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# Soils of the area between the Waha and Farakwo Rivers, Ivory Coast

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# INTRODUCTION

The soils of the north eastern Ivory Coast are derived principally from igneous and metamorphic rocks of the Basement complex which have been subjected to periods of deep weathering followed by erosion and dissection in past geological periods.

Therefore all the soils tend to have a relatively low pH status, low cation exchange capacities and a moderately poor base saturation. They are only moderately fertile. This situation is typical of most areas lying within the savanna belt of West Africa.

The soils of the Ferke area lie within this region. However the climate of the area is very suitable for the growth of sugar cane and provided there is sufficient depth of soil to allow unrestricted growth of the plant roots and hold sufficient moisture to sustain growth between irrigation applications, the fertility status is easily rectified by the application of fertilisers.

In April 1975 an appraisal mission inspected several sites in the Ferke area as possible locations for a cane sugar plantation and mill complex.

The most suitable soils in the various areas visited are found south of the Farakwo river in the zone designated for the growing of Kenaf. They have adequate depth, good water holding capacities, are relatively homogeneous and occur in compact blocks. However they occupy a series of moderately high ridges and there are hydrological problems associated with water supply.

The soils in all the other areas visited are generally less suitable, soil distribution is more heterogeneous and rock and cuirass outcrops are more frequent. There is little difference between the soils in any of these areas. However there is a sugar cane plantation already established on these soils and agronomists consider that the cane growth is quite good and much better than one might expect.

Therefore after considering factors related to soils, hydrology, engineering and economics the part of the Kogaha Forest Reserve known as Zone 1 was selected for further detailed studies.

Hunting Technical Services Limited were invited to carry out the soil studies and a team began fieldwork in June 1975.

A reconnaissance soil survey was done first in order to confirm the appraisal missions' favourable impression and to ensure that a detailed soil survey was worthwhile. Once the reasonably favourable verdict of the reconnaissance had been obtained (see Appendix IV), detailed soil survey work began in July 1975 and continued in Zone 1 until September. When it became apparent that the amount of suitable land in Zone 1 was insufficient for requirements, the survey was extended further southwards into Zone IV. In all, 18,000 ha of land were surveyed, and fieldwork was completed by early November, 1975.

## SUMMARY

A detailed soil survey was carried out in the area between the Waha and Farakwo rivers situated in the north of the Ivory Coast.

A total of 20,200 hectares was surveyed at an overall density of one inspection site for every four hectares. Routine inspections were made by augering to a depth of one metre wherever possible. In addition a series of soil pits were excavated in representative soil types and ten of these were sampled for chemical and physical analyses. A series of infiltration tests were also carried out at selected sites.

The chemical analyses confirmed that the soils were acid and generally deficient in nutrients, particularly phosphates.

Soil boundaries were delineated on 1:20,000 scale aerial photographs and the information was transferred to 1:10,000 scale base maps.

A land suitability classification for sugar cane was devised, based on easily observable physical characteristics of the soil and landscape which were of practical importance to the sustained growth of sugar cane under project conditions. Cane suitability maps were prepared.

It was found that 10,900 hectares of land were suitable for cane production.

The irregular boundaries and the high degree of variability in some units mapped as suitable inevitably means that small percentages of unsuitable land may occur within these units.

A program of soil conservation will be necessary to deal with excess water in the wet season.

## CONCLUSIONS

The soil and land class units have irregular boundaries and there is a high degree of variability in some of the mapped units. The soils are relatively infertile in common with all the soils in the Ferke area and indeed are fairly typical of the soils in the entire West African savanna belt.

However the climate of the area is ideally suited for the growth of sugar cane and agronomists consider that cane growth on the present sugar estate is better than one might expect on such soils.

Clearly there is therefore potential for the development of a sugar cane plantation provided that the various limitations are carefully recognised.

These limitations may be counteracted by careful selection of the most suitable land, implementation of adequate fertiliser practices and attention to erosion control methods.

## TERMS OF REFERENCE

After the reconnaissance soil survey (see Appendix IV), had shown that the area was similar to the Ferke I sugar complex and suitable for cane sugar development, the brief of the study was to:

'conduct a detailed soil survey of the Kogaha Forest Reserve west of Longitude $5^{O}$ 15'W. The soil is to be examined at an overall density of at least one bore per four hectares, and is to be extended southwards from the River Waha until 6000 hectares of land suitable for cane plantations has been found. The major soil types are to be characterised by profile description, chemical analyses, available soil water capacity determinations and by field infiltration tests. Maps are to be produced showing the distribution of the soils and of cane suitability classes. These maps are to be accompanied by an explanatory report'.

During the course of the survey, the amount of suitable land required was increased to 7,750 ha gross, to give a net area of 6,200 ha after irrigation blocks had been laid out.

# LOCATION OF PROJECT AREA

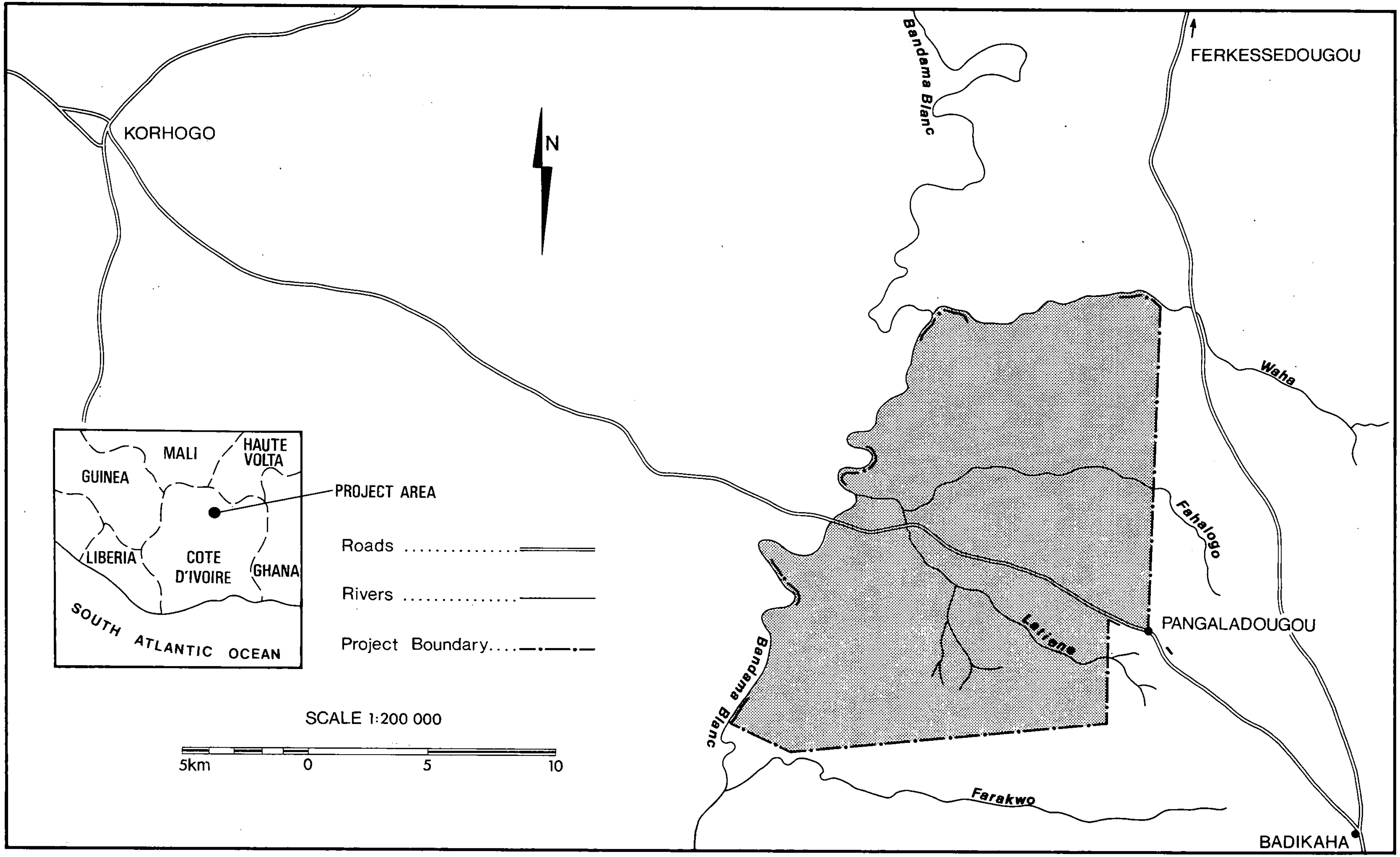


Figure 1-1

# CHAPTER 1

# THE PHYSICAL ENVIRONMENT

## 1.1 Location and Access

The area that was finally covered by the detailed soil survey was approximately 18,000 ha, extending from the Waha river in the north and just reaching the Farakwo river in the south west. Both of these streams flow westwards into the Bandama Blanc river. The area lies in the northern part of the Ivory Coast between the geographical coordinates $9^{\circ}14'$-$9^{\circ}24'$N latitude and $5^{\circ}15'$-$5^{\circ}24'$W longitude. Administratively, it forms part of the Tafiré sous-préfecture in the Katiola préfecture.

