambara Mountains. Especially during the period June - August the skies are frequently overcast, resulting in a considerable reduction in radiation temperature and hence evapotranspiration. However, the latter still exceeds precipitation during this season but . no serious droughts occur, particularly due to residual soil moisture from the long rains.

c) the short rainy season

The short rains are less reliable than the long rains with respect to their onset as well as to their intensity. On average they start during the last week of October, but the commencement of the short rains can vary from late August to late November. In general the rains stop by mid-December, but also the end of the rains shows considerable fluctuations over the years, from early November to the first week of January. On average the length of this season is 65 days, but a length of 130 days has been recorded as well. Occassionally the short rains can be absent completely as for instance in 1983 (see Table 2), and in such cases the intermediate season merges into the main dry season resulting in a very serious drought.

The mean precipitation during the short rains is 550 mm, with recorded extreme values of 40 mm (during a failing season) and 1290 mm. In general the precipitation exceeds the evapotranspiration, but about one in every four years will give a serious shortfall in the precipitation.

Table 2 : Monthly, mean monthly, annual and mean annual rainfall data (in mm) covering the period 1961-1984, recorded at Kwamtili.

| Year | J | F | M | A | M | J | J | A | S | O | N | D | Year total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1961 | 86 | 33 | 51 | 106 | 171 | 57 | 108 | 68 | 172 | 368 | 401 | 164 | 1785 |
| 1962 | 146 | 70 | 146 | 126 | 50 | 29 | 79 | 99 | 56 | 44 | 70 | 212 | 1127 |
| 1963 | 73 | 64 | 136 | 298 | 115 | 112 | 70 | 36 | 55 | 73 | 372 | 226 | 1630 |
| 1964 | 47 | 46 | 184 | 157 | 138 | 38 | 8 | 74 | 52 | 192 | 25 | 127 | 1088 |
| 1965 | 80 | 23 | 122 | 107 | 224 | 13 | 50 | 98 | 149 | 248 | 292 | 137 | 1543 |
| 1966 | 152 | 60 | 265 | 158 | 243 | 104 | 38 | 61 | 71 | 114 | 115 | 16 | 1397 |
| 1967 | 8 | 50 | 132 | 318 | 354 | 41 | 114 | 85 | 428 | 279 | 380 | 54 | 2243 |
| 1968 | - | 81 | 290 | 189 | 243 | 154 | 48 | 68 | 30 | 168 | 403 | 119 | 1793 |
| 1969 | 109 | 59 | 156 | 101 | 156 | 59 | 59 | 206 | 68 | 343 | 374 | 57 | 1747 |
| 1970 | 103 | 13 | 143 | 122 | 130 | 26 | 49 | 39 | 80 | 68 | 54 | 255 | 1082 |
| 1971 | 18 | 4 | 192 | 106 | 112 | 130 | 104 | 38 | 43 | 26 | 12 | 119 | 904 |
| 1972 | 125 | 95 | 45 | 145 | 360 | 8 | 95 | 53 | 269 | 353 | 322 | 249 | 2119 |
| 1973 | 61 | 52 | 111 | 225 | 138 | 59 | 25 | 74 | 44 | 88 | 179 | 135 | 1191 |
| 1974 | 71 | 10 | 24 | 102 | 97 | 68 | 143 | 44 | 27 | 64 | 155 | 25 | 830 |
| 1975 | 127 | - | 96 | 127 | 100 | 58 | 68 | 24 | 143 | 83 | 76 | 197 | 1099 |
| 1976 | 18 | 97 | 135 | 300 | 154 | 86 | 69 | 47 | 135 | 130 | 77 | 85 | 1333 |
| 1977 | 47 | 22 | 71 | 129 | 40 | 52 | 31 | 168 | 229 | 389 | 214 | 304 | 1696 |
| 1978 | 191 | 114 | 431 | 564 | 170 | 113 | 61 | 33 | 21 | 63 | 372 | 175 | 2308 |
| 1979 | 298 | 115 | 194 | 344 | 549 | 113 | 78 | 57 | 88 | 87 | 223 | 142 | 2288 |
| 1980 | 29 | 39 | 25 | 222 | 148 | 14 | 52 | 164 | 84 | 10 | 317 | 217 | 1321 |
| 1981 | 40 | 17 | 325 | 132 | 143 | 57 | 82 | 77 | 79 | 340 | 66 | 346 | 1704 |
| 1982 | 57 | 29 | 62 | 167 | 255 | 109 | 180 | 55 | 192 | 452 | 373 | 195 | 2126 |
| 1983 | - | 36 | 91 | 191 | 338 | 77 | 135 | 60 | 85 | 36 | 70 | 67 | 1186 |
| 1984 | 15 | - | 96 | 417 | 142 | 166 | 122 | 40 | 63 | 258 | 235 | 239 | 1793 |
| mean | 79 | 47 | 147 | 202 | 190 | 73 | 78 | 74 | 111 | 178 | 216 | 161 | 1556 |
| S.D. | 70 | 35 | 99 | 117 | 115 | 44 | 41 | 46 | 94 | 137 | 139 | 87 | 450 |

d) the main dry season

The short rains are followed by the main dry season, which is to start by mid-December and will end around mid-March. Occassionally the dry season will be much longer than its average length of 95 days, especially when the short rains fail, e.g. in 1971 and 1983. The dry season can be much shorter as well, when the short rains more or less merge into the long rains, as in seasons 1977/1978 and 1978/1979 (see Table 2). Extreme dry seasons of 270 days and 20 days respectively have been recorded.

The main dry season is characterized by dry spells of several weeks with interruptions of short periods with heavy rainstorms. High temperatures prevail, the mean temperatures range around 26 - 27°C with mean maxima around 31 - 33°C. Strong north-easterly (Kaskazi) winds are typical for this season. Like during the intermediate season the rains are of orographic origin. The average precipitation is 185 mm, with a variation of 20 mm to 445 mm, The monthly rainfall data (as given in Table 2) are mis-leading because the precipitation is concentrated in a few rainstorms and therefore is not very effective to crop production.

Table 2 presents the monthly rainfall data of the period 1961 - 1984 and clearly indicates the high degree of variation in the four weather seasons at Kwamtili.

In section 3.4 the rainfall and the potential evapotranspiration data are used together with the waterholding characteristics of the soils to determine the impact of the dry spells on the two crops cocoa and coconut.

## 2.2 GEOLOGY AND PHYSIOGRAPHY

### 2.2.1 Geology

In the geological sense the rocks occuring at the Estate belong to the Usaguran system and they are of metamorphic origin. In general the rocks belong structurally to the big north - south Mozambique belt, and probably are of Archaen (Pre-Cambrium) age. The rocks are extensively migmatized. The main rock types are

pyroxene, hornblende, acid granulites, and banded gneisses, in which quartz and feldspars are the dominant minerals, although garnet and biotite commonly are major constituents (Agrar- und Hydrotechnik, 1976b).

Faulting is responsible for the uplifting of the Usambara Mountains in general as well as for the formation of a number of valleys in particular, of which the Muzi river valley is one. The NNE fault of the Muzi valley is probably a dextral tear fault, accompanied by a number of small secondary faults at an angle with the main fault (Hartley & Moore, 1965).

### 2.2.2 Physiography

Kwamtili Estate is situated at the foot of the Usambara Mountains Complex. Due to secondary faulting (probably in connection with the uplifting of the Usambaras) a dense drainage system has been formed giving the landscape a "hummocky" character of small rounded hills. Particularly from the air or on aerial photographs this "hummocky" landform is very striking.

Three landscape units may be distinguished in the area as follows:

Hills and ridges : the higher "hummocks" within the Estate, having their base at altitudes between 160 - 200 m above sealevel. Mostly these hills are 30 - 80 m elevated above their surrounding, with a maximum altitude of 250 m above m.s.l. The almost flat summits are usually small and narrow, the upper slopes are mostly sloping to moderately steep (8 - 30%), whereas the middle and lower slopes usually have gradients between 15 - 50%.

Small valley bottoms : the small valleys seperate the individual hills and ridges. The small streams in these convex and U-shaped valleys carry water most of the time, but the smallest ones as well as the sections higher up-stream run dry during the dry season.

Alluvial flats of the Muzi river : built up from recent alluvial deposits of the Muzi river these flats are the lowest parts of the Estate at altitudes between 140 - 160 m above m.s.l. In most places the flats are narrow, between 30 - 50 m, but locally, where the river has formed big looping meanders, they are as wide as 200 - 300 m. Flooding of the flats occurs annually.

# CHAPTER 3 - SOILS

## 3.1 PREVIOUS WORK

In 1961 Anderson studied the nearby Maramba Estate (Anderson, 1961 and 1963). He described representative soils of the upper slopes on three types of parent material, i.e. basic, intermediate and quartzofeldspathic gneisses. Although the marked differences in soils related to the differences in parent material do not seem to be present in the Kwamtili area, the soil types of Anderson resemble the ones at Kwamtili. Anderson's 'ferruginous tropical soils' and 'ferralitic soils with stonelines' are the Kwamtili and Mtai series respectively of the present study.

A reconnaissance soil survey of the whole of the Tanga Region shows major physiographic units with soil complexes and associations (Agrar- und Hydrotechnik, 1976c). For the Kwamtili area 'undulating to rolling footslopes around the mountains' are indicated, 'with moderately deep to deep, well drained, yellowish red clay loams and clays with moderate organic matter contents in the topsoils'. The soils have been classified as a complex of Chromic Luvisols, Luvic Phaeozems and Chromic Cambisols. The present detailed study confirms this general description and classification, although the dominant soils at Kwamtili are better classified as Ferric Luvisols and Ferralic Cambisols.

## 3.2 SURVEY METHODS

Prior to the fieldwork a physiographic photo-interpretation was carried out using enlargements of aerial photographs taken in 1976 by Geosurvey International Ltd. Nairobi. The photographs are of very good quality. The scale of the original photographs is approximately 1:30,000, the enlargements employed are at an approximate scale 1:12,500. The image numbers are 2447 and 2448 of film 286, run 20. The photographs were used not only for interpretation but also as a base map for the preparation of the soil and suitability maps. The photographs used are not rectified and using this material as a

basemap has the disadvantage that the scale is only approximate. Consequently, the maps should not be used for precise measurements of distances and surfaces and the hectarages presented in this report may thus slightly differ from reality.

In the field first the physiographic deliniations based on the photo-interpretation were checked. Next the major soils of each physiographic unit were studied and described.

The actual field mapping was done with help of the 1:12,500 scale aerial photographs, together with the Kwamtili Estate Map of 1969, at a scale of 1:5,000. A total of 250 field observations were made, being augerings to a maximum depth of 200 cm following a free survey pattern. In a free survey the observations are located along physiographically determined representative toposequences and at places where surface features indicate possible soil differences. In addition 11 profile pits were described in detail and from these pits 49 samples were collected for chemical and physical analyses in the laboratory of the National Soil Service at Mlingano.

As a result of both fieldwork and laboratory analyses each mapping units is described in terms of soil type, gravel content and depth, slope angle and position on the slope as main parameters. These results of the survey are presented on the 1:5,000 soil map.

## 3.3 DESCRIPTION OF SOIL SERIES AND MAPPING UNITS

### 3.3.1 Systematics and nomenclature

The soils of the Kwamtili Estate have been mapped at series level. A soil series is defined as a natural group of soils with a unique combination of site features and morphological characteristics. Five soil series have been distinguished, based on the differences in soil depth, soil drainage and soil texture.

For each soil series phases have been indicated. Soil phases are sub-divisions of soil series based on characteristics which are significant to the use and management of the land but are not diagnostic for the separation of the soil series themselves. The phases recognized are gravel, slope and soil depth phases.

Mapping units as they appear on the soil map are basically natural landform units, each with a particular pattern of soils. On the map they are indicated with a code and their major characteristics are described in the legend. The codes have the form of a fraction. The numerator of the code indicates the landform, the denominator shows the soils (series and phase) found within the unit.

The landform units recognized at Kwamtili have been described in section 2.2.2. The codes used for the landform units are :

H - Hills and ridges
- Hs - Hillslopes
  - Hs1 - sloping
  - Hs2 - moderately steep
  - Hs3 - steep
  - Hs4 - very steep
- Hl - Lower hillslopes
  - Hl1 - sloping
  - Hl2 - moderately steep

V - Valleys
- Vs - Valley sideslopes
  - Vs1 - sloping
  - Vs2 - moderately steep
- Vw - Valley bottoms, waterlogged

A - Alluvial flats
- Aa - Alluvial floodplains

The description of the soils of each mapping unit follows the outlines and definitions given in the FAO 'guidelines for soil profile description' (FAO, 1977). Each series has been classified according to the FAO/Unesco 'legend of the soil map of the world' (Unesco, 1974), and according to the USDA Soil Taxonomy (Soil Conservation Service, 1975).

The classes employed for soil depth, organic matter content and soil reaction are as given below.

| thickness of topsoil (cm) | class |
|---|---|
| 0 - 10 | very thin |
| 10 - 20 | thin |
| 20 - 30 | moderately thick |
| 30 - 40 | thick |
| over 40 | very thick |

| thickness of solum (cm) | class |
|---|---|
| 0 - 25 | very shallow |
| 25 - 50 | shallow |
| 50 - 80 | moderately deep |
| 80 - 120 | deep |
| over 120 | very deep |

| organic matter content (%) | class |
|---|---|
| below 1 | very low |
| 1 - 3 | low |
| 3 - 8 | moderate |
| 8 - 15 | high |
| over 15 | very high |

| soil reaction (pH - $H_2O$) | class |
|---|---|
| 6.7 - 7.3 | neutral |
| 6.1 - 6.6 | slightly acid |
| 5.6 - 6.0 | medium acid |
| 5.1 - 5.5 | strongly acid |
| 4.5 - 5.0 | very strongly acid |

### 3.3.2 Soil series and mapping units

This paragraph describes the five soil series recognized at the Kwamtili Estate, together with their physiographic setting. A detailed and technical description of typifying profiles of each series, together with the chemical and physical laboratory data is given in Appendix II.

Hs/Kw KWAMTILI SERIES, typical phase

The Kwamtili series are very deep, well drained soils, with colours ranging from yellowish red to red. They are mainly sandy clay to clayey, with the topsoils usually slightly sandier. Below 100 cm depth these soils may have a gravel content upto 15%. The soil reaction is slightly to medium acid. The soils have a moderate natural fertility and often good possibilities for root development.

Setting: The Kwamtili series occur mainly on the slopes of the hills and ridges, with slopes ranging from 15% to as much as 45%. They are also found on some of the summits. On the estate they cover 65 ha (= 14%) in total.

Topsoil characteristics: The topsoils are 10 - 20 cm deep and have dark reddish brown colours. They are sandy clay loam to clay loam mainly, but sandy clay occassionally occur. They are moderately well structured, with friable, subangular structures. The organic carbon content is moderate (2.0 - 2.5%) and the C/N ratios are around 9. They are slightly acid to neutral, with pH values between 6 and 7.

Subsoil characteristics: The subsoils below 10 - 20 cm have yellowish brown to red colours, clayey textures, and are friable with moderate subangular blocky structures. The subsoils are uniform in appearance and they have more clay than the topsoils. Below 100 cm small amounts (2 - 5%) of fine gravel is usually present. In places the gravel content can be as high as 15%.

Natural fertility aspects: The soils have a moderate organic matter content and a moderate level of total nitrogen. The amount of available phosphorus is low. The soils have a high capacity to retain nutrients, but the actual amounts of calcium and potassium are moderate to low. The pH values range between 5.5 and 6.5.

Soil classification: FAO/Unesco : Ferric Luvisol
USDA : Oxic Paleustalf

The mapping units distinguished are :

Hs1/Kw on crest, upper and middle slopes, 2-16%; extent 30 ha

Hs2/Kw on upper and middle slopes 16-30%; extent 15 ha

Hs3/Kw on upper and middle slopes 30-45%; extent 10 ha.

Hl/Kw KWAMTILI SERIES, lower slope phase

The soils of this phase of the Kwamtili series are similar to the soils of the typical phase. The location on the lower slopes, however results in an influx of lateral soil water from the lands higher on the slopes. This process continues during a part of the dry season, which gives these soils a better soil moisture status and consequently they are less susceptible to drought stress.

The mapping units recognized are :

Hl1/Kw on lower slopes, 8-16%; extent 7 ha

Hl2/Kw on lower slopes, 16-30%; extent 3 ha.

Hs/Kwd KWAMTILI SERIES, deep phase

This phase of the Kwamtili series consists of deep soils with an effective soil depth of 80 - 120 cm. The other soil properties and the fertility aspects, as well as the topographic setting of the soils of this phase are similar to those of the Kwamtili series, typical phase. In total this deep phase covers 31 ha (= 7%) of the estate.

The mapping units distinguished are :

Hs1/Kwd on crests and hillslopes, 2-16%; extent 12 ha

Hs2/Kwd on hillslopes, 16-30%; extent 12 ha

Hs3/Kwd on hillslopes, 30-45%; extent 5 ha

Hs4/Kwd on hillslopes, 45-60%; extent 2 ha

Hs/Kwg KWAMTILI SERIES, gravelly phase

This phase of the Kwamtili series comprises deep soils, with a gravel content in the subsoil below 50 cm of over 15%, often as high as 50%, thus limiting the effective depth of the soils. With respect to their other properties and fertility aspects these soils are similar to the soils of the Kwamtili series, typical phase. The total area covered by this phase is 81 (= 17%) of the estate.