The boundaries of the area are shown on the location map (Figure 1.1). The southern boundary was determined by the southward extent of units of suitable land and is not therefore related to any continuous physiographic feature. The eastern boundary of the area to the north of the Korhogo-Badikaha road approximates to the $5^{\circ}15'$ line of longitude, but was actually a line drawn north from Pangaladougou village, as this passed through identifiable points on aerial photographs. South of the road the eastern boundary followed an old piste opened up during a previous survey (SOGETHA, 1972). No part of the area is more than 12 km from the Bandama river.

All the area north of the Korhogo-Badikaha road lies within the Kogaha forest reserve and most of the area south of the road lies within the Silue forest reserve. The area as a whole has been uninhabited and virtually untouched for several decades. A few traces of cultivation were observed, but these were all old and apparently the work of people who lived west of the Bandama or east of Pangaladougou. Tracks and footpaths were therefore extremely rare. Access in the area south of the road was much facilitated, however, by a network of excellent pistes opened up in the SOGETHA study. The area north of the road was opened up by two pistes which were cut northwards to the Waha river from the Korhogo-Badikaha road. One of these pistes was located slightly west of centre of the survey area and the other was close to the eastern boundary. Because nearly all the survey was conducted in the rainy season considerable difficulty was experienced with river crossings. The bridge over the Bandama was often only passable on foot and was completely submerged for the whole of September, necessitating crossing the river by boat. The Fahalogo river which flows roughly through the centre of the survey area was often impassable to vehicles and long distances often had to be covered on foot to reach the northernmost parts of the area.

## 1.2 Climate

The climate of the project area is tropical subhumid, with a hot dry season lasting from November to March and a unimodal rainy season which lasts from April to October and peaks in August-September. The climate of this part of West Africa is controlled by the north-south movement of the intertropical convergence zone, which separates the hot dry air stream (Harmattan) coming from the Sahara in the north, from the humid, comparatively cool air stream (Mousson) coming from the Atlantic Ocean to the south (Eldin, 1971).

There are long term meteorological stations at Korhogo and Ferkéssédougou where climatic records have been taken since 1922 and 1927 respectively. There are some gaps in the Korhogo records. More recently climatic data have been available from the IRAT station, a few kilometres west of Ferkéssédougou, on the road to Korhogo. Measurements of rainfall and evaporation have also been taken 5 kilometres south of Korhogo over a period of 3 years during an ORSTOM hydrological study (Molinier, 1971).

The general characteristics of the climate of the region were summarised by SOGETHA (1972) as follows:-

TABLE 1.1 Climatic Summary of the Project Region

| | Annual Average | Wet Season (April-October) | Dry Season (November-March) |
|---|---|---|---|
| Rainfall (mm) | 1350-1400 | 1250-1300 | 100 |
| Temperature (°C) | 27 | 25 | 29 |
| Insolation (hours/month) | 210 | 150 | 260 |
| Evaporation (mm) (Piché Evaporimeter) | 1100 | 40-50 per month | 130-160 per month |

### 1.2.1 Temperature

Temperatures are fairly evenly warm throughout the year. The annual mean is 27°C, the monthly means varying from 25°C in August-September to 29°C in March. These are no figures to hand for diurnal variation, but it is generally thought that night temperatures are sufficiently low in the cane-harvesting dry season to permit the build up of satisfactory sucrose levels.

### 1.2.2 Rainfall

The monthly and annual average amounts of rainfall for three meteorological stations adjacent to the project area are shown in Table 1.2 The maximum and minimum amounts are also given for Korhogo and Ferkéssédougou.

The figures for the IRAT stations were taken for the period 1971-1974, all of which were relatively dry years.

As the isohyets run roughly north-south in this part of the Ivory Coast, the rainfall totals for the project area (longitude $5^{o}15'$-$5^{o}25$ W) are probably closer to the Ferkéssédougou (longitude $5^{o}12'$W) figures, but the difference between Korhogo and Ferkéssédougou is hardly significant. Of more significance to an irrigation project is the variation in monthly and annual rainfall over a period of years. The variation in annual rainfall over a period of 44 years at Ferkéssédougou is shown in Figure 1.2. The variation is not great for a climate of this type and a rainfall of at least 900 mm can be relied on. More variation, however, was recorded over a similar period at Korhogo, with a maximum of 2045 mm in 1957 and a minimum of 811 mm in 1961. In 1954 when Ferkéssédougou was experiencing its highest recorded rainfall of 1972 mm, Korhogo had a lower than average annual total of 1307 mm. This emphasises the local variation between two meteorological stations only 55 km apart.

### 1.2.3 Rainfall Intensity and Erosivity

Much of the precipitation in the area occurs as localised short duration showers which can be of very high intensity. These are also longer falls of low to medium intensity which are usually quite widespread. Both patterns of rainfall distribution were observed by the soil survey team during the course of field work in the rainy season.

Rainfall intensity is of primary importance in defining erosion risk. The erosivity of the rainfall is defined as its potential ability to cause erosion (Hudson, 1971). Storms of very high intensity, which are usually preceded by very high winds were seen to produce severe damage to native crops, in addition to causing flooding and erosion along the roads.

Unfortunately, no direct measurements of rainfall intensity have been taken at Korhogo or Ferkéssédougou meteorological stations, and intensity estimates are based on rainfall per rain day. On this basis, SOGETHA (1972)