The mapping units recognized are :

Hs1/Kwg on crests and hillslopes, 2-16%; extent 15 ha

Hs2/Kwg on hillslopes, 16-30%; extent 51 ha

Hs3/Kwg on hillslopes, 30-45%; extent 13 ha

Hs4/Kwg on hillslopes, 45-60%; extent 2 ha.

Hs/Mt MTAI SERIES, typical phase

The Mtai series comprises moderately deep, well drained soils, with dark reddish brown to yellowish red and red colours. The textures are clay loam to clay, with the topsoils textures sandy clay loam. Gravel is always present in these soils below 50 cm depth, in places the gravel content is as high as 75%. The soil reaction ranges between medium and slightly acid. The natural fertility of the soils is moderate. The limited soil depth will restrict the root development.

Setting : The soils of the Mtai series occur on the summits, upper, middle and lower slopes throughout the estate area, with the slopes ranging between 5% and 60%. In total they cover 115 ha (= 24%) of the Kwamtili estate.

Topsoil characteristics : The topsoils are about 10 cm thick and have dark reddish brown to dark red colours. They have sandy clay loam textures mainly and they are moderately well structured. The organic carbon content is moderate (2.0 - 2.5%). The topsoils are slightly acid with pH values around 6.5.

Subsoil characteristics : The subsoils have a maximum effective depth of 80 cm. They are red to yellowish red coloured. The textures are clay mostly, but small amounts of gravel are always present, in amount increasing with depth.

Natural fertility aspects : The soils have a moderate organic matter content, with a moderate level of total nitrogen (C/N ratio 7 - 9). The amount of available phosphorus is low. The exchangeable calcium amounts are low as well. The pH values range between 5.5 and 6.5.

Soil classification : FAO/Unesco : Ferralic Cambisols, petric phase
USDA : Oxic Ustropept

The mapping units distinguished are :

Hs1/Mt on crests and hillslopes, 2-16%; extent 36 ha

Hs2/Mt on hillslopes, 16-30%; extent 42 ha

Hs3/Mt on hillslopes, 30-45%; extent 31 ha

Hs4/Mt on hillslopes, 45-60%; extent 6 ha.

Hs/Mts MTAI SERIES, shallow phase

This phase of the Mtai series comprises shallow to very shallow soils, with an effective soil depth of 20 - 50 cm. The other soil properties, the fertility aspects and the physiographic positions are similar to those of the soils of the Mtai series. In total the Mtai series, shallow phase covers 28 ha (= 6%).

Soil classification : FAO/Unesco : Ferralic Cambisol, petric-lithic phase
USDA : Lithic Ustropept

The mapping units recognized are :

Hs1/Mts on crests and hillslopes, 2-16%; extent 13 ha

Hs2/Mts on hillslopes, 16-30%; extent 6 ha

Hs3/Mts on hillslopes, 30-45%; extent 4 ha

Hs4/Mts on hillslopes, 45-60%; extent 5 ha.

Vs/Mw MWANZI SERIES, typical phase

The series consists of deep, in places very deep, moderately well drained soils, which are mostly dark yellowish brown coloured. The prevailing textures are sandy clay and clay. Small amounts (2 - 5%) of gravel are always present deeper than 80 cm. The soils have a moderate organic matter content in the topsoil. The natural fertility is fairly high. When the soils dry out they tend to become compact and hard and thus limiting the root development. As a result from their physiographic position these soils receive appreciable amounts of sub-surface lateral water.

Setting : The soils of the Mwanzi series occur on the lower slopes of the hills and ridges, close to the bottom of a number of small valleys, and on the transition towards the alluvial flats of the Muzi river. The slopes range between 5 and 20%. In total these soils are found on 51 ha (= 11%) of the estate area.

Topsoil characteristics : The topsoils, 15 - 30 cm thick, have very dark yellowish brown colours. They have sandy clay loam textures and they are well structured. The topsoils, with an organic carbon content of 2.0 - 2.5%, qualify for a mollic epipedon. The reaction of the topsoils is neutral, with pH values around 7.

Subsoils characteristics : The subsoils below 15 - 30 cm have dark brown to dark yellowish brown colours and sandy clay to clay textures. They are well structured. The subsoils have a firm consistence when dry, while the consistence is hard when the soils are dry. Gravel is present in amounts upto 15% below 80 cm.

Natural fertility aspects : The soils are moderately well provided with organic matter in the topsoil and they have a moderate level of total nitrogen (C/N ratios 8 - 10). The amounts of available phosphorus are low (1 - 2 ppm). Availability of calcium and magnesium is good. The soils are only moderately well provided with potassium. The pH values range between 6.5 and 7.5.

Soil classification : FAO/Unesco : Luvic Phaeozem
USDA : Udic Argiustoll

The mapping units distinguished are :

$\frac{Vs1}{Mw}$ on lower slopes and valley bottoms, 2-16%; extent 46 ha

$\frac{Vs2}{Mw}$ on lower slopes, 16-20%; extent 5 ha.

$\frac{Vs}{Mwg}$ MWANZI SERIES, gravelly phase

This phase of the Mwanzi series consists of deep soils, with a gravel content in the subsoil of over 15%, often as much as 50%, in places present as a kind of stoneline of about 20 cm thick. The other soil properties and the fertility aspects of this phase are similar to those of the Mwanzi series, typical phase. The soils are found on the same physiographic positions as those of the Mwanzi series. The total area covered by this phase is 21 ha (= 4%) of the estate.

The mapping units recognized are :

$\frac{Vs1}{Mwg}$ on lower slopes and valley bottoms, 2-16%; extent 16 ha

$\frac{Vs2}{Mwg}$ on lower slopes 16-20%; extent 5 ha.

$\frac{Vs}{Mwm}$ MWANZI SERIES, moderately deep phase

This phase of the Mwanzi series contains moderately deep (50 - 80 cm) soils. A gravel content of over 15% is always present. The other major soil properties as well as the fertility aspects of these soils are alike the soils of the Mwanzi series. The soils of this phase are found on the lower slopes of the hills and ridges and along a number of small streams. The slopes range between 5% and 15% mostly.

Only one mapping unit has been distinguished :

$\frac{Vs}{Mwm}$ on lower slopes and valley bottoms, 2-16%; extent 29 ha.

$\frac{Vw}{Ki}$ KIJITO SERIES, typical phase

The soils of this series are moderately deep to deep and poorly drained. They have moderately thick very dark brown topsoils over yellowish brown to greenish grey mottled subsoils. The textures are mainly clay, which are gravelly in the lower subsoil. Waterlogging occuring during the greater part of the year makes these soils unsuitable for most agricultural uses.

Setting : The Kijito series occur on a number of valley bottoms, mostly where the valleys show some widening. The Kijito series cover 8 ha (= 2%) of the estate area.

Topsoil characteristics : The topsoils are 20 - 30 cm thick and have very dark brown to dark brown colours. They have sandy clay loam textures and moderately well developed structures. The organic matter content is moderate, and the soil reaction is medium acid.

Subsoil characteristics : The subsoils below 40 cm are strongly mottled with colours ranging from dark yellowish brown to dark greenish grey. The textures are gravelly clay. They are moderately well structured and they have a firm consistence.

Natural fertility aspects : The soils are well provided with nutrients, except phosphorus, which is fairly low. The topsoils have an organic carbon content of 1.5 - 2.0% and are medium acid. The subsoils are neutral, with pH values around 7.0. The sodium content is increasing with depth, reaching ESP values close to 6 in the lower subsoil.

Soil classification : FAO/Unesco : Gleyic Phaeozem, sodic phase
USDA : Abrubtic Argiaquoll

One mapping unit has been distinguished :

$\frac{Vw}{Ki}$ on mostly waterlogged valley bottoms, 0-2%; extent 8 ha.

$\frac{Aa}{Mw}$ MUZI SERIES, typical phase

The series comprises very deep, well drained soils with loamy sand textures. The soil colours are reddish brown to yellowish red. The organic matter content of the soils is low and the soil reaction is slightly acid to neutral.

Setting : The soils of the Muzi series only occur along the two branches of the Muzi river on the alluvial flats with slopes between 2 - 5%, which are subject to annual flooding during the rainy seasons. The total area covered by these soils is 33 ha, i.e. 7% of the Kwamtili estate.

Topsoil characteristics : The topsoils, 20 - 25 cm thick, are dark brown sandy loams, with a weak structure. The organic carbon percentage ranges between 1.0 and 1.5. The pH values are around 6.5.

Subsoil characteristics : The subsoils below 20 - 25 cm to a depth of at least, 150 cm are very uniform, with reddish brown to yellowish red colours. The textures are loamy sand throughout. The subsoils have weakly developed structures. In spite of their alluvial origin, the subsoils do not show any stratification.

Natural fertility aspects : These soils have a good natural fertility level and they are well provided with nutrients, including phosphorus. The topsoils have a fairly low organic matter content with moderate levels of total nitrogen (C/N ratio 5 - 10). The soil reaction of the subsoil is neutral, with pH values around 6.8.

Soil classification : FAO/Unesco : Eutric Fluvisol
USDA : Mollic Ustifluvent

Only one mapping unit has been recognized :

$\frac{Aa}{Mu}$ on the alluvial flats along the Muzi river, slope 0-5%; extent 33 ha.

## 3.4 SOIL MOISTURE ANALYSIS

Cocoa and coconut are crops usually found in climates with high humidity, high temperatures and preferably with a well distributed annual rainfall of at least 1500 mm. When the rainfall, like at Kwamtili, is not evenly distributed over the year a moisture deficit will occur during the dry seasons. This deficit develops when the loss of water from the leafs exceeds the water uptake by the roots. Apart from the rainfall and its distribution the deficit depends on the potential evapotranspiration (ETo), on the crop factor (kc) which relates ETo to the actual evapotranspiration (ETa), and on the water storage capacity of the soils. With the above mentioned parameters, the occurence of periods with water deficit for the crops have been calculated for 10-day periods (= decades) for all the 20 years of rainfall records at Kwamtili.

Due to the lack of sufficient meteorological data the potential evapotranspiration could not be calculated. Therefore the data of the Mlingano Agricultural Research Station have been used, which station has a more or less comparable climatic setting.

The water requirements for cocoa in full production will be close to the potential evapotranspiration since the kc-value for mature cocoa with light shade and undergrowth ranges between 0.9 and 1.1 (Doorenbos and Pruitt, 1977). The kc-value of coconut is also estimated at 0.9-1.1.

The water storage capacity of the soils has been calculated from laboratory measurements on undisturbed and disturbed samples. The analysis of samples of representative profiles at the Estate indicates an average moisture holding capacity of 75 mm/meter soil, which corresponds with a range in maximum soil moisture storage of 30 mm to 105 mm for soils with a depth of 50 cm and 150 cm respectively.

The calculation of the water balances resulted in data for the actual evapotranspiration (ETa) for each decade during the 20 years. The ratio between ETa and ETo indicates the soil moisture availability and possible moisture stress in the crops. It is thought that no

serious moisture stress occurs when the ration ETa/ETo is between 0.67 and 1.00. Moisture stress leading to a limited growth is expected to happen when the ratio is between 0.50 and 0.67. Serious moisture stress with substantial growth and yield reduction occurs when ETa/ETo is less than 0.50. In this moisture analysis only the latter figure has been used.

Appendix I gives the tabulated results of the calculations in terms of the occurence of serious moisture stress in the crops per decade for the soils of the Kwamtili Estate. For easy reference the rainfall data per decade for the last 20 years are given as well.

The results indicate that in an average year there are two seasons with moisture stress in the crops at Kwamtili, the first from about mid-January till late-March and the second from about mid-August till end-October. These seasons, however are not well fixed and notably the second one occurs only in half of all the years, and the start of this second dry season also varies considerably and in some years the second dry season is more severe than the first one. For perennial tropical tree crops like cocoa and coconut the length of the dry spells is of more importance than the time of the year they take place. For the soils with 105 mm, 75 mm and 30 mm total moisture storage the average length of the most severe dry spell in one year is about 60 days, 75 days and 90 days respectively. However, the length varies considerably, with extreme values of 40 days and 130 days. The other dry season with moisture stress has an average length of 50 days, 50 days and 55 days respectively, again varying in intensity with extreme values of 30 days and 80 days.

The three soil moisture storage classes used in general can be related to the soil series recognized at the Kwamtili Estate as follows:

30 mm storage : soils of the Mtai series

75 mm storage : soils of the Kwamtili series, deep and gravelly phase;
soils of the Mwanzi series

105 mm storage : soils of the Kwamtili series, typical phase;
soils of the Muzi series.

In Table 3 the results have been summarized for three soil series on a monthly basis.

Table 3 : Occurence of moisture stress on three major soil series at Kwamtili Estate during the period 1963 - 1984

A : Kwamtili series, typical phase and Muzi series

| Month | 63 | 64 | 65 | 66 | 67 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | Probability % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | - | - | - | - | X | X | - | - | - | - | - | X | X | - | - | - | - | - | X | X | 30 |
| Feb. | X | X | X | - | X | X | X | - | X | X | X | X | X | - | - | X | X | X | X | X | 80 |
| Mar. | - | - | X | - | - | - | X | X | X | X | X | X | X | - | - | X | X | X | - | - | 55 |
| Apr. | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | 5 |
| May. | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | 5 |
| Jun. | - | - | - | - | - | - | - | - | - | X | - | - | X | - | - | - | - | - | - | - | 10 |
| Jul. | - | X | - | - | - | X | - | - | X | - | - | - | X | - | - | X | - | - | - | - | 25 |
| Aug. | - | - | - | - | - | X | X | - | X | - | - | X | - | - | - | - | - | - | - | - | 15 |
| Sep. | X | X | - | - | - | X | X | - | X | X | - | X | - | X | - | - | X | - | - | - | 45 |
| Oct. | X | - | - | X | - | X | X | - | X | X | X | - | - | X | X | X | - | - | X | - | 55 |
| Nov. | - | - | - | - | - | X | X | - | - | - | X | - | - | - | - | - | - | - | - | - | 15 |
| Dec. | - | - | - | X | - | - | - | - | - | X | - | - | - | - | - | - | - | - | X | - | 15 |

B : Kwamtili series, deep gravelly phases , and Mwanzi series

| Month | 63 | 64 | 65 | 66 | 67 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | Probability % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | - | - | - | - | X | X | X | - | - | - | - | X | X | - | - | - | X | - | X | X | 40 |
| Feb. | X | X | X | - | X | X | X | - | X | X | X | X | X | - | - | X | X | X | X | X | 80 |
| Mar. | - | - | X | - | - | - | X | X | X | X | X | X | X | - | - | X | X | X | - | - | 55 |
| Apr. | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | 5 |
| May. | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | 5 |
| Jun. | - | - | - | - | - | - | - | - | - | X | X | - | X | - | - | X | - | - | - | - | 20 |
| Jul. | - | X | X | - | - | X | - | - | X | - | - | - | X | - | - | X | - | - | - | - | 30 |
| Aug. | X | X | - | - | - | X | - | X | X | - | X | X | - | X | X | - | - | - | - | - | 45 |
| Sep. | X | X | - | X | - | X | X | - | X | X | - | X | - | X | - | - | X | - | - | X | 55 |
| Oct. | X | - | - | X | - | X | X | - | X | X | X | - | - | X | X | X | - | - | X | - | 55 |
| Nov. | - | - | - | - | - | X | X | - | - | - | X | - | - | - | - | - | - | - | - | - | 15 |
| Dec. | - | X | - | X | - | - | - | - | - | X | - | - | - | - | - | - | - | - | X | - | 20 |

C : Mtai series

| Month | 63 | 64 | 65 | 66 | 67 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | Probability % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | - | X | - | - | X | X | X | X | X | X | - | X | X | - | - | X | X | X | X | X | 70 |
| Feb. | X | X | X | - | X | X | X | - | X | X | X | X | X | - | - | X | X | X | X | X | 80 |
| Mar. | - | - | X | - | - | - | X | - | X | X | X | X | X | - | - | X | X | X | - | - | 55 |
| Apr. | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | 5 |
| May. | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | 5 |
| Jun. | - | - | X | - | X | X | - | X | - | X | X | - | X | - | X | X | X | - | X | - | 55 |
| Jul. | - | X | X | X | - | X | - | - | X | - | - | - | X | X | X | X | - | - | X | - | 50 |
| Aug. | X | X | - | X | - | X | X | X | X | X | X | X | - | X | X | - | - | - | - | X | 65 |
| Sep. | X | X | - | X | - | X | X | - | X | X | - | X | - | X | - | - | X | - | - | X | 55 |
| Oct. | X | - | - | X | - | X | X | - | X | X | X | - | - | X | X | X | - | - | X | - | 55 |
| Nov. | - | X | - | - | - | X | X | - | - | - | X | - | - | - | - | - | X | - | - | - | 25 |
| Dec. | - | X | - | X | X | - | - | - | - | X | - | - | - | - | X | - | - | - | X | - | 30 |

X : Serious moisture stress.

# CHAPTER 4. LAND SUITABILITY EVALUATION

## 4.1 INTRODUCTION

This chapter concerns the interpretation of the collected land and soil resources data into terms of suitability for cocoa and coconut cultivation.

Land suitability refers to the fitness of a given tract of land for a specific use and land evaluation is the process of assessing this suitability (FAO, 1976). The purpose of the land suitability evaluation is to provide a technical framework for the rehabilitation and diversification of Kwamtili Cocoa Estate.

The land suitability evaluation presented has an ecological approach. It relates the specific ecological requirements of cocoa and coconut with the ecological conditions of the different land units.

Different degrees of suitability depend upon the relationships between inputs (costs) and benefits (actual or anticipated). Although in the end "suitability" must be a question of cost/benefit analysis within the environmental possibilities for sustained land use, economics did not enter the evaluation.

The evaluation is presented as follows :

- a description of the structure of the land suitability classification (Section 4.2)
- cocoa cultivation as practised at Kwamtili and its environmental requirements (Section 4.3)
- coconut cultivation as proposed for Kwamtili and its environmental requirements (Section 4.4)
- the land suitability assessment for cocoa and coconut (Section 4.5)
- conclusions and recommendations (Section 4.6)

## 4.2 THE LAND SUITABILITY CLASSIFICATION

### 4.2.1 The Structure of the Classification

The method of the land suitability evaluation used is a system adopted in all studies of the National Soils Service and which has been developed by FAO (FAO, 1976).

Following this system three levels of classification are recognised, i.e. Land Suitability Orders, Land Suitability Classes and Land Suitability Subclasses.

Land Suitability Orders separate land assessed as Suitable (S) from land which is not suitable (N) for the specific land use being considered.

Land Suitability Classes indicate relative degrees of suitability. The classes are numbered in order of decreasing suitability (increasing limitations) :

Class S1 : Highly Suitable Land. Land having no significant limitations (optimal or near optimal conditions for sustained use). No special management or improvements are require.

Class S2 : Suitable Land. Land having minor limitations that may require some simple special management practices or minor land improvements which can be implemented easily.

Class S3 : Moderately Suitable Land. Land with limitations which in aggregate are moderate ; the limitations may affect productivity or require special inputs and/or improvements. The overall advantage of its use, although still attractive, will be significantly inferior to that expected under S1.

Class S4 : Marginally Suitable Land. Land with limitations which in aggregate are severe and which seriously reduce productivity or require corrections or inputs which are only marginally justified.

Class N. Not Suitable Land. Lands with limitations which cannot be corrected with existing knowledge and which preclude its successful and sustained use.

Land Suitability Subclasses reflect the nature of the main limitations which determined their classification. Subclasses are indicated by lower case suffixes. The Subclasses considered in this evaluation are :

d = unfavourable drainage conditions (excess sub-surface water)

e = erosion hazard

f = flooding hazard

m = limited (soil) moisture availability (droughtstress)

n = limited nutrient availability (low soil fertility)

r = adverse rooting conditions (incl. limited soil depth and gravels)

There are no subclasses for class S1

4.2.2. Land Utilization Types, Land Qualities and Land Characteristics

As there is no absolute and generally applicable value of land, the concept of land suitability is meaningful only in relation to the use of land for a specific purpose and in a defined manner. Land utilization types are specific uses of the land defined in detail.
For Kwamtili, two land utilization type are considered, i.e. cocoa and coconut cultivation, described and defined in par. 4.3.1 and 4.4.1 respectively.

Having described the land utilization types, the next step is to select and determine the land characteristics and land qualities that will be used in the suitability assessment.
For cocoa and coconut cultivation at Kwamtili, the following land qualities and characteristics have been selected :

Temperature regime

Mean annual and monthly temperatures and mean monthly maximum and minimum temperatures define the temperature regime. These data are not available for Kwamtili Estate and have been taken from a comparable site in the coastal area of Tanga.

Moisture availability

Daily rainfall is recorded at Kwamtili Estate since 1961 and the data are considered to be representative for the entire Estate. Representative soil profiles were sampled and studied to determine their water storage capacities. With these data the occurence of periods with moisture stress have been calculated (see section 3.4) and these data together with the effective soil depth, have been used as diagnostic land qualities.

Drainage conditions

Poor drainage and waterlogging adversely affect the growth of cocoa and coconut due to the restriction of oxygen supply to the plant root system. The natural soil drainage is the best diagnostic criterion of this land quality and the following natural soil drainage classes are used :

- poorly drained: soil remains wet and saturated for a large part of the time
- imperfectly drained: soil remains wet for significant periods of the year, but not all the time
- moderately well drained: soil is wet for a small but significant part of the time
- well drained: optimal conditions for most crops.

Nutrient availability

Use has been made of the following characteristics :

- soil reaction (pH) of both topsoil and subsoil
- organic matter content of the topsoil (% organic carbon x 1.72)
- the cation exchange capacity (CEC in me/100 g soil)
- exchangeable Calcium and Magnesium in the topsoil in me/100 g soil)
- exchangeable Potassium in the topsoil (in me/100 g soil)

Rooting conditions

Rooting conditions are controlled by effective soil depth and the ease of root penetration. The effective depth is the depth to a limiting horizon, e.g. rock, hard pan or toxic soil layer. Rootability is also determined by physical soil properties such as the occurence of compact horizons and the presence of large amounts of gravel. Particularly at Kwamtili, subsoil gravel is an important limiting factor, as it both restricts root penetration and limits the waterholding capacity of the soils.

Flood hazard

Flooding of the Muzi River floodplain occurs a few times a year after heavy rains. Although most flash-floods are restricted to a few days only, the amount of water is often considerable. The following classes are used :

class 0 - no flooding
class 1 - flash-floods occuring only in exeptional years and causing little damage
class 2 - flash-floods occuring regularly, but causing little damage to crops
class 3 - flash-floods occuring regularly and causing considerable damage to crops
class 4 - flash-floods occuring frequently, but causing only moderate damage to crops
class 5 - flash-floods occuring frequently and causing extensive damage and destruction of crops.

Erosion hazard

At Kwamtili slope angle is the most important land characteristic to indicate the land's susceptibility to erosion.

## 4.3 COCOA LAND UTILIZATION TYPE AND THE ENVIRONMENTAL REQUIREMENTS

This section describes and defines the cocoa land utilization type considered in the suitability assessment and its environmental requirements. For the latter, the basic information is from

observations on the performance of the crop at Kwamtili itself and from Smyth (1967), Wessel (1971), Arens (pers. comm.), de Geus (1973), Wood (1975), de Alvim (1977) and Embrechts and Sys (1981).

### 4.3.1. Cocoa Land Utilization Type

Only the Estate type of cocoa cultivation is being considered, described and defined as follows :

- considering the traditional markets of Kwamtili cocoa, all replanting will be with criollo cultivars
- there will be no intercropping
- the present shade crop (mainly kapok) is considered to be too heavy and will be reduced to a light Gliricidia shade
- irrigation is not considered
- to reduce evapotranspiration, management will include a strict weed control
- there will be a moderately high level of necessary inputs, incl. the use of fertilizers, insecticides (Helopeltis) and fungicides (podrot and black pod) and the control of pests like rodents (squirrels and monkeys)
- management will include skilled and experienced staff, and labour availability is not considered to be a limitation

### 4.3.2. Environmental Requirements

#### Temperature regime

Mean annual temperatures between 25-26°C are considered to be optimal for the crop. A mean monthly minimum temperature of 15°C is often mentioned as the lower limit for successful cultivation, in East Africa corresponding with an altitude limit of approx. 500 m. above sealevel. Long periods with temperatures above 30-32°C may result in abnormal growth of the cocoaplant, but when cultivated under shade these high temperatures hardly occur in the cocoa areas of East Africa.

Considering the above, the temperature regime at Kwamtili is not a limiting factor. For the Tanga region as a whole, altitude is probably the best parameter to express the temperature regime, with optimal conditions found below 250 m and with an upper limit of 500 meter above sealevel.

Moisture availability and Rooting conditions

Rainfall should preferably exceed waterloss by evapotranspiration in most months of the year, and without irrigation 1200 mm of rain (100 mm/month) is often considered as a minimum requirement for a good cocoa crop. Total annual rainfall is a less important consideration than rainfall distribution.

At Kwamtili, in an 'average' year there are two periods with less than 100 mm of rain/month i.e. the period January - February (with 60 mm/month) and the June - August period (75 mm/month). Although far from optimal, these dry spells are only slightly limiting for cocoa. Unfortunately, drought is not a function of average rainfall, but a function of the departure of rainfall from normal, or its variability. During the 1961 - 1986 period there were 4 years with meteorological dry spells of over 6 months (1962, 1970, 1976/77 and 1983/84), of which the 1983/84 period was particularly dry with 8 months, with less than 100 mm/month. During these dry years cocoa at Kwamtili suffered considerably.

A better parameter than the meteorological drought is the physiological drought. In periods with physiological drought all plant available water is exhausted and the crop suffers from severe moisture stress. Physiological drought depends not only on rainfall but also on soil water retention characteristics, rooting depth and crop evapotranspiration.

In chapter 3.4 all periods of physiological drought for mature cocoa have been calculated for the major soil types of the area, using the rainfall data of 1961-1986. Based on these calculation, crop performance at the Estate and available literature, it is estimated that periods with moisture stress of less than 30 days in any year are not limiting. Unfortunately, these conditions are not found at

Kwamtili. Moisture stress during periods of over 90 days, on the other end are damaging. The damage appears to be slight in soils where this situation occurred only once in the 1961-1985 period, but where this occurred in 8 years or more, the damage appears to be severe. The former situation is found on the very deep soils, with an effective soil depth of over 150 cm, the latter situation occurred on soils with an effective soil depth of only 50 cm. The intermediate situations are as follows :

| | frequency and length of moisture stress | | |
|---|---|---|---|
| | 60 days | 90 days | 100 days |
| soil depth | | | |
| 150 cm | 14x | 4x | 1x |
| 100 cm | 22x | 6x | 4x |
| 50 cm | 27x | 13x | 8x |

(1961-1986 period)

Based on above calculations, it is concluded that effective soil depth is the simpliest to use parameter of the moisture availability land quality. The data result in the following effective soil depth specifications for the land suitability assessment for cocoa at Kwamtili (in cm) :

| optimal conditions | degree of limitations | | | |
|---|---|---|---|---|
| | slight | moderate | severe | very severe |
| non existing | $\geq$ 120 | 100-120 | 80-100 | $<$ 80 |

An exception is made for the soils on the lower slopes receiving lateral subsurface water from higher grounds. For these soils the length of the period with moisture stress is used.

Many soils at Kwamtili are gravelly and some are even very gravelly. Gravel causes bifurcation and poor development of the tap root and, when present in great quantities, can prevent root penetration altogether.

Very significant for Kwamtili is also the fact that in gravelly soils the water retention capacity is very limited increasing droughtstress. Based on actual field observations and literature data, the following land suitability specifications apply :

| | optimal conditions | degree of limitations slight | moderate | severe |
|---|---|---|---|---|
| gravel content 00-100 cm | ≤5% | 5-15% | 15-25% | ≥ 25% |

Drainage conditions and Flooding hazard

Adequate soil aeration is essential to satisfactory growth of cocoa. The groundwatertable should be at least 150 cm below the surface and preferably much deeper. Also the crop's tolerance to even short periods of waterlogging is very low. The following specifications are generally accepted as or basis for land suitability assessment :

| | optimal conditions | degree of limitations slight | moderate | severe |
|---|---|---|---|---|
| soil drainage | well | moderately well | imperfect | poor |
| Flooding | never | rare | infrequent | frequent |

Nutrient availability

An 'ideal' cocoa soil has a well structured topsoil with well over 3% good quality organic matter and a soil pH of about 6.5. The tolerated pH range is 5.0-7.5 with no soil layer having a pH below 4.0 within the first meter. Base saturation values should preferably be over 50% in the topsoil and over 35% in the subsoil. Based on extensive data provided by Wood (1975) and de Geus (1973) the following specifications have been adopted :

| | optimal conditions | degree of limitation slight | moderate | severe |
|---|---|---|---|---|
| pH (00-100 cm) | 6.5 | 5.5-6.5 | 4.8-5.5 | ⊳ 4.8 |
| org C topsoil % | ⊲ 2.5 | 1.5-2.5 | 0.5-1.5 | ⊳ 0.5 |
| exch. Ca topsoil (meq) | ⊲ 10 | 4-10 | 2-4 | ⊳ 2 |
| exch. Mg topsoil (meq) | ⊲ 2.5 | 1.5-2.5 | 0.5-1.5 | ⊳ 0.5 |
| exch. K topsoil (meq) | ⊲ 0.3 | 0.2-0.3 | 0.1-0.2 | ⊳ 0.1 |

Erosion hazard

Cocoa being a perennial crop and cultivated under shade, the crop can even be planted in hilly terrain on steep slopes without causing many problems of erosion. The soil survey carried out at Kwamtili however clearly indicated that on steep slopes with gradients over 30% 'invisible and gradual' erosion had reduced the thickness of the topsoil considerably. The fact that a large majority of the feeding roots are found in the topsoil, makes this horizon particularly important. Another aspect is the fact that in steep terrain the construction and maintenance of estate roads may be difficult. The latter has also been observed at Kwamtili.
It is for these reasons that gradient has also been considered as a diagnostic criteria for suitability assessment, whereby areas with slope gradients of over 45% are considered to be unsuitable for replanting.

Specifications for the suitability assessment

In table 4, the optimal conditions and degree of limitations for each of the diagnostic land qualities are summarized.

Table 4 : Specifications for the physical Suitability evaluation of land for cocoa cultivation in the coastal areas of Tanga, Tanzania

| LAND QUALITY | TYPIFYING DIAGN. CRITERIA | OPTIMAL CONDITIONS | DEGREE OF LIMITATION | | | |
|---|---|---|---|---|---|---|
| | | | SLIGHT | MODERATE | SEVERE | VERY SEVERE |
| Temperature regime | altitude (m) | <250 | 250-350 | 350-500 | >500 | - |
| Moisture availability/ | moisture stress periods (days/year) | 0-30 | 30-60 | 60-90 | 90-120 | >120 |
| Rooting condition | effective soil depth (cm) | - | >120 | 100-120 | 80-100 | < 80 |
| | gravel (0-100 cm) (%) | <5 | 5-15 | 15-25 | 25-40 | > 40 |
| | permeability (cm/hr) | 2-6 | 6-12 or 1-2 | 12-25 or 0.5-1 | > 25 or <0.5 | - |
| Drainage conditions | natural drainage (class) | well | mod.well | imperf. | poorly | very poorly |
| Nutrient availability | soil pH | 6.5 | 5.5-6.5 | 4.8-5.5 | < 4.8 | - |
| | org. C topsoil (%) | >2.5 | 1.5-2.5 | 0.5-1.5 | <0.5 | - |
| | exch. Ca topsoil (me/100g) | > 10 | 4-10 | 2-4 | < 2 | - |
| | exch. Mg topsoil (me/100g) | >2.5 | 1.5-2.5 | 0.5-1.5 | < 1.5 | - |
| | exch. K topsoil (me/100g) | >0.3 | 0.2-0.3 | 0.1-0.2 | <0.1 | - |
| Flooding hazard | flooding | never | rare | infrequent | frequent | - |
| Erosion hazard | slope angle (%) | < 16 | 16-30 | 30-45 | - | > 45 |

## 4.4. COCONUT LAND UTILIZATION TYPE AND ENVIRONMENTAL REQUIREMENTS

This section concerns the description and the definition of the type of coconut cultivation and its environmental requirements considered in the land suitability assessment.
Concerning the environmental requirements, the basic information is from Child (1964), Frémond et al. (1966), Murray (1977), Arens (pers. comm.) and Schuiling (pers. comm.).

### 4.4.1. Coconut Land Utilization Type

The Kwamtili rehabilitation and diversification programme includes the cultivation of coconut. For Kwamtili, coconut is a new crop, to be cultivated in an Estate type of cultivation and management, with appropriate levels of inputs and management as follows :

- cultivation of high yielding varieties proven to be adapted to the environment of the coastal areas of Tanga. The varieties used could be either dwarf or dwarf x tall crosses and will be disease resistant.
- careful bush clearing and land preparation ; particular care should be taken to avoid, as far as possible, disruption of the humus-rich topsoil.
- good and careful management, particularly during the early phases of the project. It has been proven repeatedly that the success and productivity of a coconut plantation depend to a large extent on the care paid to the crop during planting and its immature stage.
  Good management would include :
  - well cared nurseries and good nursery husbandary
  - selection of the most vigorous and advanced seedlings in the nursery for planting in the field
  - proper planting techniques
  - the use of manure and mulch
  - the establishment of a leguminous cover crop (Centrosema, Pueraria, etc.)
  - proper weed control

- no interrow cropping
- skilled staff and labour

4.4.2. Environmental Requirements

There are only few of the world's useful plants that thrive in places so scattered and at the same time so varied as the coconut. Its extensive distribution, even where it does not appear to be associated with man's activities, has led to the widely held view that the coconut can grow almost anywhere in the coastal areas of the tropical world. However, to grow well and to produce abundant and profitable yields, the range of ecological conditions is limited.

Temperature regime

The optimal mean annual temperature for best growth and maximum yield is considered to be about 27°C with a diurnal range of 6-7°C. With low temperatures for more than s short time, floral and fruiting abnormalities will strongly affect productivity.
Although coconut plantations have been established successfully at Tabora at an elevation of 1300 m, in the coastal areas of Tanga the best temperature regimes are found below 300 m. approximately, where the ocean acts as a buffer against too rapid changes in the temperature and the light intensity is highest.