# VARIATION IN ANNUAL RAINFALL OVER 47 YEARS AT FERKESSEDOUGOU (BETWEEN 1927-1974)

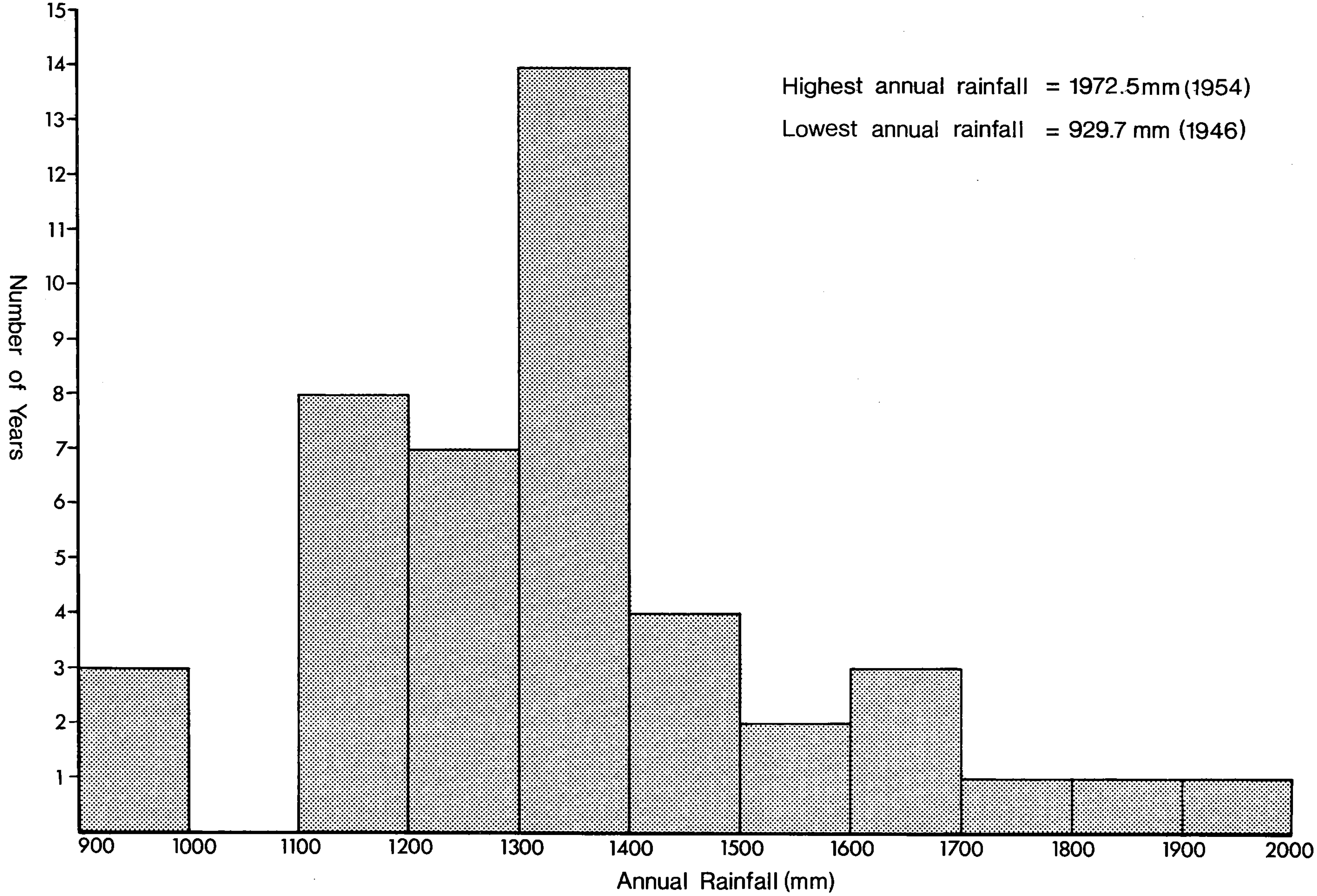


Figure 1·2

TABLE 1.2 <u>Rainfall at Korhogo, Ferkessédougou and IRAT</u>

| Met. Station | | Month | | | | | | | | | | | | Year | No. of Years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | J | F | M | A | M | J | J | A | S | O | N | D | | |
| | Max | 30.1 | 74.8 | 140.4 | 200.9 | 246.5 | 264.8 | 369.9 | 481.4 | 422.4 | 385.0 | 118.0 | 98.8 | 2045 | |
| Korhogo | Mean | 5.5 | 15.7 | 48.3 | 98.9 | 123.2 | 156.1 | 190.4 | 300.4 | 278.5 | 133.8 | 41.3 | 10.6 | 1403 | 22 |
| | Min | 0 | 0 | 0 | 13.6 | 53.5 | 45.4 | 47.6 | 104.2 | 94.0 | 33.3 | 5.4 | 0 | 811 | |
| | Max | 58.6 | 108.5 | 110.9 | 225.9 | 257.9 | 288.9 | 340.9 | 512.5 | 513.1 | 201.6 | 109.0 | 106.1 | 1972 | |
| Ferké | Mean | 5.7 | 17.6 | 45.9 | 87.4 | 142.5 | 155.5 | 184.4 | 300.8 | 247.7 | 111.9 | 33.9 | 9.1 | 1342 | 40 |
| | Min | 0 | 0 | 0 | 27.7 | 47.2 | 74.2 | 37.7 | 85.2 | 165.4 | 28.8 | 0.3 | 0 | 925 | |
| IRAT | Mean | 0 | 7.6 | 78.4 | 124.4 | 121.1 | 130.1 | 147.8 | 272.5 | 203.2 | 88.4 | 0 | 15.2 | 1193 | 4 |

Ferke data for the years 1931 - 74

Korhogo data for the years 1953 - 74

IRAT data for the years 1971 - 74

TABLE 1.3 Rainfall Characteristics over 3 years of the area 5 km South of Korhogo

a) 1968

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total rainfall (mm) | 0 | 61.9 | 101.6 | 109.7 | 80.7 | 135.7 | 114.8 | 271.1 | 186.9 | 90.0 | 20.7 | 5.4 | 1178.5 |
| No. of days of rain | 0 | 4 | 5 | 9 | 9 | 12 | 15 | 19 | 17 | 12 | 3 | 1 | 106 |
| No. of showers | 0 | 5 | 6 | 9 | 9 | 13 | 15 | 21 | 19 | 15 | 4 | 1 | 117 |
| Max. intensity (mm/hr) of heaviest shower | 0 | 42 | 48 | 42 | 126 | 138 | 78 | 78 | 114 | 80 | 75 | - | 138 |
| Total rain over 18 mm/hr (mm) | 0 | 34.9 | 55.4 | 34.6 | 47.2 | 95.4 | 50.6 | 164.2 | 118.9 | 41.6 | 10.3 | 0 | 653.1 |

b) 1969

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total rainfall (mm) | 0 | 38.0 | 93.8 | 38.0 | 92.0 | 179.6 | 412.3 | 315.9 | 243.2 | 131.6 | 128.9 | 0 | 1673.3 |
| No. of days of rain | 0 | 4 | 6 | 7 | 7 | 9 | 13 | 17 | 13 | 15 | 6 | 0 | 97 |
| No. of showers | 0 | 4 | 6 | 7 | 8 | 9 | 18 | 18 | 15 | 16 | 8 | 0 | 109 |
| Max. intensity (mm/hr) of heaviest shower | 0 | 66 | 72 | - | 87 | 123 | 150 | 132 | 96 | - | 45 | 0 | 150 |
| Total rain over 18 mm/hr (mm) | 0 | 22.0 | 37.6 | 0 | 28.5 | 118.5 | 277.6 | 210.4 | 112.8 | 9.0 | 67.8 | 0 | 884.2 |

c) 1970

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total rainfall (mm) | 0 | 18.0 | 9.0 | 86.7 | 124.4 | 99.0 | 342.4 | 181.9 | 235.6 | 26.0 | 79.7 | 0 | 1202.7 |
| No. of days of rain | 0 | 1 | 2 | 6 | 10 | 11 | 16 | 15 | 13 | 6 | 5 | 0 | 85 |
| No. of showers | 0 | 1 | 2 | 8 | 11 | 11 | 17 | 17 | 15 | 6 | 5 | 0 | 93 |
| Max.intensity (mm/hr) of heaviest shower | 0 | - | - | 93 | 84 | 66 | 114 | 60 | 96 | - | 72 | 0 | 114 |
| Total rain over 18 mm/hr (mm) | 0 | 0 | 0 | 34.2 | 44.8 | 17.6 | 169.5 | 57.1 | 106 | 0 | 57.5 | 0 | 486.7 |

calculated the values of the Fournier-Henin erosion index which came to 3.9 and 4.9 for Ferkéssédougou and Korhogo respectively, indicating a potentially quite erosive rainfall.

In the recent ORSTOM study of the basin south of Korhogo (Molinier, 1971), direct measurements of rainfall intensity were taken over a three year period. The results are summarised in Table 1.3.

These observations were recorded in the Waraniéné basin at latitude 9°25'N, longitude 5°39'W, 5 km SW of Korhogo, and 40 km W of the project area. The general distribution pattern in the project area should be similar, although actual amounts of rainfall may be slightly lower.

The intensity of 18 mm per hour is taken by Molinier as the threshold intensity above which run-off will occur. This is a lower figure than the 25 mm suggested by Hudson (1971) as the limiting erosive intensity with particular reference to Africa. If one accepts the Hudson figure, the figures for total erosive rain may be slightly reduced. Nevertheless, the figures show several maximum intensities of over 100 mm/hour and this is highly erosive by any standards.

Although it is not advisable to draw definite conclusions on data relating to only three years it is possible to recognise the following broad trends:-

(a) Showers of high to very high intensity may occur in any month of the year, with the possible exception of January and December.

(b) About half the total annual rainfall is regarded as being likely to cause run-off (and hence erosion).

(c) There is a tendency for the highest intensity showers to fall early in the rainy season, in June and July.

From the data, one can conclude that erosion will be a major problem in the project area unless adequate control measures are taken.

1.2.4 Insolation

Insolation is highest during the dry season rising to 260 hours per month although the maximum potential insolation is around 360 hours per month. In the rainy season monthly totals may fall below 150 hours, and the annual average is about 210 hours per month. During the dry season the hot northerly harmattan winds are frequently dust-laden. It is thought that light haze increases the total incoming radiation by decreasing the direct component less than it enhances the diffuse component. In heavy haze, both the components and the total radiation will be decreased.