Moisture availability

Since the crop is produced continuously through the year and the nut takes a full year to mature from pollination, ideally the tree should never undergo severe moisture stress. Under prolonged drought the inflorescence may abort, affecting the production of nuts 28-30 months later (Murray, 1977).
Drought not only results in a reduction in the number of nuts per palm but also reduces the amount of copra per nut.

Uneven distribution of annual rainfall may be compensated for by special environmental conditions under which coconuts so often grow; that is, where seepage of groundwater occurs from higher ground.

The highest yields of coconuts have been observed under such specialized ecological conditions. These conditions are also found in some of the lower slopes at Kwamtili.
Dry spells may also be compensated for by deep soils with good moisture storage capacities. Wilting occurs much earlier in shallow soils with low moisture storage capacities and palms with small root systems than in deep soils with large root systems.

A synthesis of the moisture availability in the major soil types at Kwamtili over the period 1961-1986 is provided by the calculations in chapter 3.4. It is concluded that also for the coconut palm at Kwamtili the effective soil depth is the simpliest to use parameter to assess moisture availability :

| optimal conditions | degree of limitations | | | |
|---|---|---|---|---|
| | slight | moderate | severe | very severe |
| > 120 (cm) or lateral seepage | 100-120 | 80-100 | 50-80 | < 50 |

Drainage conditions and Flooding hazard

The coconut palm is very sensitive to excess water and water-logging. Fluctuating water tables within the rooting zone restrict root development and cause the coconut roots to die of asphyxiation. The palm requires a well aerated and free drained soil and light textured, somewhat excessively drained soils are often preferred. Considering the occurrence of severe dry spells, the specifications for Kwamtili have been slightly modified, as follows :

| | optimal conditions | degree of limitations | | | |
|---|---|---|---|---|---|
| | | slight | moderate | severe | very severe |
| soil drainage | well | mod.well | somewh.exc. or imperfect | excess. or poor | N/A |
| fluctuating groundwater (within) | > 150 | 120-150 | 50-120 | < 50 | N/A |
| Flooding hazard | never | very rare | rare | infrequent | frequent |

Rooting conditions

The coconut palm tolerates a wide range of rooting conditions. In many areas the palm is cultivated on beach sands or other soils with sandy textures. Medium textured soils and even clay soils may also be suited, provided the internal drainage is adequate and the soil does not tend to be waterlogged in the wet season and bake dry and crack in the dry season. The most important feature already mentioned is good drainage. Together with good drainage, it is important to have a reasonably deep soil for the roots to exploit, particularly in climates with long dry spells. The roots, being relatively thick, have great difficulty in penetrating compacted soils, hardpans and gravel layers; in either case growth and cropping will be poor.
The following specifications have been adopted :

| | optimal conditions | degree of limitations slight | moderate | severe | very severe |
|---|---|---|---|---|---|
| eff.soil depth | > 120 cm | 100-120 | 80-100 | 50-80 | < 50 cm |
| gravel content (00-100cm) | <5% | 5-15 | 15-40 | 40-60 | > 60 |
| permeability cm/hour | 2-6 | 6-12 or 1-2 | 12-25 or 0.5-1 | > 25 or <0.5 | N/A |

Nutrient availability

As mentioned earlier, coconuts will grow on sands of which chemical analysis shows little or no nutrient content. In spite of not being very demanding, the productivity of the crop will depend on the availability of nutrients, and particularly on nitrogen, potassium and phosphorus.
Fertile soils, well provided with organic matter, and with sufficient available phosphorus and exchangeable potassium are prefered.
The palm tolerates a wide pH range, but at pH values below approx. 5.0 growth abnormalities occur which are likely to be associated with toxic levels of aluminium, reducing root development. Based on literature data on the removal of nutrients by the crop (Frémond et al., 1966)

and experimentation (Murray, Arens), the following specifications have been used in the land suitability assessment of the Kwamtili lands :

| | optimal conditions | degree of limitations slight | moderate | severe |
|---|---|---|---|---|
| pH (00-100 cm) | 6-7.5 | 5-6 | 1.5-5.0 | <4.5 |
| K exch. (me) | >0.4 | 0.2-0.4 | <0.2 | N/A |

Erosion hazard

Cultivated properly and with a dense leguminous cover crop, coconut can be planted in hilly terrain and on steep slopes. Studies carried out in Indonesia indicated that with a well established cover crop and without intercropping or grazing, coconut plantations may be established on slopes over 30% without causing erosion, but in most plantations on steeper slopes, the lands are terraced. For similar reasons as explained in the paragraph on the specifications for cocoa, slope gradient has been considered in the land suitability assessment, as follows :

| | optimal conditions | degree of limitations slight | moderate | severe |
|---|---|---|---|---|
| slope gradient (%) | < 16 | 16-30 | 30-45 | > 45 |

Specifications for the suitability assessment

In table 5 the specifications for the land suitability assessment for coconut cultivation in the Kwamtili area are summarized.

Table 5 : Specifications for the physical Suitability evaluation of land for coconut cultivation in the coastal areas of Tanga, Tanzania

| LAND QUALITY | TYPIFYING DIAGN. CRITERIA | OPTIMAL CONDITIONS | DEGREE OF LIMITATION | | | |
|---|---|---|---|---|---|---|
| | | | SLIGHT | MODERATE | SEVERE | VERY SEVERE |
| Temperature regime | altitude (m) | > 300 | 300-500 | > 500 | - | - |
| Moisture availability/ | moisture stress periods (days/year) | 0-60 | 60-75 | 75-90 | 90-120 | > 120 |
| Rooting condition | effective soil depth (cm) | > 120 | 100-120 | 80-100 | 50-80 | < 50 |
| | gravel (0-100 cm) (%) | < 5 | 5-15 | 15-40 | 40-60 | > 60 |
| | permeability (cm/hr) | 2-6 | 6-12 or 1-2 | 12-25 or 0.5-1 | > 25 or < 0.5 | - |
| Drainage conditions | natural drainage (class) | well | mod. well | somew. exc. or imperf. | excess. or poorly | very poorly |
| | fluctuating groundwater (cm) | > 150 | 120-150 | 50-120 | < 50 | - |
| Nutrient availability | soil pH (0-100 cm) | 6-7.5 | 5-6 | 4.5-5.0 | < 4.5 | - |
| | exch. K (me/100g) | > 0.4 | 0.2-0.4 | < 0.2 | - | - |
| Flooding hazard | flooding (class) | never | very rare | rare | infrequent | frequent |
| Erosion hazard | slope angle (%) | < 16 | 16-30 | 30-45 | - | > 45 |

## 4.5. THE LAND SUITABILITY ASSESSMENT

The physical land suitability assessment is made by comparison of the (physical) requirements of cocoa and coconut cultivation with the (physical) conditions of each land or mapping unit as indicated on the soil map.

In tables 4 and 5 of the previous paragraphs (page 35 and 41 resp.), the specifications for the land suitability assessment for cocoa and coconut are indicated. The requirements are expressed in terms of diagnostic land characteristics such as altitude, effective depth, gravel content, soil pH, etc.
The diagnostic characteristics of each mapping unit are described in chapter 3 and are summarized in table 6 (page 45 and 46).
Matching table 6 with tables 4 and 5 results in the physical land suitability rating of each of the 28 mapping units for cocoa and coconut cultivation (table 7 page 49 and 50).
The land suitability maps (maps 2 and 3) indicate the geographic distribution of the suitable and unsuitable lands of Kwamtili for cocoa and coconut cultivation and also indicate the major type(s) of limitation.

### 4.5.1 Land Suitability for Cocoa

Highly Suitable to Suitable Lands (class S1/S2)

Lands of this class are found on the lower slopes with slope gradients between 8-16% and with very deep, gravel free red ferrallitic soils of the Kwamtili series (mapping unit Hl1/Kw). Some lateral influx of seepage water from higher grounds reduces the average period with moisture stress to 30-60 days.
The lands of this class cover only 7 ha, scattered over the Estate in the form of small units.

Suitable Lands (class S2)

Lands of this class are found on hillslopes with very deep, gravel-free soils of the Kwamtili series. Dominant slope gradients are between 2-16% but locally the gradients are up to 25-30%, depending on the position. Moisture stress during long dry spells is the only major limitation (subclass S2m). The suitable hill slope lands cover

45 ha in total, some of it in fairly large units, permitting the establishment of a few separate blocks of homogeneous land.
A few lower slopes (unit H12/Kw) also belong to this class; due to the slope gradient (16-30% and locally slightly steeper) and position on the slope there is a slight erosion hazard (subclass S2e). The lands of this subclass only cover 3 ha.

Moderately Suitable Lands (class S3)

Moderately suitable lands for cocoa are found on hillslopes with 100-120 cm deep, almost gravel free soils of the Kwamtili series. Depth is restricting the water storage capacity of the soils and a mature cocoa crop will be subject to moisture stress for 60-75 days in an average year, moderately affecting growth and productivity of the crop (subclass S3m). The lands of this subclass covers 29 ha in small units scattered over most of the Estate and require a careful management aimed at maximum water conservation.

Another 10 ha of moderately suitable lands are found on steep hillslopes in the southern sector of the Estate, with very deep, gravel-free soils of the Kwamtili series. Topography (30-45%) is the main limitation as it reduces infiltration and maximum water storage; the soils are subject to erosion and many are already slightly eroded (subclass S3e).

A third group of moderately suitable land for cocoa cultivation are some of the footslopes and small concave valleys (mapping units Vs1/Mw and Vs2/Mw) covering in total 51 ha of the Estate. The soils of these units are deep, moderately well to imperfectly drained soils with dark coloured humus-rich topsoils and yellowish clayey and dense subsoils of the Mwanzi series. Stagnant subsurface water, some waterlogging during the rainy season and the compact subsoils restricting root development are moderate limitation for optimal growth and productivity of the cocoa crop (subclass S3dr).

Marginally Suitable Land (class S4)

Marginally suitable land for cocoa cultivation covers approx. 30% of Kwamtili Estate. Three types of marginal cocoa land can be distinguished:

- the alluvial floodplain of the Muzi River and its main tributary. The soils are sandy throughout (Muzi series), with low water storage capacities and during the dry season they dry out quickly. Regular (annually) flooding, in some years with the character of a forceful flashflood is the major limitation for cocoa cultivation (subclass S4f).
- many of the small valley bottoms with gravelly soils, dense subsoils and unfavourable drainage conditions during the rainy season. The unfavourable rooting conditions (compact horizons and considerable amounts of gravel) and the unfavourable drainage conditions during the wet season are the major limiting factors (subclass S4r).
- hillslopes with very gravelly, red ferrallitic soils. The soils with up to 40% ferrugenous gravels are droughty and during an average year the cocoa crop will suffer from severe moisture stress for periods between 60-90 days and longer. The moisture stress and poor rooting conditions classify these soils as marginally suitable (subclass S4r).

Unsuitable Lands (class N)

Large tracts of lands at Kwamtili must be considered unsuitable for cocoa cultivation. The unsuitable lands include :

- very gravelly soils with water storage capacities too low for a cocoa crop to 'survive' severe dry spells (subclass Nmr)
- very steep lands with slopes over 45% and with very gravelly and/or shallow soils (subclasses Nre and Ne)
- poorly drained valley bottomland, locally also very gravelly (subclasses Nd and Nr)

Table 6 : Diagnostic land qualities of the Kwamtili lands for the assessment of land suitability for Cocoa and Coconut

| LAND QUALITY | TYPIFYING DIAGN. CHARACTERISTIC | MAPPING UNIT | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Hs1 Kw | Hs2 Kw | Hs3 Kw | Hl1 Kw | Hl2 Kw | Hs1 Kwd | Hs2 Kwd | Hs3 Kwd | Hs4 Kwd | Hs1 Kwg | Hs2 Kwg | Hs3 Kwg | Hs4 Kwg |
| Temperature regime | altitude (m) | 150-250 | | | 150-200 | | 150-250 | | | | 150-250 | | | |
| Moisture availability/ Rooting conditions | moisture stress period (days/year) | 50-60 | | | 30-60 | | 60-75 | | | | 60-90 | | | |
| | effective soil depth(cm) | >150 | | | >150 | | 100-120 | | | | 80-100 | | | |
| | gravel (0-100 cm) (%) | <5 | | | <5 | | 5-15 | | | | 15-40 | | | |
| | permeability (cm/hr) | 2-6 | | | 2-6 | | 2-6 | | | | 2-6 | | | |
| Drainage conditions | soil drainage (class) | well | | | well | | well | | | | well | | | |
| | fluctuating ground-water depth (cm) | >150 | | | >150 | | >150 | | | | >150 | | | |
| Nutrient availability | soil pH | 5.5-7.0 | | | 5.5-7.0 | | 5.5-7.0 | | | | 5.5-7.0 | | | |
| | org. C topsoil (%) | 2.0-2.5 | | | 2.0-2.5 | | 2.0-2.5 | | | | 2.0-2.5 | | | |
| | exch. Ca topsoil(me/100g) | 8-15 | | | 8-15 | | 8-15 | | | | 8-15 | | | |
| | exch. Mg topsoil(me/100g) | 2-4 | | | 2-4 | | 2-4 | | | | 2-4 | | | |
| | exch. K topsoil(me/100g) | 0.3-0.5 | | | 0.3-0.5 | | 0.3-0.5 | | | | 0.3-0.5 | | | |
| Flooding hazard | flooding (class) | never | | | never | | never | | | | never | | | |
| Erosion hazard | slope angle (%) | 2-16 | 16-30 | 30-45 | 8-16 | 16-30 | 2-16 | 16-30 | 30-45 | 45-60 | 2-16 | 16-30 | 30-45 | 45-60 |

Table 6 : Diagnostic land qualities of the Kwamtili lands for the assessment of land suitability for Cocoa and Coconut (cont'd)

| LAND QUALITY | TYPIFYING DIAGN. CHARACTERISTIC | MAPPING UNIT | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Hs1 Mt | Hs2 Mt | Hs3 Mt | Hs4 Mt | Hs1 Mts | Hs2 Mts | Hs3 Mts | Hs4 Mts | Vs1 Mw | Vs2 Mw | Vs1 Mwg | Vs2 Mwg | Vs Mwm | Vw Ki | Aa Mu |
| Temperature regime | altitude (m) | 150-250 | | | | 150-250 | | | | 150-200 | | 150-200 | | 150-200 | 150-200 | 150-200 |
| Moisture availability/ Rooting conditions | moisture stress period (days/year) | 90-120 | | | | > 120 | | | | 30-60 | | 50-60 | | 60-75 | 0-30 | 60-90 |
| | effective soil depth (cm) | 50-80 | | | | 20-50 | | | | 100-120 | | 80-100 | | 50-80 | 80-120 | > 150 |
| | gravel (0-100 cm)(%) | 15-75 | | | | 15-75 | | | | < 5 | | 15-50 | | 15-50 | 15-40 | < 5 |
| | permeability (cm/hr) | 2-6 | | | | 2-6 | | | | 0.5-2.0 | | 0.5-2.0 | | 0.5-2.0 | < 0.5 | 6-12 |
| Drainage conditions | soil drainage (class) | well | | | | well | | | | mod.well | | mod.well | | mod.well | poorly | well |
| | fluctuating ground-water depth (cm) | > 150 | | | | > 150 | | | | 80-120 | | 80-120 | | 80-120 | 0-80 | 50-150 |
| Nutrient availability | soil pH | 5.5-6.5 | | | | 5.5-6.5 | | | | 6.0-7.5 | | 6.0-7.5 | | 6.0-7.5 | 6.0-7.0 | 6.5-7.0 |
| | org. C topsoil (me/100g) | 2.0-2.5 | | | | 2.0-2.5 | | | | 2.0-2.5 | | 2.0-2.5 | | 2.0-2.5 | 1.5-2.0 | 1.0-1.5 |
| | exch. Ca topsoil (me/100g) | 3-5 | | | | 3-5 | | | | 5-8 | | 5-8 | | 5-8 | 4-7 | 5-8 |
| | exch. Mg topsoil (me/100g) | 3-4 | | | | 3-4 | | | | 2-4 | | 2-4 | | 2-4 | 5-9 | 2-4 |
| | exch. K topsoil (me/100g) | 0.3-0.4 | | | | 0.3-0.4 | | | | 0.4-0.5 | | 0.4-0.5 | | 0.4-0.5 | 1.0-1.5 | 0.5-0.6 |
| Flooding hazard | flooding (class) | never | | | | never | | | | never | | never | | never | rare | frequent |
| Erosion hazard | slope angle (%) | 2-16 | 16-30 | 30-45 | 45-60 | 2-16 | 16-30 | 30-45 | 45-60 | 2-16 | 16-20 | 2-16 | 16-20 | 2-16 | 0-2 | 2-5 |

### 4.5.2. Land Suitability for Coconut

Highly Suitable Lands (class S1)

Highly suitable lands for coconut are found on some of the lower slopes, where seepage of lateral groundwater from higher grounds permits maximum coconut yields (mapping unit Hl1/Kw). Highly suitable lands are also found on hillslopes with very deep, well drained, gravel-free ferrallitic soils of the Kwamtili series (mapping unit Hs1/Kw). Together, the highly suitable lands cover 37 ha or 8% of the Estate, but unfortunately the units are small and scattered over the area.