1.2.5 Potential Evaporation and Evapotranspiration

Evanporation data as measured by Piché Evaporimeter and Colorado pan were available for a limited period from Ferkéssédougou meteorological station. Class A pan data were available from IRAT. The results are summarised in Table 1.4. Piché and Colorado pan data are after Molinier (1971a) and SOGETHA (1972) respectively.

The true potential evaporation will lie somewhere between the Piché and Colorado and Class A pan estimates.

Thornthwaite, Turc and Blaney and Criddle estimates of potential evapotranspiration were calculated by SOGETHA, while Papadakis (1966) used a vapour pressure calculation to arrive at his evapotranspiration estimate for Ferkéssédougou. Insufficient data were available for the calculation of the Penman estimate. The figures obtained are discussed in section 1.2.6.

1.2.6 Annual Moisture Balance

The difference between rainfall and potential evapotranspiration in any given month is an important factor in the planning of water resources for any form of agriculture. In a survey covering all the coastal countries of West Africa, Papadakis (op. cit.) quotes figures for rainfall surplus and 'drought stress' (excess of potential evapotranspiration over rainfall) in different months of the year. Although estimates of potential evapotranspiration are somewhat crude they can be used as a fair approximation and a monthly moisture balance diagram was drawn up for Ferkéssédougou (Figure 1.3) using rainfall data from section 1.2.2 and Papadakis evapotranspiration estimates. There is an annual moisture deficit (drought stress-rainfall surplus) of 384 mm, and as expected, drought stress is at a maximum between December and February. There are 4 months with a significant rainfall surplus, and 2 months in which rainfall and potential evapotranspiration are approximately equal.

SOGETHA (op. cit.) also attempted to construct an agricultural moisture budget using their estimate of potential evapotranspiration mentioned in Section 1.2.5. They took average estimates for monthly evapotranspiration and compared them with monthly rainfall totals for separate years at Ferkéssédougou. This enabled a plot of the length of the growing season (defined as the number of months without drought stress) to be formulated for each year. An obvious limitation to this is that potential

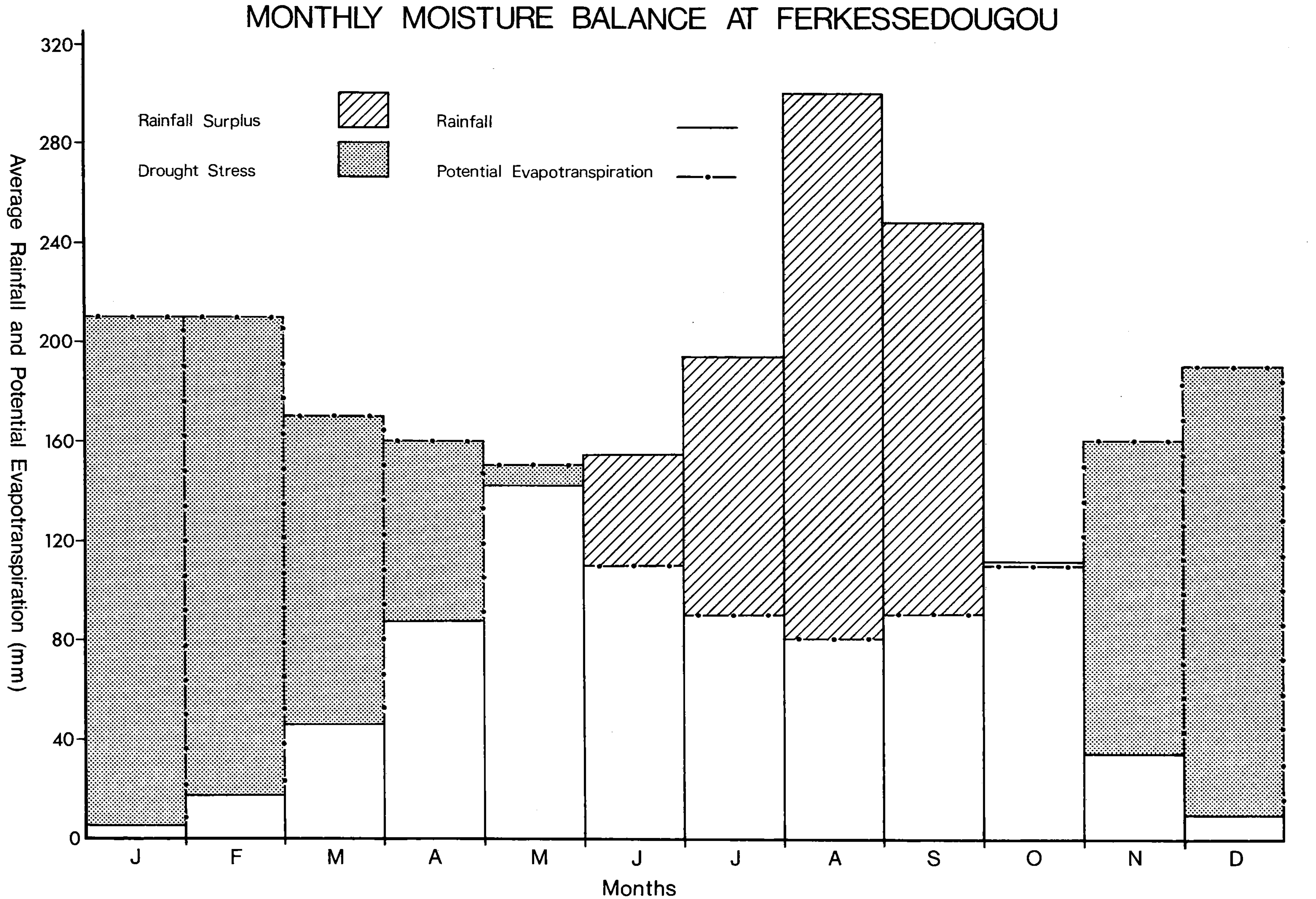
MONTHLY MOISTURE BALANCE AT FERKESSEDOUGOU
Rainfall Surplus
Drought Stress
Rainfall
Potential Evapotranspiration
Average Rainfall and Potential Evapotranspiration (mm)
320
280
240
200
160
120
80
40
0
J
F
M
A
M
J
J
A
S
O
N
D
Months

Figure 1·3

TABLE 1.4 Potential Evaporation at Ferkéssédougou and IRAT

| Station | Apparatus | Period | Average Evaporation (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
| Ferké | Piché | 1961-70 | 149.2 | 143.6 | 146.5 | 96.7 | 80.2 | 55.5 | 45.6 | 39.9 | 39.2 | 56.7 | 74.7 | 108.8 | 1035.8 |
| Ferké | Colorado Pan | 1957-59 | 180.0 | 205.0 | 239.0 | 234.0 | 180.0 | 171.0 | 177.0 | 114.0 | 105.0 | 140.0 | 141.0 | 155.0 | 2040.0 |
| IRAT | Class A Pan | 1971-74 | 208.2 | 229.3 | 235.3 | 193.8 | 196.8 | 153.5 | 141.5 | 130.7 | 136.1 | 154.5 | 154.5 | 154.8 | 2089.1 |

evapotranspiration varies from year to year and will be related to some degree to rainfall by the effect of vapour pressure, cloud cover etc. However, bearing this limitation in mind in addition to the vagueness of the evapotranspiration estimates, the general conclusions of the moisture budget calculations are probably valid. These are:-

(a) The period of dry season moisture deficit may extend right through to July if the early rains are poor, but can be broken as early as May.

(b) The rainy season period of moisture surplus lasts until October-December, according to the year.

(c) Although the rainfall is basically unimodal it is possible for the rainy season to be interrupted by a quite severe dry spell, which is potentially very hazardous for rain grown crops which have recently germinated.

## 1.3 Geology

The area is underlain by Precambrian igneous and metamorphic rocks of the basement complex, dominated by granites and granitic gneisses. Mineralogically these granites and gneisses are dominated either by muscovite and biotite, or muscovite alone. Quite large flakes of muscovite were often found in the subsoils during the soils investigation, and were sometimes exposed at the surface in stripped areas on lower slopes. The degree of metamorphism seems to have been very variable with outcrops of recognisable granite and gneiss sometimes separated by a distance of only one metre on the ground. Outcrops occur most frequently in a band running roughly parallel to and about one km east of the Bandama river, but also occur locally in other parts of the project area.