Suitable Lands (class S2)

Suitable lands for coconut are found on hillslopes with 100-120 cm. deep, almost gravelfree soils of the Kwamtili series. The soil depth is not optimal and is slightly restricting the water storage capacity and in an average year the coconut will be subject to moisture stress for 60-75 days, reducing maximum growth and yields. (Subclass S2m).

Hillslopes and lower slopes with very deep, gravelfree Kwamtili soils also have been classified as suitable; these lands are moderately steep with slope gradients of 16-30% and require a careful management during the early stages of the crop to reduce the risk of erosion (subclass S2e). The total area of suitable lands is approx. 40 ha or 9% of the Estate.

Moderately Suitable Lands (class S3)

Approximately 145 ha or 31% of the Kwamtili Estate lands have been classified as moderately suitable for coconut. In this suitability class lands are grouped with various ecological conditions and with different type(s) of limitations for coconut cultivation.

The biggest group of moderately suitable land constitute the hillslopes with reddish ferrallitic soils of the Kwamtili series, gravelly in the subsoil. The latter limits the water storage capacity of the soils and a mature coconut tree will be subject to periods with moisture stress between 75-90 days in most years (Suitability Subclass S3mr). These lands cover 79 ha.

A second group of moderately suitable land for coconut are some of the small concave valleys and footslopes (mapping units Vs1/Mw and Vs2/Mw). The soils of this group are characterized by clayey and dense subsoils (Mwanzi series) causing water stagnation and locally waterlogging may occur during the rainy season. The dense and compact subsoils also act as a barrier for proper root development (suitability subclass S3dr).

Moderately suitable land is also found on hillslopes with deep to very deep soils, but with gradients between 30 and 45%. The steep topography requires very careful management and conservation practices to avoid erosion (suitability subclass S3e).

Marginally Suitable Land (class S4)

Only 21 ha or 5% of the Kwamtili lands have been classified as marginal for coconut cultivation. The marginal lands are characterized by soils with dense, compact and gravelly subsoil horizons (Mwanzi series, gravelly phase; mapping unit Vs1/Mwg) found in small concave valleys. During the wet season some waterlogging occurs.
The unfavourable subsoil characteristics seriously restrict root development, resulting in an environment only marginally suitable for coconut (subclass S4r).

Unsuitable Lands (class N)

Approx. 47% or 217 ha of the Kwamtili Estate lands are unstuitable for coconut cultivation. The greater part, 166 ha or 36% of the Estate is formed by lands with very gravelly and/or shallow soils with very low moisture storage capacities resulting in long periods of drought stress for the coconut palm. Moreover, many of the gravel layers restrict root development (subclassoes Nmr and Nr). Some of these lands are situated on very steep slopes with slope gradients of over 45% (subclass Nre and Ne).
Also many of the small valley bottoms and the flood plain of the Muzi River are classified as unsuitable due to unfavourable drainage conditions, and frequent flashfloods (subclasses Nd and Nf).

Table 7 : Land suitability rating of the mapping units of Kwamtili

| LAND QUALITY | MAPPING UNIT | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hs1 Kw | Hs2 Kw | Hs3 Kw | Hl1 Kw | Hl2 Kw | Hs1 Kwd | Hs2 Kwd | Hs3 Kwd | Hs4 Kwd | Hs1 Kwg | Hs2 Kwg | Hs3 Kwg | Hs4 Kwg |
| Temperature regime (t) | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 |
| Moisture availability (m) | 2/1 | 2/1 | 2/1 | 1-2/1 | 1-2/1 | 3/2 | 3/2 | 3/2 | 3/2 | 3/3 | 3/3 | 3/3 | 3/3 |
| Drainage conditions (d) | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 |
| Nutrient availability (n) | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 |
| Rooting condition (r) | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 3/2 | 3/2 | 3/2 | 3/2 | 4/3 | 4/3 | 4/3 | 4/3 |
| Flood hazard (f) | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 |
| Erosion hazard (e) | 1/1 | 2/2 | 3/3 | 1/1 | 2/2 | 1/1 | 2/2 | 3/3 | 5/5 | 1/1 | 2/2 | 3/3 | 5/5 |
| Physical Land Suitability for: | | | | | | | | | | | | | |
| Cocoa cultivation | S2m | S2m | S3e | S1/S2m | S2e | S3m | S3m | S3m | Ne | S4r | S4r | S4r | Ne |
| Coconut cultivation | S1 | S2e | S3e | S1 | S2e | S2m | S2m | S3e | Ne | S3mr | S3mr | S3mr | Ne |

The rating is given as a fraction, whereby the numerator refers to cocoa cultivation and the denominator to coconut. The scale 1 to 5 reflects increasing limitations, from none (1) to very severe (5).

Table 7 : Land suitability rating of the mapping units of Kwamtili (cont'd)

| LAND QUALITY | MAPPING UNIT | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hs1/Mt | Hs2/Mt | Hs3/Mt | Hs4/Mt | Hs1/Mts | Hs2/Mts | Hs3/Mts | Hs4/Mts | Vs1/Mw | Vs2/Mw | Vs1/Mwg | Vs2/Mwg | Vs/Mwm | Vw/Ki | Aa/Mu |
| Temperature regime (t) | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 |
| Moisture availability (m) | 4/4 | 4/4 | 4/4 | 4/4 | 5/5 | 5/5 | 5/5 | 5/5 | 1-2/1 | 1-2/1 | 2/1 | 2/1 | 3/2 | 1/1 | 3/3 |
| Drainage conditions (d) | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 3/3 | 3/3 | 3/3 | 3/3 | 3/3 | 5/5 | 3/3 |
| Nutrient availability (n) | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 1-2/1 | 2/1 | 2/1 | 2/1 | 2/1 | 2/1 | 1/1 | 3/2 |
| Rooting condition (r) | 5/4-5 | 5/4-5 | 5/4-5 | 5/4-5 | 5/5 | 5/5 | 5/5 | 5/5 | 3/3 | 3/3 | 4/3-4 | 4/3-4 | 5/4-5 | 4/4 | 1/2 |
| Flood hazard (f) | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 1/1 | 2/3 | 4/5 |
| Erosion hazard (e) | 1/1 | 2/2 | 3/3 | 5/5 | 1/1 | 2/2 | 3/3 | 5/5 | 1/1 | 2/2 | 1/1 | 2/2 | 1/1 | 1/1 | 1/1 |
| Physical Land Suitability for: | | | | | | | | | | | | | | | |
| Cocoa cultivation | Nr | Nr | Nr | Nre | Nmr | Nmr | Nmr | Nmr | S3dr | S3dr | S4r | S4r | Nr | Nd | S4f |
| Coconut cultivation | Nr | Nr | Nr | Nre | Nmr | Nmr | Nmr | Nmr | S3dr | S3dr | S4r | S4r | Nr | Nd | Nf |

# CHAPTER 5

## CONCLUSIONS AND RECOMMENDATIONS

The results of the physical land suitability assessment for the cultivation of cocoa and coconut under an Estate type of management are summarized in Tables 8 and 9 respectively.

The following conclusions and recommendations are made :

1. The environmental conditions at Kwamtili vary considerably :

- Mean annual rainfall amounts to 1556 mm. but over the last 25 years extremes have been recorded as low as 830 mm. and as high as 2308 mm/year. Severe periods of drought are a common phenomenon and periods of 200 consecutive days without rain have been recorded.

- The lands are strongly dissected and steep slopes are present throughout the Estate. Approx. 20% of the lands is steeper than 30% and 53% has slopes between 8-30%. Relatively flat land is only found on the summits of the ridges and these areas are usually small in size.

- The soil conditions are complex and vary often over very short distances. They are particularly intricate in the occurrence and depth of gravelly layers.

2. Cocoa and coconut require an evenly distributed rainfall or otherwise a continuous supply of water for optimal growth and yield. Considering the erratic rainfall and the occurrence of long dry spells, the capacity of the soils to retain and supply water to the crop is a major criterion for their suitability.

Field and laboratory studies carried out by the survey team indicate that at Kwamtili an effective soil depth of 80 cm is the absolute minimum for successful cultivation of cocoa and coconut, provided the soil is gravel free.

3. Mainly due to the above mentioned limitations, i.e. erratic rainfall, gravelly and/or shallow soils and locally steep relief, the overall suitability of the Kwamtili lands for cocoa and coconut is limited. A summary of the suitability ratings is given in Table 8 (for cocoa) and Table 9 (for coconut). The tables indicate that 145 ha of land (31.5% of the Estate) is suitable to moderately suitable for cocoa and 224 ha (48.5%) for coconut.

4. Due to the complex soil pattern, the suitability differs over short distances and many suitable lands are found in small units, difficult to use and manage separately.
In spite of this, there are good possibilities for the layout of 5 sizeable blocks of suitable and fairly homogeneous land :

- one block in the south, covering approx. 40 ha
- one small block SE of the Lake, covering approx. 10 ha
- 2 blocks in the central sector of the Estate, one around the labour camp and one in the central eastern part. These blocks cover approx. 15 and 30 ha respectively
- one block in the extreme north, covering approx. 20 ha

For any extension of the plantable areas, land would have to be sought outside the Estate.

5. Coconut has been introduced as a diversification crop. However, it should be noted that the lands unsuitable for cocoa are generally also unsuitable for coconut.

6. It has suggested that (supplementary) irrigation would greatly improve the suitability of the lands, particularly for cocoa. Apart from technical feasibility and economic justification, irrigation will only improve the suitability of the lands which are already suitable. Many of the unsuitable lands will not become suitable when irrigated.

7. The fertility status of most soils at Kwamtili is satisfactory and not a major limitation for cultivation. For cocoa, the use of phosphate fertilizers (rock phosphate or TSP) particularly in the planting hole, would be beneficial, as well as small amounts of N-fertilizer (10-25 grs/tree). It is suggested that the nutrient status of crops and soils be monitored regularly.

Table 8 : Lands of Kwamtili grouped according to their physical Suitability for Cocoa

| Suitability Rating | Total Area(ha) | Perc. % | Major Limitation(s) |
|---|---|---|---|
| Highly Suitable/Suitable Land (S1/S2) | 7 | 1.5 | - |
| Suitable Land (S2) | 48 | 10.4 | 45 ha : Limited moisture availability<br>3 ha : Limited moisture availability and erosion |
| Moderately Suitable Land (S3) | 90 | 19.5 | 29 ha : Limited moisture availability<br>10 ha : steep slopes (30-45%) ; limited moisture availability<br>51 ha : dense subsoils ; excess soil water (rainy season) |
| Marginally Suitable Land (S4) | 133 | 28.8 | 100 ha : gravelly soils ; very limited moisture availability<br>33 ha : excess soil water or flooding |
| Unsuitable Land (N) | 184 | 39.8 | 166 ha : very gravelly soils ; serious moisture stress<br>10 ha : very steep slopes (>45%) ; very gravelly soils<br>8 ha : flashfloods ; poor drainage conditions |

Table 9 : Lands of Kwamtili grouped according to their physical Suitability for Coconut

| Suitability Rating | Total Area(ha) | Perc. % | Major Limitation(s) |
|---|---|---|---|
| Highly Suitable Land (S1) | 37 | 8.0 | - |
| Suitable Land (S2) | 42 | 9.1 | 24 ha : Limited moisture availability<br>18 ha : mod. steep slopes (16-30%) |
| Moderately Suitable Land (S3) | 145 | 31.4 | 79 ha : gravelly soils ; limited moisture availability<br>51 ha : dense subsoils ; excess soil water (rainy season)<br>15 ha : steep slopes (30-45%) : limited moisture availability |
| Marginally Suitable Land (S4 | 21 | 4.5 | 21 ha : dense and gravelly subsoils ; excess soil water during rainy season |
| Unsuitable Land (N) | 217 | 47.0 | 166 ha : very steep slopes (>45%) ; very gravelly soils<br>41 ha : flashfloods, poor drainage conditions |

8. The Kwamtili lands have a limited physical suitability for alternative crops. For further diversification, the following crops may be considered :

- bitter oranges and bitter lemons; citrus is generally better adapted to moisture stress and can more easily withstand long periods of dry spells
- bananas in the humid valley bottoms, lower slopes and footslopes.
- annuals and semi annuals such as chillies; the cocoa dryer could be used to dry the chilly crop and avoid the occurrence of black markings which often arise when the crop is sun dried.

Along the small streams, (semi-) wild oilpalms are common in the Kwamtili area and it has suggested that this crop could be introduced as well. However, the suitability of the lands for oilpalm is limited to the better drained valley bottoms and lower footslope areas only, not permitting plantations at a commercial scale. Moreover, in the Tanga Region palm oil will have to compete with coconut oil and where produced by small farmers the market value of palm oil is far below that of coconut oil (e.g. Muheza market).

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# SOILS OF THE KWAMTILI ESTATE

and their

# SUITABILITY FOR CULTIVATION

of

# COCOA and COCONUT

## APPENDICES

I Supporting data for soil moisture analysis

II Description and analytical data of representative profiles

APPENDIX I

This appendix presents the tabulated results of the assessment of the periods with soil moisture deficit and expected moisture stress for mature cocoa and coconut, i.e. with a well developed root system.

The assessment is based on the calculation of the actual evapotranspiration using rainfall potential evapotranspiration and soil moisture storage capacity as parameters. The ratio between the calculated actual evapotranspiration (ETa) and the potential evapotranspiration (ETo) determines the occurence and intensity of moisture stress. Serious moisture stress, with substantial growth reduction, will occur when ETa is less than 1/2 ETo.

The formulae used for the calculations are :

$ETa = ETo$ (when $P \geq ETo$)

$ETa = p + (S_{n-1} - S_n)$ and $S_n = S_{n-1} \cdot e^{\frac{PWL}{S_{n-1}}}$ (when $ETo > P$)

with

P : precipitation

ETo : potential evapotranspiration

ETa : actual evapotranspiration

$S_n$ : soil moisture storage for a given period n

$S_{n-1}$ : soil moisture storage for the period previous to n

PWL : potential water loss (= P - ETo, only when $ETo > P$)

The rainfall data employed are those recorded daily since 1963. The potential evapotranspiration data are from the Agricultural Research Institute Mlingano, with a similar climatic setting compared to Kwamtili. The soil moisture storage has been determined by laboratory analyses of the moisture retention of undisturbed soil samples of the Estate area. The average supporting data (based on 18 samples) for the moisture retention of the soils of the Kwamtili, Mtai and Mwanzi series are as follows :

| depth | FC | PWP | FC-PWP | Db | AMC |
|---|---|---|---|---|---|
| 0-40 | 21.7 | 17.3 | 4.4 | 1.29 | 5.7 |
| 40-90 | 24.5 | 19.0 | 5.5 | 1.27 | 7.0 |
| 90-150 | 26.2 | 19.6 | 6.6 | 1.23 | 8.1 |

FC : field capacity (gravimetric)

PWP : permanent wilting point (gravimetric)

Db : bulk density ($g/cm^3$)

AMC : available moisture capacity (mm/dm)

Thence the results indicate that the most common soils at the Estate (Kwamtili, Mtai and Mwanzi series) have a waterstorage capacity of 5.7 mm/10 cm soil for the top 40 cm. The subsoils, between 40-90 cm have a waterstorage capacity of 7.0 mm/10 cm soil and the deeper subsoils, below 90 cm, the capacity is 8.1 mm/10 cm.

Three levels of maximum moisture storage are distinguished. These are 30 mm, 75 mm and 105 mm and these levels correspond with soil depth of 50 cm, 120 mm and 150 cm respectively.

With these data the soil moisture storage capacity can be calculated for the soils of each mapping unit. Although the deep soils (over 120 cm deep) have the highest soil moisture storage capacity and are thus less subject to frequent and intensive moisture stress to crops than the shallow and gravelly soils, drought is a common phenomenon in all soils at the Kwamtili Estate, also in the deep ones (see tables 11,12 and 13). In these tables each 'S' indicates the calculated occurence of moisture stress during a decade (= period of 10 days). The tables also present the probability of moisture stress, based on the frequency of occurence during the 20 years of rainfall records.

Computing the results of the three tables the following may be concluded :

Soils of the Kwamtili series, typical phase, and Muzi series with a maximum soil moisture storage of 105 mm have drought stress characteristic as follows :

Frequency of moisture stress periods
in 5 years out of 10: one period with moisture stress
in 3 years out of 10: two periods with moisture stress
in 2 years out of 10: three periods with moisture stress

Average length of the periods with moisture stress
the longest period in any one year: 65 days (variation 40-110 days)
the second period in any one year : 50 days (variation 30-80 days)
the third period in any one year : 40 days (variation 30-60 days)

Time of the year with the most likely occurence of moisture stress
late-January till late-March (85% probability)
early-September till early-November (45% probability)
early July till mid-August (30% probability)

Soils of the Kwamtili series, deep and gravelly phases, and Mwanzi series with a maximum soil moisture storage of 75 mm have the following drought stress characteristics :

Frequency of moisture stress periods
in 4 years out of 10: one period with moisture stress
in 4 years out of 10: two periods with moisture stress
in 2 years out of 10: three periods with moisture stress

Average length of the periods with moisture stress
the longest period in any one year: 75 days (variation 40-120 days)
the second period in any one year : 50 days (variation 30-80 days)
the third period in any one year : 40 days (variation 30-70 days)

Time of the year with the most likely occurence of moisture stress
mid-January till late-March (90% probability)
mid-August till early-November (50% probability)
late-June till mid-August (45% probability)

Soils of the Mtai series with a maximum soil moisture storage of 30 mm have drought stress characteristics as follows :

Frequency of moisture stress periods

in 2 years out of 10: one period with moisture stress

in 5 years out of 10: two periods with moisture stress

in 3 years out of 10: three periods with moisture stress

Average length of the periods with moisture stress

the longest period in any one year: 90 days (variation 50-130 days)

the second period in any one year : 55 days (variation 30-80 days)

the third period in any one year : 50 days (variation 40-70 days)

Time of the year with the most likely occurence of moisture stress

mid-December till late-March (90% probability)

late-July till mid-November (60% probability)

early-June till mid-July (55% probability)

Table 10 : Rainfall data for 10-day periods during 1963 - 1984 at Kwamtili Estate

| | '63 | '64 | '65 | '66 | '67 | '70 | '71 | '72 | '73 | '74 | '75 | '76 | '77 | '78 | '79 | '80 | '81 | '82 | '83 | '84 | mean | S.D. | ETo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. 1-10 | 12 | 47 | 63 | - | - | 36 | - | 125 | 38 | - | 93 | 7 | 40 | 2 | 168 | - | 23 | 2 | - | - | 33 | 47 | 57 |
| 11-20 | - | - | 17 | 80 | 8 | 17 | - | - | 23 | 34 | 20 | - | - | 170 | 77 | - | - | 55 | - | 3 | 25 | 42 | 59 |
| 21-31 | 61 | - | - | 72 | - | 50 | 18 | - | - | 37 | 14 | 11 | 7 | 19 | 53 | 29 | 17 | - | - | 12 | 20 | 23 | 57 |
| Feb. 1-10 | 57 | 21 | 11 | 15 | 50 | - | - | 60 | - | 5 | - | 54 | - | - | 10 | 31 | - | 29 | 16 | - | 18 | 22 | 56 |
| 11-20 | - | - | 12 | 45 | - | 11 | - | 33 | 52 | - | - | 14 | - | 41 | 37 | 7 | 17 | - | 20 | - | 14 | 18 | 56 |
| 21-28 | 7 | 25 | - | - | - | 2 | 4 | 2 | - | 5 | - | 29 | 22 | 73 | 68 | 1 | - | - | - | - | 12 | 22 | 56 |
| Mar. 1-10 | 31 | 19 | - | 28 | 85 | 4 | 65 | 5 | 21 | 13 | 26 | 5 | 41 | 117 | - | 5 | - | - | - | - | 23 | 32 | 56 |
| 11-20 | 55 | 51 | - | 98 | 21 | 53 | - | 16 | 25 | - | 3 | 25 | 8 | 59 | 75 | - | 15 | 14 | 65 | 55 | 31 | 29 | 56 |
| 21-31 | 50 | 114 | 122 | 139 | 26 | 86 | 127 | 24 | 65 | 11 | 67 | 105 | 22 | 255 | 119 | 20 | 310 | 48 | 26 | 41 | 89 | 79 | 54 |
| Apr. 1-10 | 38 | 121 | 15 | 112 | 157 | 57 | 23 | 19 | 26 | 9 | 36 | 40 | 15 | 98 | 103 | 65 | 53 | 74 | 41 | - | 55 | 43 | 49 |
| 11-20 | 161 | 30 | 92 | 34 | 99 | 34 | 54 | 95 | 36 | 21 | 63 | 112 | 47 | 104 | 151 | 88 | 18 | 40 | 14 | 100 | 70 | 44 | 46 |
| 21-30 | 99 | 6 | - | 12 | 62 | 31 | 29 | 31 | 163 | 72 | 28 | 148 | 67 | 362 | 90 | 69 | 61 | 53 | 136 | 317 | 92 | 95 | 44 |
| May 1-10 | 84 | 31 | 44 | 53 | 142 | 76 | 70 | 99 | 84 | 28 | 27 | 58 | 15 | 122 | 85 | 117 | 88 | 127 | 86 | 76 | 76 | 36 | 42 |
| 11-20 | 26 | 38 | 44 | 56 | 132 | 43 | 34 | 149 | 25 | 24 | 66 | 39 | 6 | 23 | - | 31 | 46 | 67 | 110 | 12 | 49 | 40 | 41 |
| 21-31 | 5 | 69 | 136 | 134 | 80 | 11 | 8 | 112 | 29 | 45 | 7 | 57 | 19 | 25 | 464 | - | 9 | 61 | 142 | 54 | 73 | 103 | 40 |
| June 1-10 | 6 | 15 | - | 18 | 22 | 5 | 3 | 8 | - | 8 | 30 | 11 | - | 43 | 113 | 14 | 57 | 7 | 63 | 39 | 23 | 28 | 39 |
| 11-20 | 54 | 23 | 13 | 13 | 5 | 18 | 82 | - | 31 | 11 | 18 | 39 | 13 | 37 | - | - | - | 28 | - | 13 | 20 | 21 | 39 |
| 21-30 | 52 | - | - | 73 | 14 | 3 | 45 | - | 28 | 49 | 10 | 36 | 39 | 33 | - | - | - | 74 | 14 | 114 | 29 | 32 | 39 |
| July 1-10 | 22 | - | 1 | 15 | - | 15 | 36 | 28 | - | 61 | 28 | - | - | 20 | 38 | 35 | 57 | 39 | 29 | 78 | 25 | 23 | 38 |
| 11-20 | 20 | - | 29 | 10 | 41 | 16 | 50 | 60 | - | 79 | 28 | 45 | 27 | 13 | 16 | 5 | 23 | 10 | 19 | 16 | 25 | 21 | 38 |
| 21-31 | 28 | 8 | 20 | 13 | 73 | 18 | 18 | 7 | 25 | 3 | 12 | 24 | 4 | 28 | 24 | 12 | 2 | 131 | 87 | 28 | 28 | 32 | 39 |
| Aug. 1-10 | 6 | 18 | 75 | 53 | - | - | 17 | - | 16 | 38 | 16 | - | 78 | 16 | - | 48 | 16 | 21 | 22 | 36 | 24 | 24 | 40 |
| 11-20 | 9 | 34 | 13 | 4 | 33 | 13 | 9 | 10 | 36 | 6 | 8 | 47 | 84 | 12 | 22 | 84 | 26 | 11 | - | 4 | 23 | 24 | 41 |
| 21-31 | 21 | 22 | 10 | 4 | 52 | 26 | 12 | 43 | 22 | - | - | - | 6 | 5 | 35 | 32 | 35 | 23 | 38 | - | 19 | 16 | 42 |
| Sep. 1-10 | 22 | 13 | 31 | 37 | 241 | 65 | 14 | 190 | 14 | 5 | 84 | 11 | 8 | 19 | 50 | 74 | 12 | 16 | 45 | 18 | 48 | 62 | 44 |
| 11-20 | 13 | 13 | 59 | 10 | 5 | 2 | 29 | 71 | 5 | 22 | 50 | 21 | 184 | - | 26 | 9 | 67 | 116 | 7 | 45 | 38 | 46 | 46 |
| 21-30 | 20 | 26 | 59 | 24 | 182 | 13 | - | 8 | 25 | - | 9 | 110 | 37 | 2 | 12 | 1 | - | 60 | 33 | - | 31 | 45 | 48 |
| Oct. 1-10 | 17 | 5 | 127 | 12 | 7 | 29 | 1 | 244 | 15 | 2 | 27 | 17 | 142 | 7 | 24 | 7 | 217 | 171 | 31 | 74 | 59 | 77 | 50 |
| 11-20 | 15 | 45 | 54 | 24 | 12 | 14 | 15 | 58 | 65 | - | 20 | 42 | 35 | 40 | 56 | 3 | 53 | 201 | - | 28 | 39 | 43 | 52 |
| 21-31 | 41 | 142 | 67 | 78 | 260 | 25 | 10 | 51 | 8 | 62 | 36 | 71 | 212 | 16 | 11 | - | 70 | 80 | 5 | 156 | 70 | 71 | 51 |
| Nov. 1-10 | 17 | 2 | 169 | 44 | 266 | 1 | - | 247 | 4 | 102 | - | 20 | 121 | 31 | 98 | 191 | 66 | 22 | 39 | 153 | 80 | 85 | 50 |
| 11-20 | 199 | 17 | 57 | 8 | 48 | 12 | 5 | 59 | 95 | 49 | 10 | 25 | 25 | 45 | 96 | 73 | - | 145 | 27 | 32 | 51 | 51 | 50 |
| 21-30 | 156 | 6 | 66 | 63 | 66 | 41 | 7 | 16 | 80 | 4 | 66 | 32 | 68 | 296 | 29 | 53 | - | 206 | 4 | 50 | 65 | 75 | 52 |
| Dec. 1-10 | 36 | 33 | 24 | 12 | 41 | 100 | 41 | 134 | 36 | 25 | 145 | 30 | 27 | 134 | 13 | 77 | 75 | 166 | 17 | 56 | 61 | 49 | 53 |
| 11-20 | 28 | 26 | 96 | 4 | - | 64 | 60 | 94 | 99 | - | 46 | 15 | 99 | 18 | 2 | 123 | 150 | 29 | 22 | 63 | 52 | 45 | 55 |
| 21-31 | 162 | 68 | 17 | - | 13 | 91 | 18 | 21 | - | - | 8 | 40 | 178 | 23 | 127 | 17 | 121 | - | 28 | 120 | 53 | 59 | 56 |

S.D. = Standard Deviation of rainfall data. ETo = Potential Evapotranspiration.

Table 11 : Expected occurence of moisture stress on soil of Kwamtili series, typical phase and Muzi series

| | '63 | '64 | '65 | '66 | '67 | '70 | '71 | '72 | '73 | '74 | '75 | '76 | '77 | '78 | '79 | '80 | '81 | '82 | '83 | '84 | Probability (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. 1-10 | - | - | - | - | S | - | - | - | - | - | - | - | - | - | - | - | - | - | - | S | 10 |
| 11-20 | S | - | - | - | S | S | - | - | - | - | - | S | S | - | - | - | - | - | S | S | 35 |
| 21-31 | - | - | S | - | S | - | - | S | S | - | S | S | S | - | - | - | - | - | S | S | 45 |
| Feb. 1-10 | - | - | S | - | - | S | S | - | S | S | S | - | S | - | - | - | S | - | S | S | 50 |
| 11-20 | S | S | S | - | S | S | S | - | - | S | S | S | S | - | - | S | S | S | S | S | 75 |
| 21-28 | S | S | S | S | S | S | S | S | S | S | S | - | S | - | - | S | S | S | S | S | 85 |
| Mar. 1-10 | - | S | S | - | - | S | - | S | S | S | S | S | - | - | - | S | S | S | S | S | 65 |
| 11-20 | - | - | S | - | - | - | S | S | S | S | S | S | S | - | - | S | S | S | - | - | 55 |
| 21-31 | - | - | - | - | - | - | - | S | - | S | - | - | S | - | - | S | - | - | - | - | 20 |
| Apr. 1-10 | - | - | - | - | - | - | - | S | - | S | - | - | S | - | - | - | - | - | - | S | 20 |
| 11-20 | - | - | - | - | - | - | - | - | - | S | - | - | - | - | - | - | - | - | S | - | 10 |
| 21-30 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| May 1-10 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 11-20 | - | - | - | - | - | - | - | - | - | - | - | - | S | - | - | - | - | - | - | - | 5 |
| 21-31 | - | - | - | - | - | - | - | - | - | - | - | - | S | - | - | - | - | - | - | - | 5 |
| June 1-10 | - | - | - | - | - | - | - | - | - | S | - | - | S | - | - | - | - | - | - | - | 10 |
| 11-20 | - | - | - | - | - | - | - | - | - | S | - | - | S | - | - | - | - | - | - | - | 10 |
| 21-30 | - | - | - | - | - | S | - | - | - | - | S | - | - | - | - | S | - | - | - | - | 15 |
| July 1-10 | - | S | - | - | - | S | - | S | - | - | - | - | S | - | - | - | - | - | - | - | 20 |
| 11-20 | - | S | - | - | - | S | - | - | S | - | - | - | - | - | - | S | - | - | - | - | 20 |
| 21-31 | - | S | - | - | - | S | - | - | - | - | S | - | S | - | - | S | - | - | - | - | 25 |
| Aug. 1-10 | - | S | - | - | - | S | - | S | S | - | S | - | - | - | S | - | - | - | - | - | 30 |
| 11-20 | S | - | - | - | - | S | - | S | - | - | S | - | - | - | - | - | - | - | - | - | 20 |
| 21-31 | - | - | - | - | - | - | - | - | - | S | S | S | - | S | - | - | - | - | - | - | 20 |
| Sep. 1-10 | - | S | - | - | - | - | S | - | S | S | - | S | - | S | - | - | S | - | - | - | 35 |
| 11-20 | S | S | - | S | - | S | - | - | S | S | - | S | - | S | - | - | - | - | - | - | 40 |
| 21-30 | S | - | - | - | - | S | S | - | - | S | - | - | - | S | S | - | S | - | - | S | 40 |
| Oct. 1-10 | S | S | - | S | - | - | S | - | S | S | - | - | - | S | S | S | - | - | - | - | 45 |
| 11-20 | S | - | - | S | - | S | S | - | - | S | S | - | - | - | - | S | - | - | S | - | 40 |
| 21-31 | - | - | - | - | - | S | S | - | S | - | - | - | - | S | S | S | - | - | S | - | 35 |
| Nov. 1-10 | S | - | - | - | - | S | S | - | S | - | S | - | - | - | - | - | - | - | - | - | 35 |
| 11-20 | - | - | - | - | - | S | S | - | - | - | S | - | - | - | - | - | - | - | - | - | 15 |
| 21-30 | - | - | - | - | - | - | S | - | - | - | - | - | - | - | - | - | - | - | S | - | 10 |
| Dec. 1-10 | - | - | - | S | - | - | - | - | - | - | - | - | - | - | - | - | - | - | S | - | 10 |
| 11-20 | - | S | - | S | - | - | - | - | - | S | - | S | - | - | - | - | - | - | S | - | 25 |
| 21-31 | - | - | - | S | - | - | S | - | - | S | - | - | - | - | - | - | - | - | - | - | 15 |

S = serious moisture stress (act evapotr. < 0.5 potential evapotr.)

Table 12 : Expected occurence of moisture stress on soils of Kwamtili series, deep and gravelly phase and Mwanzi series

| | '63 | '64 | '65 | '66 | '67 | '70 | '71 | '72 | '73 | '74 | '75 | '76 | '77 | '78 | '79 | '80 | '81 | '82 | '83 | '84 | Probability (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. 1-10 | - | - | - | - | S | - | - | - | - | - | - | - | - | - | - | - | - | - | S | S | 15 |
| 11-20 | S | - | - | - | S | S | S | - | - | - | - | S | S | - | - | S | S | - | S | S | 50 |
| 21-31 | - | S | S | - | S | - | S | S | S | - | S | S | S | - | - | - | S | S | S | S | 65 |
| Feb. 1-10 | - | S | S | - | - | S | S | - | S | S | S | - | S | - | - | - | S | - | S | S | 55 |
| 11-20 | S | S | S | - | S | S | S | - | - | S | S | S | S | - | - | S | S | S | S | S | 75 |
| 21-28 | S | S | S | S | S | S | S | S | S | S | S | S | S | - | - | S | S | S | S | S | 90 |
| Mar. 1-10 | - | S | S | S | - | S | - | S | S | S | S | S | - | - | S | S | S | S | S | S | 75 |
| 11-20 | - | - | S | - | - | - | S | S | S | S | S | S | S | - | - | S | S | S | - | - | 55 |
| 21-31 | - | - | - | - | - | - | - | S | - | S | - | - | S | - | - | S | - | - | - | - | 20 |
| Apr. 1-10 | - | - | - | - | - | - | - | S | - | S | - | - | S | - | - | - | - | - | - | S | 20 |
| 11-20 | - | - | - | - | - | - | - | - | - | S | - | - | - | - | - | - | - | - | S | - | 10 |
| 21-30 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| May 1-10 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 11-20 | - | - | - | - | - | - | - | - | - | - | - | - | S | - | - | - | - | - | - | - | 5 |
| 21-31 | - | - | - | - | - | - | - | - | - | - | - | - | S | - | - | - | - | - | - | - | 5 |
| June 1-10 | - | - | - | - | - | - | - | - | - | S | - | - | S | - | - | - | - | - | - | - | 10 |
| 11-20 | - | - | - | - | - | - | - | - | - | S | S | - | S | - | - | S | - | - | - | - | 20 |
| 21-30 | - | S | S | - | - | S | - | S | - | - | S | - | - | - | - | S | - | - | - | - | 30 |
| July 1-10 | - | S | S | - | S | S | - | S | S | - | - | - | S | - | - | - | - | - | - | - | 35 |
| 11-20 | - | S | - | - | - | S | - | - | S | - | - | - | - | - | - | S | - | - | - | - | 20 |
| 21-31 | - | S | S | - | - | S | - | - | - | - | S | - | S | - | - | S | S | - | - | - | 35 |
| Aug. 1-10 | S | S | - | - | - | S | - | S | S | - | S | S | - | S | S | - | S | - | - | - | 45 |
| 11-20 | S | - | - | - | - | S | - | S | - | - | S | - | - | S | S | - | - | - | - | - | 30 |
| 21-31 | S | S | - | S | - | - | - | - | S | S | S | S | - | S | - | - | - | - | - | S | 45 |
| Sep. 1-10 | S | S | - | - | - | - | S | - | S | S | - | S | - | S | - | - | S | - | - | S | 45 |
| 11-20 | S | S | - | S | - | S | - | - | S | S | - | S | - | S | - | - | - | - | S | - | 45 |
| 21-30 | S | - | - | S | - | S | S | - | S | S | - | - | - | S | S | - | S | - | - | S | 50 |
| Oct. 1-10 | S | S | - | S | - | - | S | - | S | S | - | - | - | S | S | S | - | - | - | - | 45 |
| 11-20 | S | - | - | S | - | S | S | - | - | S | S | - | - | - | - | S | - | - | S | - | 40 |
| 21-31 | - | - | - | - | - | S | S | - | S | - | - | - | - | S | S | S | - | - | S | - | 35 |
| Nov. 1-10 | S | - | - | - | - | S | S | - | S | - | S | - | - | - | - | - | - | - | - | - | 25 |
| 11-20 | - | - | - | - | - | S | S | - | - | - | S | - | - | - | - | - | - | - | - | - | 15 |
| 21-30 | - | S | - | - | - | - | S | - | - | - | - | - | - | - | - | - | - | - | S | - | 15 |
| Dec. 1-10 | - | - | - | S | - | - | - | - | - | - | - | - | - | - | - | - | - | - | S | - | 10 |
| 11-20 | - | S | - | S | - | - | - | - | - | S | - | S | - | - | S | - | - | - | S | - | 30 |
| 21-31 | - | - | - | S | - | - | S | - | - | S | - | - | - | - | - | - | - | - | S | - | 20 |

S = serious moisture stress (act evaptr. < 0.5 potential evapotr.)