The contact zone of a belt of arkosic schist runs roughly along the course of the Bandama. According to the 1:50,000 geological map of Sodemi the schist only extends into the project area in the westward meanders of the Bandama and schist was only observed in the Bandama river bed during the course of field work.

## 1.4 Geomorphology

As the project area has a homogenous geology, apart from minor local variations, and a relatively stable geological history in which periods of deep weathering were followed by erosion and dissection of the weathering surface, soil parent materials are related to the geomorphic history rather than the geology, and can therefore be interpreted in relation to the resulting topography.

### 1.4.1 Topography

The topography of the area is undulating, with long gentle slopes rarely exceeding five per cent gradients and interfluves usually topped by cuirasse plateaux and locally interrupted by outcrops of granite or gneiss. The altitude varies from 280 to 380 metres above sea level, and the amplitude of individual toposequences is usually less than 70 m. The idealised toposequence, examples of which are illustrated with relation to soil and vegetation type in Figures 3.2 and 3.3, can be broken into a number of facets, the topographic features of which are described below:-

(a) Cuirasse Plateaux

Except in rare cases where granite or gneiss outcrops as small inselbergs, the plateaux form the highest part of the toposequence. Slopes are usually very gentle or flat, and the plateaux are usually bounded by steep scarp slopes with outcrops and boulders of cuirasse at the land surface. This scarp may be up to 8 metres high but occasionally may exist as a barely recognisable break of slope leading down to the connecting slope. In the southern and eastern part of the project area two distinct levels of cuirasse plateau are commonly found, one with a pronounced scarp at the higher level and the other with a less recognisable break of slope within the lower level unit.

The form of the plateau is sometimes slightly dish-shaped, falling to areas of shallow soils and outcropping cuirasse in the centre. In other cases, the plateaux slope gently towards the scarp, with odd cuirasse outcrops not bearing much relation to present topography. The latter type of form is usual when a second higher plateau is present, and is particularly well represented in the southern part of the project area. Both plateau forms were also described in a granitic savanna region of the northern Ivory Coast by Avenard (1971).

(b) Connecting Slopes

Below the scarp there is a long gentle connecting slope running down to the valley. This is slightly concave just below the scarp, but is rectilinear over most of its length. Gradients range from 1 to 6 per cent, 2 to 4 per cent being the most common. In places, usually on the lower parts of this unit, the smooth surface of this part of the landscape is broken by surface run-off rills and runnels, giving a regular wavy micro-meso relief of up to 70 cm amplitude, and with crests separated by 20 to 100 metres. These areas are more recognisable on the aerial photographs by their distinctive fan-like pattern then they are on the ground. Where surface run-off has been more severe or more effectively canalised gullies of up to 10 metres depth are formed. These are not common, but occur locally in one or two specific areas.

The lower part of the connecting slope may also be interrupted by outcrops of indurated laterite or ferricrete. The formation of this material is discussed in section 1.4.2. It hardens irreversibly on drying and may outcrop as a small scarp.

(c) Convex Lower Slopes

At the foot of the rectilinear connecting slope there is often a short convex slope running down to the stream. This appears to have been formed recently by downcutting of the stream bed. Slopes may be as high as 10 per cent, but are generally in the 4 to 8 per cent range. Because of the recent downcutting and stripping, rock outcrops commonly occur on these convex lower slopes. These slopes are also likely to have outcrops of ferricrete, and to suffer from the erosion rilling and gullying described above. Occasionally this unit is not always apparent, and connecting slopes run gently down to the valley bottom.

(d) Valley Bottoms of Minor Streams

The minor and intermediate streams of the area may run through narrow trench-like valleys formed at the junction of the downcut lower slopes, but there are also discontinuous flat areas of alluvial and gully wash deposits in some valleys.

(e) Terraces Along the Bandama River

Along the Bandama there is a well developed series of alluvial terraces. Each terrace has the conventional structure of a high levée closest to the river, with very gently graded backslopes running down to narrow backswamps furthest from the river. This structure is quite weak and in places hardly discernible. There are two distinct terraces in most of the area, the upper of which is by far the most extensive, being up to half a kilometre wide in places. There appears to be a narrow intermediate terrace in the central part of the area.

(f) Outcrops of Granite and Granitic Gneiss

Granite and granitic gneiss may outcrop anywhere in the toposequence although they are most common either forming the summits of certain interfluves, on the lower connecting slope, downcut lower slopes or in the beds of streams. There is a band of interfluves running parallel to and about 1 km east of the Bandama river which are dominated by rock outcrops, which usually take the form of boiler plate slabs or low convex inselbergs but in one case an inselberg rises to about 50 m above the adjacent cuirasse plateau. Where the rock is most gneissic it tends to occur in low ridges, running roughly NNE-SSW parallel to the granite-schist contact zone. In the reconnaissance survey this granite gneiss dominated area was mapped out as a separate landscape unit, but as it is also influenced by cuirasse and has the same topographic form, with long connecting slopes and convex lower slopes leading down to small streams or the Bandama terraces, the outcrops of rock are included in the generalised landscape sequence described above.

### 1.4.2 Geomorphogenesis

The present landscape is derived from the dissection of a highly planed erosion surface, in which the underlying rock was subjected to a long period of deep chemical weathering possibly under a climate more humid than the present one. In the lower parts of this landscape conditions were ideal for the mobilisation and segregation of iron and aluminium oxides and hydroxides and thick layers of plinthitic material were formed. These conditions were changed by an alteration in base level or change in climate occurring sometime in the Tertiary period. Water tables dropped and the plinthitic material which became exposed at the surface hardened irreversibly to cuirasse. The deeply weathered rock, which formerly formed the crests of interfluves, was much softer than the cuirasse and indurated plinthite and was therefore dissected in preference to the now indurated old stream areas, by new streams, thus inverting the original landscape. A period of erosion followed in which the long connecting slopes retreated backwards to the cuirasse, which eventually outcropped as an escarpment. As two distinct levels of cuirasse exist in part of the project area, this process must have been interrupted at some stage, either by a fluctuation in base level or a change in climate. This part of West Africa is thought to have been subjected to a number of comparatively wet and dry periods during the late Tertiary and Quaternary eras and a period of fluctuating water table conditions, followed by drying and erosion, is very likely to lead to cuirasse formation.

As erosion proceeded, cutting back the connecting slopes, the cuirasse eventually broke up to furnish boulders and also the large quantities of ferruginous gravels which are prominent features of the present soils. As the material behind the scarp consisted either of cuirasse or plinthite, which would harden irreversibly on exposure, the scarp was self-reinforcing, with erosion of hard cuirasse at the front being matched by the formation of new cuirasse at the rear. Sheets of hard cuirasse occurring towards the centre of present plateau areas may have been formed when old plinthite deposits were exposed by surface wash and rilling.

Most of the granite and gneiss outcrops probably protruded above the original erosion surface as low residuals, and there is a site in the western central part of the area where a flat cuirasse plateau abuts directly onto a prominent granite inselberg. The valleys and slopes of the granite and gneiss dominated areas are almost certainly of the same age as those of the cuirasse areas.

It is not possible to correlate the erosional and alluvial depositional events in the area with any certainty. However, the deposition of the material forming the higher and more extensive of the Bandama terraces may have taken place during the period when the base level remained constant and the connecting slope pediments were formed. The lower terrace may be contemporaneous with a later, shorter hiatus in base level depression. The period of base level stability that allowed the extensive pedimentary connecting slopes to develop appears to have finished quite recently. The streams have cut down into narrow valleys, and the lower slopes have been stripped off accordingly, giving them their convex form and often exposing only partially weathered or fresh rock at the surface. The surface wash, rilling and runnelling features seen in some middle and lower parts of the connecting slopes were probably initiated at this time.

In the present day landscape therefore, the oldest surfaces are the resistant cuirasse plateaux at the summits of interfluves. Although two levels of cuirasse exist they have probably been formed in a similar period of geological time, probably in the late Tertiary era, and just represent

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different phases of base level fluctuations. The upper plateaux will be the oldest. Two levels of erosion surface have been recognised in this part of West Africa (Avenard, 1971, Verheye, 1974), but the early Tertiary surface is thought to have been primarily bauxitic rather than ferruginous, to be much higher than the late Tertiary surface, and to only occur in isolated locations (Ahn, 1970);

1.4.3 Soil Parent Materials

Soil parent materials are often heterogenous, containing materials derived from different sources that have been subjected to different cycles of erosion and redeposition. Nevertheless it is possible to relate parent material to present day landforms.