Table 13 : Expected occurence of moisture stress on soils of Mtai series

| | '63 | '64 | '65 | '66 | '67 | '70 | '71 | '72 | '73 | '74 | '75 | '76 | '77 | '78 | '79 | '80 | '81 | '82 | '83 | '84 | Probability (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. 1-10 | - | - | - | S | S | - | S | - | - | S | - | S | - | S | - | S | - | S | S | S | 50 |
| 11-20 | S | S | - | - | S | S | S | S | S | - | - | S | S | - | - | S | S | - | S | S | 65 |
| 21-31 | - | S | S | - | S | - | S | S | S | - | S | S | S | - | - | S | S | S | S | S | 70 |
| Feb. 1-10 | - | S | S | - | - | S | S | - | S | S | S | - | S | S | - | - | S | S | S | S | 65 |
| 11-20 | S | S | S | - | S | S | S | - | - | S | S | S | S | - | - | S | S | S | S | S | 75 |
| 21-28 | S | S | S | S | S | S | S | S | S | S | S | S | S | - | - | S | S | S | S | S | 90 |
| Mar. 1-10 | - | S | S | S | - | S | - | S | S | S | S | S | - | - | S | S | S | S | S | S | 75 |
| 11-20 | - | - | S | - | - | - | S | S | S | S | S | S | S | - | - | S | S | S | - | - | 55 |
| 21-31 | - | - | - | - | - | - | - | S | - | S | - | - | S | - | - | S | - | - | - | - | 20 |
| Apr. 1-10 | - | - | - | - | - | - | - | S | - | S | - | - | S | - | - | - | - | - | - | S | 20 |
| 11-20 | - | - | - | - | - | - | - | - | - | S | - | - | - | - | - | - | - | - | S | - | 10 |
| 21-30 | - | S | S | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 10 |
| May 1-10 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 11-20 | - | - | - | - | - | - | - | - | - | - | - | - | S | - | S | - | - | - | - | - | 10 |
| 21-31 | S | - | - | - | - | - | - | - | - | - | - | - | S | - | - | S | - | - | - | - | 15 |
| June 1-10 | S | - | S | - | - | S | S | - | S | S | - | - | S | - | - | S | - | - | - | - | 40 |
| 11-20 | - | - | S | - | S | S | - | S | - | S | S | - | S | - | S | S | S | - | S | S | 55 |
| 21-30 | - | S | S | - | S | S | - | S | - | - | S | - | - | - | S | S | S | - | S | - | 50 |
| July 1-10 | - | S | S | - | S | S | - | S | S | - | - | S | S | - | - | - | - | - | - | - | 40 |
| 11-20 | - | S | - | S | - | S | - | - | S | - | - | - | - | S | S | S | - | - | S | - | 40 |
| 21-31 | - | S | S | S | - | S | - | - | - | - | S | - | S | - | - | S | S | - | - | - | 40 |
| Aug. 1-10 | S | S | - | - | - | S | - | S | S | - | S | S | - | S | S | - | S | - | - | - | 50 |
| 11-20 | S | - | - | S | - | S | S | S | - | S | S | - | - | S | S | - | - | - | S | S | 55 |
| 21-31 | S | S | S | S | - | - | S | - | S | S | S | S | - | S | - | - | - | - | - | S | 55 |
| Sep. 1-10 | S | S | - | - | - | - | S | - | S | S | - | S | S | S | - | - | S | S | - | S | 55 |
| 11-20 | S | S | - | S | - | S | - | - | S | S | - | S | - | S | - | - | - | - | S | - | 45 |
| 21-30 | S | S | - | S | - | S | S | - | S | S | - | - | - | S | S | S | S | - | - | S | 60 |
| Oct. 1-10 | S | S | - | S | - | - | S | - | S | S | - | - | - | S | S | S | - | - | - | - | 45 |
| 11-20 | S | - | - | S | S | S | S | - | - | S | S | - | - | - | - | S | - | - | S | - | 45 |
| 21-31 | - | - | - | - | - | S | S | - | S | - | - | - | - | S | S | S | - | - | S | - | 35 |
| Nov. 1-10 | S | S | - | - | - | S | S | - | S | - | S | - | - | - | - | - | - | - | - | - | 30 |
| 11-20 | - | S | - | - | - | S | S | - | - | - | S | - | - | - | - | - | S | - | - | - | 25 |
| 21-30 | - | S | - | - | - | - | S | - | - | S | - | - | - | - | - | - | S | - | S | - | 25 |
| Dec. 1-10 | - | - | - | S | - | - | - | - | - | - | - | - | - | - | S | - | - | - | S | - | 15 |
| 11-20 | - | S | - | S | S | - | - | - | - | S | - | S | - | - | S | - | - | - | S | - | 35 |
| 21-31 | - | - | S | S | S | - | S | - | S | S | S | - | - | - | - | S | - | S | S | - | 50 |

S = serious moisture stress (act evapotr. <0.5 potential evapotr.)

## APPENDIX II

This appendix contains the description of representative profiles of the soil series recognized in the Kwamtili area. The soil series description includes the results of the chemical and physical laboratory analyses.

### a) Soil Description and Classification

The soils are described and classified according to :

- Guidelines for soil profile description, FAO, Land and Water Development Division, 1977.
- FAO/Unesco Soil map of the world, Vol. I Legend. Unesco, 1974.
- Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. USDA, 1975.

### b) Laboratory Methods and Procedures

The laboratory methods and procedures are those used in the laboratory of the National Soil Service, Mlingano, Tanga.

Collected 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.

- particle size analyses: hydrometer method based on Stoke's Law (clay and silt fractions) and USDA standard sieves (sand fraction)
- pH ($H_2O$ and $CaCl_2$): electrode method, with pH meter on 1:2.5 soil/$H_2O$ and on 1:2.5 soil/$CaCl_2$ (0.01M) mixtures.
- organic carbon: Walkey and Black method, wet acid-dichromate digestion and $FeSO_4$ titration.
- total nitrogen: semi-micro Kjeldahl; digestion with sulphuric acid, using seleninum + potassium sulphates as catalystes, followed by ammonium destillation
- available phosphorus: Bray and Kurtz II method, extraction with 0.1M HCl and 0.03M $NH_4F$ colour development by ammonium molybdate + stannous chloride
- exchangeable cations: ammonium acetate extraction (at pH 7.0) followed by EDTA titration (Ca + Mg) and flame photometric determination (Na + K).
- bulk density: determined on oven-dry, undisturbed core samples
- field capacity: pressure plate extractor (1/3 bar) on undisturbed samples
- permanent wilting point: pressure membrane extractor (15 bar) on disturbed samples

## KWAMTILI SERIES, TYPICAL PHASE

### General infromation on the site and soil

Location: Kwamtili Estate, 600 m S of the Director's house and 200 m E of the Ngambo road.
Physiography: long straight middle slope (15%) within a rolling country.
Elevation: approximately 250 m.
Parent material: strongly weathered mantle of reddish clay derived from Usagaran gneisses.
Vegetation/land use: well established cocoa, with an open shading of kapok trees.
Soil: very deep, well drained, reddish brown to red, sandy clay to clay, with a thin topsoil. Udic Tropustic soil moisture regime.
Description: the soil was described on 12/2/1985 by National Soil Service.

### Soil profile description

**Ap** (00 - 13 cm): dark reddish brown (5YR3/4, moist) sandy clay loam; moderate, fine and medium subangular blocky; sticky and plastic when wet, friable when moist; many fine pores; many fine, and common medium roots; neutral; clear, smooth boundary

**BA** (13 - 42 cm): reddish brown (5YR4/4, moist) sandy clay; moderate medium subangular blocky; sticky and plastic when wet, friable when moist; few medium pores; common, fine and medium roots; neutral; gradual, smooth boundary

**Bt1** (42 - 60 cm): yellowish brown (5YR4/6, moist) sandy clay; moderate medium subangular blocky; sticky and plastic when wet, friable when moist; patchy thin clay cutans; many fine pores; few fine roots; few (2-5%) weathering minerals, mainly quartz; neutral; gradual, smooth boundary

**Bt2** (60 - 106 cm): red (2.5YR4/8, moist) sandy clay; moderate medium subangular blocky; very sticky and plastic when wet, friable when moist; broken moderately thick clay cutans; many fine pores, few fine roots; few (2-5%) weathering minerals, mainly quartz; neutral; gradual, smooth boundary

**Bt3** (106 - 160+ cm): red (2.5YR4/8, moist) slightly gravelly clay; moderate medium subangular blocky; very sticky and plastic when wet, friable when moist; broken thin clay cutans; many fine pores; few fine roots; few (5%) weathering minerals and gravel, mainly quartz; neutral.

### ANALYTICAL DATA

| Horizon | | | Ap | BA | Bt1 | Bt2 | Bt3 |
|---|---|---|---|---|---|---|---|
| Depth (cm) | | | 00-13 | 13-42 | 42-60 | 60-106 | 106-160 |
| TEXTURE | sand | % | 56 | 53 | 50 | 50 | 42 |
| | coarse silt | % | 3 | 4 | 4 | 2 | 3 |
| | fine silt | % | 8 | 1 | 3 | 3 | 4 |
| | clay | % | 33 | 42 | 43 | 45 | 51 |
| | class | | SCL | SC | SC | SC | C |
| pH $H_2O$ | 1 : 2.5 | | 7.0 | 6.9 | 6.9 | 7.1 | 7.3 |
| pH $CaCl_2$ | 1 : 2.5 | | 6.6 | 6.2 | 6.1 | 6.4 | 6.7 |
| organic C | | % | 2.3 | 1.3 | 0.8 | 0.7 | 0.6 |
| total N | | % | 0.29 | 0.14 | 0.10 | 0.08 | 0.06 |
| C/N ratio | | | 8 | 9 | 8 | 9 | 10 |
| available P | | ppm | 5.1 | 2.0 | 1.9 | 2.0 | 1.7 |
| exch. Ca | | me/100g | 16.0 | 7.0 | 5.5 | 4.5 | 4.0 |
| exch. Mg | | " | 1.5 | 1.5 | 1.0 | 2.5 | 1.5 |
| exch. K | | " | 1.0 | 0.3 | 0.2 | 0.3 | 0.4 |
| exch. Na | | " | 0.5 | 0.9 | 0.5 | 0.5 | 0.4 |
| CEC (sum) | | " | 19.0 | 9.6 | 7.2 | 7.8 | 6.3 |
| bulk density | | $g/cm^3$ | - | 1.34 | - | 1.30 | 1.27 |
| field capacity | | % | - | 21.3 | - | 22.3 | 25.1 |
| wilting point | | % | - | 17.0 | - | 18.3 | 19.1 |

### Soil classification

FAO/Unesco Legend : Ferric Luvisol

USDA Soil Taxonomy : Oxic Paleustalf, fine clayey, isohyperthermic

## MTAI SERIES, TYPICAL PHASE

### General information on the site and soil

**Location:** Kwamtili Estate, just W of the Manager's house
**Physiography:** straight steep middle slope (45%), within hilly country
**Elevation:** approximately 230 m
**Parent material:** strongly weathered mantle of reddish clay derived from Usagaran gneisses
**Vegetation/land use:** coconut, mixed with maize and cassava
**Soil:** moderately deep, well drained reddish brown to red soil with sandy clay loam thin topsoil over gravelly clay subsoil. Udic Tropustic soil moisture regime
**Description:** soil was described on 13/2/1985 by National Soil Service.

### Soil profile description

**Ap**
**00 - 08 cm**
dark reddish brown (5YR3/3, moist) sandy clay loam; moderate medium subangular blocky; sticky and plastic when wet, friable when moist; many fine, and few medium pores; many fine, and few medium roots; neutral; gradual, smooth boundary

**AB**
**08 - 20 cm**
reddish brown (5YR4/4, moist) sandy clay loam; moderate medium subangular blocky; very sticky and very plastic when wet, friable when moist; many fine, and few medium pores; many fine and medium, and few coarse roots; medium acid; gradual, smooth boundary

**Bw**
**20 - 60/80 cm**
red (2.5YR4/6, moist) gravelly clay; weak to moderate, fine and medium (sub-)angular blocky; very sticky and plastic when wet, friable when moist; many fine, and few medium pores; common fine roots; few (10% - top) to very frequent (75% - bottom) weathering gravel, mainly quartz; medium acid; gradual, wavy boundary

**Cr**
**60/80 - 120+ cm**
rotten rock

### ANALYTICAL DATA

| Horizon | | | Ap | AB | Bw |
|---|---|---|---|---|---|
| Depth (cm) | | | 00-08 | 08-20 | 20-50 |
| TEXTURE | sand | % | 59 | 57 | 41 |
| | coarse silt | % | 6 | 4 | 6 |
| | fine silt | % | 7 | 6 | 7 |
| | clay | % | 28 | 33 | 46 |
| | class | | SCL | SCL | C |
| pH $H_2O$ | 1 : 2.5 | | 6.7 | 5.9 | 5.6 |
| pH $CaCl_2$ | 1 : 2.5 | | 6.0 | 4.9 | 4.9 |
| organic C | | % | 2.2 | 1.5 | 1.1 |
| total N | | % | 0.24 | 0.20 | 0.16 |
| C/N ratio | | | 9 | 8 | 7 |
| available P | | ppm | 10.5 | 7.0 | 7.0 |
| exch. Ca | | me/100g | 2.5 | 3.0 | 3.5 |
| exch. Mg | | " | 4.0 | 3.0 | 2.5 |
| exch. K | | " | 3.3 | 1.6 | 0.1 |
| exch. Na | | " | 0.4 | 0.3 | 0.4 |
| exch. Al | | " | - | 0.1 | 0.3 |
| CEC (sum) | | " | 10.2 | 8.0 | 6.8 |
| bulk density | | $g/cm^3$ | - | 1.29 | 1.27 |
| field capacity | | % | - | 19.8 | 25.1 |
| wilting point | | % | - | 16.3 | 20.0 |

### Soil classification

FAO/Unesco Legend : Ferralic Cambisol, petric phase
USDA Soil Taxonomy : Oxic Ustropept, clayey-skeletal, isohyperthermic

## MWANZI SERIES, TYPICAL PHASE

### General information on the site and soil

Location: Kwamtili Estate, 200 m W of labour camp
Physiography: straight, lower slope (5%) of a small hill within undulating country
Elevation: approximately 200 m
Parent material: strongly weathered mantle of clays derived from Usagaran gneisses
Vegetation/land use: cocoa, with Gliricidia and kapok shade trees
Soil: deep, moderately well drained yellowish brown soil with moderately thick sandy clay loam topsoil over sandy clay subsoil, which becomes hard and compact when dried. Udic Tropustic soil moisture regime
Description: soil was described on 17/7/1985 by National Soil Service.

### Soil profile description

**Ap**
00 - 22 cm
very dark greyish brown (10YR3/3, moist); sandy clay loam; moderate to strong, fine and medium subangular blocky; sticky and plastic when wet, friable when moist; many fine and medium, and common coarse pores; many fine, and few coarse roots; neutral; clear, wavy boundary

**Bt1**
22 - 52 cm
dark yellowish brown (10YR3/6, moist) sandy clay; moderate to strong, fine and medium subangular blocky; sticky and plastic when wet, friable when moist; broken thin clay cutans on some ped faces and root channels; many fine, and common medium pores; common medium, and few coarse roots; slightly acid; clear, smooth boundary

**Bt2**
52 - 80 cm
dark yellowish brown (10YR4/4, moist) sandy clay; strong, fine and medium angular blocky; slightly sticky and plastic when wet, slightly firm when moist, slightly hard when dry; broken moderately thick clay cutans on ped faces and root channels; common, fine and medium pores; few, fine and medium roots; few (2%) weathering minerals and rock fragments; slightly acid; gradual, smooth boundary

**Bt3**
80 - 110 cm
dark yellowish brown (10YR4/6, moist) sandy clay; strong, fine and medium angular blocky; sticky and plastic when wet, firm when moist, hard when dry; patchy moderately thick clay cutans; common fine, and few medium pores; few fine roots; few (5%) weathering minerals and rock fragments, resulting in faint colour mottling; neutral; diffuse boundary

**BC**
110 - 120+ cm
dark yellowish brown, with gradual increase of weathering material and colour mottling; firm when moist and hard when dry.