The relationship between the broad types of parent material and topographic units is illustrated in Figures 3.2 and 3.3.

As mentioned in section 1.4.2, the cuirasse plateaux are mantled with materials considerably older than those on the other elements of the landscape. Much of the plateau has hard cuirasse at, or very close to, the surface. Elsewhere there are deposits of cuirasse-derived gravel in a sandy clay matrix. The clays are heavier, redder and are thought to be much more ferralitised than those found in areas below the scarp. They resemble the allochthonous drift material derived from weathering of basement complex rocks, described by Verheye (1974) and Ahn (1970). Occasionally, non-gravelly deep drifts of this sandy clay occur on the plateau, forming potentially very good soils.

The connecting slopes are mantled with colluvial pedisediments which have been weathered and transported to different degrees. The lower layers in contact with the present country rock usually consist of a transported sandy clay drift containing rock fragments in various stages of weathering and often including flakes of muscovite. This may be replaced by a fossil plinthite. These layers are usually overlain by a horizon rich in ferruginous gravel derived from cuirasse and transported down slope. This gravel layer is very variable in depth and thickness and also in the actual amount of gravel it contains. Occasionally, particularly on the upper connecting slopes, it may be absent. The surface layers above the gravel are highly mobile, usually gravel free, and deficient in clay and silt, most of which has been removed by vigorous surface wash and subsurface flow.

Where the original connecting slopes have been stripped by surface wash or lower slope downcutting, the upper layers of older and more mobile material have been, by and large, removed and the underlying colluvium derived from recent weathering forms the present soil parent material. This varies in composition from fairly homogeneous loamy sand or sandy clay loam to fairly hard rock in which the original colours and structure are virtually unaltered.

In the areas dominated by outcrops of granite or gneiss the connecting slopes are mantled with colluvial material derived mainly from the weathering of the outcropping rocks. This is generally much coarser than the colluvium of typical cuirasse areas, and it shows less stratification. Ferruginous gravels sometimes occur in the granite and gneiss areas. These may be the remnants of previous plateaux which have disintegrated, or they could be formed directly in the soil under a period of restricted drainage (Ojanuga and Lee, 1973).

The layers of ferricrete or indurated lateritic material which occurs in the lower horizons of many connecting and lower slope soils is also due to a phase of restricted drainage. They consist of a brownish yellow to white matrix with prominent red and yellowish red mottles and often include ferruginous concretions which have probably formed in situ and are usually more angular and softer than the older ferruginous gravels derived from cuirasse. Sometimes these older gravels may be trapped in the matrix during the formation of ferricrete and become recemented to produce a material very similar to cuirasse. This accounts for the outcrops of 'secondary cuirasse' which sometimes occur on connecting and lower slopes.

The valley bottoms of minor streams contain local deposits of alluvium and also colluvial material moved down slope by erosion. Rock outcrops are common in the beds of some streams.

The fluvial deposits on the Bandama terraces are stratified and may contain ferricrete in the subsoil. They are relatively high in fine sand and silt content.

## 1.5 Drainage Systems

The project area is drained by the east bank tributaries of the Bandama river. The most extensive basin is that the Fahalogo which with its southern tributary the Latiéné drains about 75 per cent of the area. The area in the north drains into the Waha, which forms the area's northern boundary, while a small area in the extreme south is drained by tributaries of the Farakwo. There are small catchments in the western part of the area where minor unnamed streams drain directly into the Bandama.

The drainage pattern shows no overall lithological control and has a dendritic form. There are sections of stream courses e.g. the middle Fahalogo where the underlying jointing pattern seems to exert some influence, as shown by some acute bends in the stream course.

## 1.6 Vegetation

The area lies well within the savanna region of the Ivory Coast and the vegetation is variably wooded savanna, enclosing forest outliers and, rarely, rock exposures. Vegetation of a specialised nature fringes the Bandama Blanc river and its tributaries.

According to Keay (1952) the area is classed as Guinea savanna and the ecologists of ORSTOM refer to it as sub Soudan savanna (Guillaumet and Adjanohoun, 1971). The term currently used on the Ivory Coast is ''savane boisée, arborée ou arbustive et forêt claire.

The following vegetation types were distinguished:

(a) Savanna

Three structural subdivisions are ready recognised and, in order of decreasing complexity, these are Savannah woodland, tree savannah and grassland.

(i) Savanna woodland

In this plant community the trees are sufficiently closely spaced to limit grasses to a few species tolerant of moderately heavy shade. Typically there are a few prominent tree species although *Isoberlinia doka* and *Uapaca togoensis* usually account for the majority.

Locally *Monotes kerstingii* and *Anogeissus leiocarpus* are important. *Andropogon tectorum* and *Beckeropsis uniseta* are the main grasses present.

Savanna woodland is widely distributed over the area and is particularly extensive north of the Fahalogo river. The plateau and connecting slope units support extensive areas of savanna woodland.

(ii) Tree savanna

This is a variable vegetation unit intermediate between the savanna woodland and the treeless grasslands described below. The distinguishing characteristics of the tree flora are the relatively numerous species and the rarity of species indicated as typical of the savannah woodland.

The most frequent trees are:

*Butyrospermum paradoxum*
*Cussonia barteri*
*Daniellia oliveri*
*Gardenia erubescens*
*Hymenocardia acida*
*Nauclea latifolia*
*Ostryoderris stuhlmannii*
*Parinari curatellifolia*
*P. polyandra*
*Piliostigma thonningii*
*Terminalia laxiflora*

The grass flora is much richer than that of the savanna woodland and two subdivisions were noted: *Schizachyrium* tree savanna and *Hyperthelia* tree savanna.

*Schizachyrium* tree savanna consists of tree savanna with an impoverished tree stratum. The dominant sward grass is *Schizachyrium sanguineum*.

*Hyperthelia* tree savanna has a variable, sometimes high density of trees and the main grass present is *Hyperthelia dissoluta*.

(iii) <u>Grassland</u>

The grassland communities are essentially treeless and there is little variety within the grasses. Two grassland divisions are recognised - cuirasse grassland and terrace grassland.

Cuirasse grassland units are generally widely separated and not particularly extensive. They are always associated with exposures of cuirasse or at sites with cuirasse at shallow depth and thus occur principally on the plateaux areas.

The principal species is *Loudetia arundinacea* with islands of *Loudetiopsis kerstingii*.

Terrace grassland forms a discontinuous strip of variable width along the bank of the Bandama Blanc, separating the riverain forest from the savanna woodland of the upland sites. *Loudetia arundinacea* is the characteristic species.

(b) <u>Forest outliers</u>

The forest contains trees which form a canopy at a height of

20 to 25 metres below which a variety of shrubs, lianas and smaller trees is present. Floristically this is the most diverse vegetation type in the area. The larger trees include:

*Anthonotha macrophylla*
*Balanites wilsoniana*
*Chlorophora excelsa*
*Cola cordifolia*
*Detarium senegalense*
*Erythrophleum suaveolens*
*Ficus spp.*
*Garcinia sp*
*Manilkara multinervis*
*Sterculia tragacantha*

In addition there are several shade tolerant grasses:

*Cyrtococcum chaetophoron*
*Olyra latifolia*
*Oplismenus hirtellus*
*Streptogyne crinita*

(c) Riverain forest

The Bandama supports a complex vegetation. The sandy banks along the river carry many tall trees including *Pterocarpus santalinoides*, *Syzygium guineense* and *Xylopia parviflora*.

Further from the river lowlying open areas carry *Vetiveria nigritana* grassland and often *Hyparrhenia cyanescens* marks the transition from the lowlying land to the better drained terrace grassland.

(d) Inselberg vegetation

Typical inselberg species include *Bombax costatum* and *Holarrhena floribunda*. Considerable expanses of bare rock are present but locally there is some colonisation by *Afrotrilepsis pilosa*. Accumulations of small rock fragments and sand support concentrations of *Loudetia arundinacea*. Other typical inselberg grasses which occur at the foot of the hill include *Andropogon pseudopricus*, *Monocymbium ceresiiforme* and *Schizachyrium exile*.