### ANALYTICAL DATA

| Horizon | | | Ap | Bt1 | Bt2 | Bt3 |
|---|---|---|---|---|---|---|
| Depth (cm) | | | 00-22 | 22-52 | 52-80 | 80-110 |
| TEXTURE | sand | % | 59 | 55 | 49 | 48 |
| | coarse silt | % | 8 | 3 | 3 | 3 |
| | fine silt | % | 2 | 3 | 1 | 1 |
| | clay | % | 31 | 39 | 47 | 48 |
| | class | | SCL | SC | SC | SC |
| pH $H_2O$ | 1 : 2.5 | | 7.3 | 6.5 | 6.6 | 6.7 |
| pH $CaCl_2$ | 1 : 2.5 | | 6.4 | 5.8 | 5.8 | 6.0 |
| organic C | | % | 2.0 | 0.9 | 0.7 | 0.4 |
| total N | | % | 0.20 | 0.12 | 0.08 | 0.08 |
| C/N ratio | | | 10 | 8 | 9 | 5 |
| available P | | ppm | 2.1 | 2.1 | 1.4 | 1.4 |
| exch. Ca | | me/100g | 7.0 | 5.0 | 6.0 | 4.5 |
| exch. Mg | | " | 4.0 | 2.5 | 5.0 | 3.5 |
| exch. K | | " | 0.5 | 0.4 | 0.1 | 0.1 |
| exch. Na | | " | 0.3 | 0.2 | 0.2 | 0.3 |
| CEC (sum) | | " | 11.8 | 8.1 | 11.3 | 8.4 |

### Soil classification

FAO/Unesco Legend : Luvic Phaeozem
USDA Soil Taxonomy : Udic Argiustoll, fine clayey, isohyperthermic

## KIJITO SERIES, TYPICAL PHASE

### General information on the site and soil

Location: Kwamtili Estate, 600 m E of the factory, just E of the Tanga road
Physiography: flat valley bottom, surrounded by hilly country
Elevation: approximately 210 m
Parent material: strongly weathered mantle of clay soils derived from Usagaran gneisses
Vegetation/land use: previous cocoa cultivation with 100% die-back of trees. Presently cover of perennial tall grasses
Soil: deep, poorly drained, with moderately thick sandy clay loam topsoil over clayey subsoil. Below 40 cm distinct colour mottling. Aquic soil moisture regime
Description: soil was described on 16/2/1985 by National Soil Service

### Soil profile description

**Ap**
**00 - 25 cm**
very dark greyish brown (10YR3/2, moist) sandy clay loam; weak to moderate, medium subangular blocky; slightly sticky and plastic when wet, friable when moist; many fine pores; many fine roots; medium acid; abrupt, smooth boundary

**BAg**
**25 - 40 cm**
dark brown (10YR3/3, moist) clay, with few medium very dark brown (10YR2/2, moist) mottles; moderate, medium and coarse subangular blocky; sticky and very plastic when wet, firm when moist; many fine, and few medium pores; common fine roots; neutral; gradual, smooth boundary

**Bg(t)1**
**40 - 70 cm**
dark yellowish brown (10YR4/6, moist), dark grey (2.5Y4/1, moist), greyish brown (2.5Y5/2, moist) and dark greenish grey (5G4/1, moist) mottled clay; moderate, medium and coarse subangular blocky; sticky and very plastic when wet, firm when moist; probably some cutans and pressure faces on larger peds; many fine, and few medium pores; few fine roots; few (2%) weathering gravel; neutral; gradual, smooth boundary

**Bg(t)2**
**70 - 90 cm**
same as Bg(t)1, but with frequent (25%) weathering quartz gravel, increasing in amount with depth.

### ANALYTICAL DATA

| Horizon | | Ap | BAg | Bg(t)1 |
|---|---|---|---|---|
| Depth (cm) | | 00-25 | 25-40 | 40-70 |
| TEXTURE sand | % | 66 | 46 | 44 |
| TEXTURE coarse silt | % | 6 | 2 | 4 |
| TEXTURE fine silt | % | 1 | 3 | 1 |
| TEXTURE clay | % | 27 | 49 | 51 |
| TEXTURE class | | SCL | C | C |
| pH $H_2O$ | 1 : 2.5 | 5.9 | 6.8 | 7.0 |
| pH $CaCl_2$ | 1 : 2.5 | 5.3 | 5.9 | 6.3 |
| Organic C | % | 1.6 | 0.7 | 0.4 |
| total N | % | 0.26 | 0.11 | 0.06 |
| C/N ratio | | 6 | 6 | 7 |
| available P | ppm | 8.4 | 4.2 | 2.8 |
| exch. Ca | me/100g | 4.0 | 7.0 | 4.0 |
| exch. Mg | " | 6.0 | 9.0 | 11.0 |
| exch. K | " | 1.5 | 0.1 | 0.1 |
| exch. Na | " | 0.6 | 0.8 | 1.0 |
| CEC (sum) | | 12.1 | 16.9 | 16.1 |

### Soil classification

FAO/Unesco Legend : Gleyic Phaeozem, sodic phase
USDA Soil Taxonomy : Abrubtic Argiaquoll, fine clayey, isohyperthermic

## MUZI SERIES, TYPICAL PHASE

### General information on the site and soil

Location: Kwamtili Estate, 150 m NW of the labour camp, close to Muzi river
Physiography: gently sloping (5%) alluvial flat/river terrace, within undulating country
Elevation: approximately 200 m
Parent material: alluvium, originally derived from strongly weathered Usagaran gneisses
Vegetation/land Use: well established cocoa with Gliricidia shade trees
Soil: very deep, well drained, with moderately thick sandy loam topsoil over very uniform reddish brown loamy sand subsoil.
Description: soil was described on 15/2/1985 by National Soil Service

### Soil profile description

**Ap**
00 - 19/26 cm
dark brown (7.5YR3/2, moist) sandy loam; weak, fine and medium subangular blocky; slightly sticky and slightly plastic when wet, very friable when moist; many fine pores; many fine, and few coarse roots; slithtly acid; clear, wavy boundary

**BA**
19/26 - 36 cm
dark brown (7.5YR4/2, moist) loamy sand; weak to moderate, fine and medium subangular blocky; slightly sticky and slightly plastic when wet, friable when moist; many fine pores; many, fine and medium roots; neutral; gradual, smooth boundary

**Bu1**
36 - 77 cm
dark reddish brown (5YR3/3, moist) loamy sand; weak to moderate, fine and medium subangular blocky; slightly sticky and slightly plastic when wet, friable when moist; many fine pores; common, fine and medium roots; neutral; gradual, smooth boundary

**Bu2**
77 - 130 cm
reddish brown (5YR4/4, moist) loamy sand; weak, fine and medium subangular blocky; slightly sticky and slightly plastic when wet, friable when moist; many fine pores; common fine roots; neutral; gradual, smooth boundary

**Bu3**
130 - 190+cm
yellowish red (5YR4/6, moist) loamy sand; weak, fine and medium subangular blocky; slightly sticky and slightly plastic when wet, friable when moist; many fine pores; few fine roots; neutral

### ANLYTICAL DATA

| Horizon | | Ap | BA | Bu1 | Bu2 | Bu3 |
|---|---|---|---|---|---|---|
| Depth (cm) | | 00-20 | 25-36 | 36-77 | 77-130 | 130-190 |
| TEXTURE sand | % | 74 | 83 | 83 | 86 | 83 |
| TEXTURE coarse silt | % | 9 | 4 | 5 | 3 | 4 |
| TEXTURE fine silt | % | 5 | 2 | 2 | 1 | 2 |
| TEXTURE clay | % | 12 | 11 | 10 | 10 | 11 |
| TEXTURE class | | SL | LS | LS | LS | LS |
| pH $H_2O$ 1 : 2.5 | | 6.4 | 6.7 | 6.7 | 6.7 | 6.8 |
| pH $CaCl_2$ 1 : 2.5 | | 5.9 | 6.2 | 5.9 | 5.8 | 5.9 |
| organic C | % | 1.1 | 1.4 | 0.6 | 0.7 | 0.4 |
| total N | % | 0.22 | 0.14 | 0.07 | 0.05 | 0.05 |
| C/N ratio | | 5 | 10 | 9 | 14 | 8 |
| available P | ppm | 62.7 | 55.9 | 71.4 | 62.7 | 69.3 |
| exch. Ca | me/100g | 8.5 | 5.0 | 3.0 | 2.5 | 2.5 |
| exch. Mg | " | 3.5 | 2.0 | 3.5 | 3.5 | 3.0 |
| exch. K | " | 0.6 | 0.6 | 1.2 | 1.0 | 1.2 |
| exch. Na | " | 0.6 | 0.4 | 0.4 | 0.4 | 0.4 |
| CEC (sum) | " | 13.2 | 8.0 | 8.1 | 7.4 | 7.1 |
| bulk density | $g/cm^3$ | 1.33 | - | - | 1.50 | - |
| field capacity | % | 11.5 | - | - | 8.8 | - |
| wilting point | % | 5.9 | - | - | 4.6 | - |

### Soil classification

FAO/Unesco Legend : Eutric Fluvisol
USDA Soil Taxonomy : Mollic Ustifluvent, sandy, isohyperthermic

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MINISTRY OF AGRICULTURE, TANZANIA

# SOIL SURVEY AND LAND EVALUATION
# KWAMTILI ESTATE

## MAP 1
## SOILS

SCALE 1:5,000

Metres 50 0 100 200 300 400 500 Metres

1986 REPORT D6

BASE MAP:-ESTATE MAP 1969

## LEGEND

| SOIL NAME | MAP SYMBOL | SLOPE | EFFECTIVE SOIL DEPTH | EXTENT (ha) | SOIL DESCRIPTION |
|---|---|---|---|---|---|
| Kwamtili series, on hill slopes | Hs1 Kw | 2-16 | >150 | 30 | Very deep, well drained soils with 10-20cm, dark low-humic fine-loamy topsoils over red clayey subsoils; Ferric Luvisols |
| | Hs2 Kw | 16-30 | >150 | 15 | |
| | Hs3 Kw | 30-45 | >150 | 10 | |
| Kwamtili series, on lower slopes | Hl1 Kw | 8-16 | >150 | 7 | as Kwamtili series on hill slopes |
| | Hl2 Kw | 16-30 | >150 | 3 | |
| Kwamtili series, deep phase | Hs1 Kwd | 2-16 | 80-120 | 12 | as Kwamtili series, on hill slopes, but deep only |
| | Hs2 Kwd | 16-30 | 80-120 | 12 | |
| | Hs3 Kwd | 30-45 | 80-120 | 5 | |
| | Hs4 Kwd | 45-60 | 80-120 | 2 | |
| Kwamtili series, gravelly phase | Hs1 Kwg | 2-16 | 80-100 | 15 | as Kwamtili series, deep phase, but with gravelly subsoils |
| | Hs2 Kwg | 16-30 | 80-100 | 51 | |
| | Hs3 Kwg | 30-45 | 80-100 | 13 | |
| | Hs4 Kwg | 45-60 | 80-100 | 2 | |
| Mtai series | Hs1 Mt | 2-16 | 50-80 | 36 | moderately deep, well drained soils with 10-15cm dark, low-humic fine loamy topsoils over red-clayey-skeletal subsoils; Ferrglic Cambisols |
| | Hs2 Mt | 16-30 | 50-80 | 42 | |
| | Hs3 Mt | 30-45 | 50-80 | 31 | |
| | Hs4 Mt | 45-60 | 50-80 | 6 | |
| Mtai series, shallow phase | Hs1 Mts | 2-16 | 20-50 | 13 | as Mtai series, but shallow only |
| | Hs2 Mts | 16-30 | 20-50 | 6 | |
| | Hs3 Mts | 30-45 | 20-50 | 4 | |
| | Hs4 Mts | 45-60 | 20-50 | 5 | |
| Mwanzi series, | Vs1 Mw | 2-16 | 80-120 | 46 | deep, moderately well drained soils, with very dark, humic, fine loamy topsoils over firm, yellowish brown clayey subsoils. Luvic Phaeozems |
| | Vs2 Mw | 16-20 | 80-120 | 5 | |
| Mwanzi series, gravelly phase | Vs1 Mwg | 2-16 | 80-100 | 16 | as Mwanzi series, but with gravelly subsoils |
| | Vs2 Mwg | 16-20 | 80-100 | 5 | |
| Mwanzi series, moderately deep phase | Vs Mwm | 2-16 | 50-80 | 29 | as Mwanzi series, gravelly phase, but moderately deep only |
| Kijito series | Vw Ki | 0-2 | 50-120 | 8 | moderately deep to deep, poorly drained soils, with very dark, humic, fine loamy topsoils over strongly mottled clayey, sometimes gravelly subsoils, Gleyic Phaeozems |
| Muzi series | Aa Mu | 0-5 | >150 | 33 | Very deep, well drained soils, with dark, low-humic sandy topsoils over reddish brown sandy subsoils Eutric Fluvisols |

MUZI RIVER

LAKE

N

KEY
- Survey area boundary
- Mapping unit boundary
- Main road
- Permanent river or stream
- Built up areas

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# SOIL SURVEY AND LAND EVALUATION
# KWAMTILI ESTATE

## MAP 2
## LAND SUITABILITY FOR COCOA

SCALE 1:5,000

Metres 50 0 100 200 300 400 500 Metres

1986

REPORT D6

BASE MAP:- ESTATE MAP 1969

## LEGEND

| SYMBOL | DESCRIPTION | MAJOR LIMITATION | EXTENT(ha) |
|---|---|---|---|
| S1/S2m | Suitable to highly Suitable | 30-60 days soil moisture deficit. | 7 |
| S2m | Suitable | 50-60 days soil moisture deficit | 45 |
| S2e | Suitable | Slight erosion hazard, slopes 16-30% | 3 |
| S3m | Moderately Suitable | 60-90 days soil moisture deficit | 29 |
| S3dr | Moderately Suitable | Restricted soil drainage, compaction of subsoils | 51 |
| S3e | Moderately Suitable | Moderate erosion hazard, slopes 30-45% | 10 |
| S4r | Marginally Suitable | Gravelly soils | 100 |
| S4f | Marginally Suitable | Frequent flash-floods | 33 |
| Nmr | Not Suitable | Over 90 days soil moisture deficit | 28 |
| Nd | Not Suitable | Poor soil drainage (valley bottoms) | 8 |
| Nr | Not Suitable | Shallow and gravelly soils | 138 |
| Nre | Not Suitable | Shallow and gravelly soils, severe erosion hazard, slopes over 45% | 6 |
| Ne | Not Suitable | Severe erosion hazard, slopes over 45% | 4 |

MUZI RIVER

LAKE

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KEY
- Survey area boundary
- Mapping unit boundary
- Main road
- Permanent river or stream
- Built up areas

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# SOIL SURVEY AND LAND EVALUATION
## KWAMTILI ESTATE

## MAP 3
# LAND SUITABILITY FOR COCONUT

SCALE 1: 5,000

Metres 50 0 100 200 300 400 500 Metres

1986 REPORT D6

BASE MAP:- ESTATE MAP 1969

## LEGEND

| SYMBOL | DESCRIPTION | MAJOR LIMITATION | EXTENT(ha) |
|---|---|---|---|
| S1 | Highly Suitable | - | 37 |
| S2m | Suitable | 60-75 days soil moisture deficit. | 24 |
| S2e | | Slight erosion hazard, slopes 16-30% | 18 |
| S3mr | Moderately Suitable | 75-90 days soil moisture deficit | 79 |
| S3dr | | Restricted soil drainage, compaction of subsoils | 51 |
| S3e | | Moderate erosion hazard, slopes 30-45% | 15 |
| S4r | Marginally Suitable | Gravelly soils | 21 |
| Nmr | Not Suitable | Over 90 days soil moisture deficit | 28 |
| Nd | | Poorly drained soils (valley bottoms) | 8 |
| Nr | | Shallow and gravelly soils | 138 |
| Nre | | Shallow and gravelly soils severe erosion hazard, slopes over 45% | 6 |
| Nf | | Frequent damaging flash-floods | 33 |
| Ne | | Severe erosion hazard, slopes over 45% | 4 |

MUZI RIVER

LAKE

N

KEY
- Survey area boundary
- Mapping unit boundary
- Main road
- Permanent river or stream
- Built up areas

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3. Soil Survey Report Selected Areas Mkata Plain, 1983
4. Soil Survey Report Matipwili Village Irrigation Scheme, 1983
5. Soil Survey and Land Suitability Report Mkindo Village Irrigation Scheme, 1986
6. Soil Survey and Land Suitability Report Kwamtili Cocoa Estate, 1986

These reports are available from the National Soil Service P.O. Box 5088, Tanga or Private Bag Ngomeni Tanga