## 1.7 Fauna

A fairly high frequency of termite mounds up to 3 m high is apparent throughout the area, and termite activity could be a minor problem when the plantation is established.

Larger animals likely to cause problems of soil redistribution are rabbits and large lizards which mainly burrow into the terrace soils.

Hippopotami, which inhabit the Bandama and come up to feed on the terraces at night could also be a problem if the terraces are planted with cane.

# CHAPTER 2

# METHODS OF STUDY

## 2.1 Field Methods

According to the terms of reference, routine soil inspections were to be made at an overall density of one per four hectares throughout the project area. Routine inspections of the soil were made using 10 cm head Jarrett augers and boring to a depth of 100 cm when possible. These augers proved very effective in penetrating stoney and compact horizons, and in the vast majority of cases, it is safe to assume that any material proved unaugerable will also be impenetrable to roots. At any site where the first attempt at augering failed to reach one metre, a second augering was attempted to assess the continuity of the limiting layer and to avoid undue downgrading of the land by chance encounter with erratic stones or boulders. At each inspection point the soils were described by natural horizons for colour, mottling, texture, content of stones and gravels and any other obvious features of relevance to their pedogenesis or their suitability for the growing of cane. Site details such as topographic position, slope, vegetation and surface features were noted. Topographic surface, and vegetational features were also recorded while walking along trace lines between inspection sites.

In order that position on the ground could be related to aerial photographs and final base maps, to ensure a fairly even density of observation and to facilitate access a network of trace lines were constructed throughout the project area. Although some of these lines were hand cut by the soil surveyors, most were constructed by local contractors using D7 bulldozers or by hand. All lines were pegged and numbered at 100 m intervals.

The routine survey was carried out as a two phase operation, with the survey of the area south of the Korhogo - Badikaha road only commencing after the survey of the original area had been completed. As the requirements of the southern survey area differed slightly from those of the original area, a different methodology in trace line layout was applied. Also experience gained in the survey of the original area was taken into account in increasing the efficiency of survey south of the road.

### Zone I

In the initial survey area (Zone I), which stretches north from the Korhogo - Badikaha road to the Waha River a skeleton of east-west trace lines at 500m intervals was planned. This approach is more economical than having lines spaced at 250m intervals and it was assumed that intervening areas could be surveyed using aerial photographs for navigation and location. However aerial photo navigation in the project area proved to be dissappointingly slow and uncertain during the reconnaissance, which was undertaken before line cutting for the routine survey had commenced, and intermediate lines were later cut between most of the originals. Original lines were cut on compass bearings from photoidentifiable points on the north-south access road so the resulting trace line spacing was not quite uniform. Because of delays in trace cutting the soil survey team made best use of available time by augering at 100m rather than 200m intervals along existing lines, with the result that the total number of observations in the original area was 3350, giving an overall density of one inspection every 3.5ha.

Zone IV

The survey of the area south of the Korhogo - Badikaha road (Zone IV) was organised when it was realised that the amount of land suitable for sugar cane in the original area would be insufficient for requirements after additional land for squaring off irrigated blocks and nursery areas had been considered. Access to this southern area was much facilitated by old pistes from the SOGETHA survey. Some of these pistes were visible on the aerial photographs and trace lines were cut at 500 m intervals running east or west from a prominent north-south SOGETHA piste. Soil inspections were made at 200m intervals along these trace lines and also along all the SOGETHA pistes. As the aim of the survey of this section was to find 3000 ha of suitable land in manageable blocks, intermediate lines were only cut in potentially favourable areas, and areas of dominantly unsuitable land were not looked at in any more detail. The survey progressed southwards until it was considered that all areas of potentially suitable land occurring in manageable blocks had been surveyed as far as the Farakwo river. Because large areas of unsuitable land were encountered and these were surveyed at a less detailed level, the overall density of observation in Zone IV was 1 bore every 5.4 hectares.

The total number of observations for the whole of the project area was 4500, giving an overall density of 1 bore per 4 hectares.

In addition to the routine auger borings, 58 soil profile pits were dug in typical representatives of the main soil types. These pits were used to characterise the soil series described in Chapter 3. All soil pits were described according to the FAO Guidelines for Soil Description.

Ten profiles were chosen as representatives of the full range of soil conditions in the area, and their major horizons were sampled for laboratory analysis. Disturbed samples were taken, air dried, ground, and sieved to 2mm for chemical and mechanical analyses. Where soil conditions permitted duplicate undisturbed core samples were taken for available water content determinations. In very gravelly horizons this was not possible and disturbed samples were taken on a volumetric basis. All chemical and physical analyses were carried out in the Chemistry laboratory of Hunting Technical Services Limited in England. For details of the laboratory methods, see Appendices I and III.

Double ring infiltration tests were carried out at five sites close to sampled pits. The method is described and results are presented in Appendix III.

At two sites in the area, the short range variability of one of the major soil types was examined by augering at very close intervals. Twenty seven augerings were done on a 50m x 25m grid, giving a density of eight inspections per hectare. Variability in other soils was examined by inspection of sections exposed in drains on the nearby sugar estate near Ferkéssédougou. The results of these variability studies are discussed in section 3.6.

## 2.2 Aerial Photo Interpretation and Mapping

The base maps used in the final mapping were not available until after the soil survey had been completed, so that the plotting of inspection sites and initial mapping had to be done on mapping material available at the time of survey. This consisted of:-

(i) 1:50,000, 20m vertical interval I.G.N. maps dated (1968), based on (1963) aerial photography.

(ii) 1:20,000 vertical aerial photographs taken at various times during 1967-72. Much of the centre of the area falls on the base frame of runs that were basically aimed at covering areas further east and west. Although most of the area was covered by photography there were patches for which there was no stereoscopic cover, and there were other places where differences in scale and photo quality made interpretation difficult.

(iii) An uncontrolled 1:20,000 mosaic prepared from the photography mentioned. Considering the short time available for its compilation, and the heterogeneity of the base material, the mosaic was of excellent quality, but there were inevitably some areas where correlation between observed features on the ground and on the mosaic was low. Unfortunately these tended to occur in the centre rather than on the fringes of the area.

A 1:20,000 enlargement of the relevant section of the 1:50,000 map was made, in order to check the overall distortion of the mosaic. Cheecks were also made by identifying prominent features recognisable on the mosaic which were situated along the north-south base line. The distance between these points was measured on the mosaic and compared with the actual distance measured along the base line. These two independent checks showed that, although locally incorrect in detail, the mosaic was accurate to within two per cent (100m in 5km) over the whole area and because of its great detail it was preferred to the magnified 1:50,000 map as the soil survey base map. The north-south base lines were easily identifiable because they had been started from points recognisable on the photographs. Similarly many of the start points on the central base line of the original set of east-west survey lines could be identified both at the start point and at the place where they reached the Bandama river. The other lines and the eastern ends of the survey lines were fixed by measuring their intercepts on the eastern base line.

Each soil survey inspection point along the survey lines was fixed by measurement, except where this clashed with the physical features on the mosaic. When there was a difference between the measured distance and the mosaic, the latter's position was taken, despite it known distortions, because in some instances the accuracy of the contractors line measurements was doubtful.

After the inspection sites had been located on the existing base maps, boundaries were plotted using stereoscopic photo interpretation to pick out the limits of physiographic units. Boundaries drawn from the photographs had to be suitably adjusted to fit the distortions of the mosaic. Detailed mapping was carried out on existing material and soil and land class maps were later adjusted to fit the final base maps. During the course of the survey a number of preliminary draft maps of land suitability for cane were produced for specific parts of the project area at the request of the client. These maps were produced without using stereoscopic air photo interpretation and relied purely on the mosaic for the plotting of boundaries. Although these maps gave a general idea of the amount and distribution of suitable land, the accuracy of boundaries was considerably inferior to that of the final maps.

# CHAPTER 3

# SOILS

## 3.1 Soil Formation

The soils of the area have been formed by the action of a humid or subhumid tropical climate on material originally derived from acid and intermediate crystalline rocks. The morphological history of the area is complex and the soil parent materials have been much moved and mixed (Section 1.4.3), and have also been exposed to soil formation processes for very different lengths of time.

Much of the parent material has already been strongly weathered and leached, probably under climatic periods more severe than those of the present day. Under a hot humid or subhumid climatic regime, the more mobile weathering products such as bases and most of the silica have been removed by leaching, leaving a clay fraction dominated by kaolinite and oxides and hydroxides of iron and aluminium. This tends to result in soil with a low cation exchange capacity, moderately poor base saturation and relatively low pH. This soil type is typical in the freely draining sites of the project area.

In places where drainage restriction occurs and the soil has been subjected to fluctuating water table conditions, mobilisation and segregation of iron, which is more mobile in the ferrous state occurs, resulting in rust mottling, and in some cases leading to the formation of iron concretions and sheets of ferricrete, which harden irreversibly to form a cuirasse if exposed at the soil surface.

As well as the physico-chemical processes of leaching and iron segregation, the present soil profile morphologies are much affected by the mechanical mass movement processes such as colluvial creep, surface erosion, and disturbance by tree fall and animal activities. Colluvial creep accounts for the downslope movement of gravel and clay derived from the break up of the cuirasse and the more sandy material derived from granite gneiss.

The surface erosion processes of wash, rill and gully formation not only affect the profile truncation but also preferentially wash out fine material from the surface horizons, leaving top soils that have high coarse sand and grit contents. The increase in clay content with depth is thought to be partly due to this lateral removal of clay from the topsoil by surface wash, and clay illuviation is considered to play a relatively minor role, especially as virtually no signs of clay movement were observed in soils of the area. In granite derived soils in an area of Upper Volta, which has a rainfall inferior to that of the project area, Boulet (1972), however, mentions a 'total and violent' leaching, effecting the structure of the soil fabric. If this process is operative in the project area, it may have the effect of destroying any cutans before they have been properly formed. In an area of dominantly leached soils, it seems likely that some clay will have been illuviated.

Soil disturbance by biological agents appears to be an important process in the area. Pinnacle termitaria rising to over three metres in height are common,and by the preferential excavation of fine earth, partly account for the frequency of stone and gravel layers. Large burrowing lizards are common, and excavate surprising quantities of material in the deep stone-free soils of the lower slopes and the upper Bandama terrace.

Treefall, which is often initiated by lightning strikes, is responsible for the excavation of lens shaped bodies of soil.

In contrast to surrounding areas, the project area has been virtually unaffected by man's activities and there are no signs of cultivation or forest fires.

## 3.2 Soil Classification

The soils of the area have undergone long and varied weathering cycles in commom with most soils of the savannah belt of West Africa. Consequently the soils are impoverished in nutrients and are relatively infertile. The nutrient problem is easily resolved by the application of fertilisers and the main practical criteria for successful cane growth are the volume of soil available for root penetration and the moisture retention capacity. This need to identify soils suitable for cane cultivation led to the adoption of a classification system based on profile morphology.

The system was based on stable physical soil properties such as depth, gravel content and texture which were readily identified in the field.

In spite of the morphological definition of soil units, they correlate with topography and geomorphology and are evolved from the initial landform/aerial photograph interpretation of the reconnaissance survey. Because of their similar morphology and usually similar geomorphic position, soils of the same classification unit usually have a similar genesis, but this is not inherent in the unit definition.

The commonly accepted soil classification system used in Francophone Africa is that of ORSTOM (Aubert, 1965), and this system is in current use in soil surveys to the north of the project area. The ORSTOM system was not used as the basis for our classification system because of its use of chemical differences as factors for distinction of soil units at a high level of classification, and its reliance on genetic criteria for the definition of its classes and subclasses do not meet the objects of this study. Nevertheless, for correlation purposes, the approximate ORSTOM equivalents to the soil units used on this survey are presented in Table 3.2.

The soil classification units used in this survey were first conceived in terms of their modal properties. The limits to the properties of each class were later fixed to minimise the number of transitional cases. Each classification unit is roughly equivalent to a soil series, as properties are similar and parent materials are usually the same within each unit. Twelve units or series were recognised; some were subdivided into phases based on depth, topsoil texture, colour or depth to gravel layer. Subscripts were added to the series figure to denote a phase division e.g. Series 4y - soil of Series 4 with a yellow subsoil.

The following subscripts were used:

| | | | |
|---|---|---|---|
| s | - | Shallow phase | e.g. 3s |
| y | - | Yellow subsoil phase | e.g. 4y |
| c | - | Coarse textured phase | e.g. 6c |
| b | - | Deep soil phase | e.g. 6b |

The general properties of the modal forms of each soil series are outlined below.

### 3.2.1 Description of Soil Series

(a) Series 1.

Series 1 soils are shallow and directly overlie unweathered granite or granite gneiss. Textures are usually coarse sandy loam or loamy sand and grey colours predominate. These soils usually occur in the vicinity of outcrops, most commonly on the crests of interfluves. They usually only support a sparse grassland dominated by *Loudetia sp.* and similar grasses.

Series 1 soils are readily distinguishable from Series 3 to 12 by their depth, which must be 30 cm or less. They differ from Series 2 in the nature of their parent material.

(b) Series 2.

Series 2 soils are shallow and directly overlie cuirasse or indurated ferricrete. Textures are variable, but are usually dominated by ferruginous gravels. These soils are most common on the cuirasse plateaux, but also occur on the connecting slopes when cuirasse of ferricrete approaches the soil surface. Like Series 1 soils, they only usually support a sparse vegetational cover.

Series 2 soils are also readily distinguishable from Series 3 to 12 by their depth which must be 30 cm or less. They differ from Series 1 by overlying cuirasse rather than unweathered rock.

(c) Series 3.

Series 3 soils consist of red sandy clays or sandy clay loams with a high content of ferruginous gravel throughout the profile. They are developed over cuirasse, plinthite or weathered rock and occur only on the cuirasse plateaux or occasionally on the upper connecting slopes. A phase 3s was defined to cater for relatively shallow variants (30-60 cm deep).

These soils differ from those of Series 4 and 5 in gravel content and Series 2 in depth. They differ from Series 6 in their redder colour and usually by their more even gravel distribution and less deep coarse textured topsoil.

(d) Series 4.

Series 4 soils consist of deep freely drained non-gravelly sandy clay loams and sandy clays, usually with a coarse sandy loam or loamy sand topsoil about 10 cm thick. The subsoil may be red or yellow and usually has high chroma colours. The yellow variant is recognised as a separate phase, 4y. In some cases there may be ferruginous mottles and concretions in the subsoil. Occasionally a few ferruginous gravels may be present.

Series 4 soils are commonly developed over plinthite or weathered rock and occur most frequently in upper connecting slope positions, where they frequently support a relatively luxuriant vegetation of vine forest or dense savanna woodland. They also occur on other connecting slope positions and on the plateaux.

These soils differ from Series 7 and 8 by their texture, from Series 3 and 6 by their lack of gravel, and from Series 5 in their lack of grit.

(e) Series 5.

Series 5 soils are similar to Series 4 except that they contain a significant quantity of grit somewhere in the profile. This grit is predominantly quartzose in nature but sometimes ferruginous grit is the major constituent. Series 5 soils occupy the same topographic situations as Series 4 soils, but tend to occur more in areas with rock outcrops.

(f) Series 6.

Series 6 soils are the most common in the project area. Their diagnostic feature is a layer of gravels usually commencing at about 30 cm from the soil surface and having a thickness varying from 10 cm to more than 70 cm. The gravel content varies from 25 per cent up to 80 per cent and is mostly ferruginous in nature although quartz gravel also often occurs in varying amounts. The gravel is usually set in a yellowish red matrix of sandy clay loam to sandy clay texture, and overlies plinthite, weathered rock, or, occasionally cuirasse. Topsoils are usually coarse sandy loam or loamy coarse sand and dark coloured. The break in texture (i.e. coarse sandy loam to sandy clay loam) often occurs just above the commencement of the gravel layer.

Two phases, 6c and 6b were separated on the basis of texture and depth to gravel layer respectively.

Phase 6c which has a texture of coarse sandy loam or loamy sand to over 60 cm depth is limited in extent and is confined mainly to the areas dominated by granite or gneiss outcrops. 6b, which has more than 40 cm of soil overlaying the gravel layer is common in upper connecting slope sites and often marks the transition from Series 6 to Series 4.

Series 6 soils are typical of connecting slopes but also occur on the plateaux. They differ from Series 3 soils by their less red colour and usually by the distribution of their gravel, although occasionally Series 6 soils may have a uniform gravel distribution through the profile. Series 6 also usually have a deeper coarser topsoil than Series 3 soils. They differ from other soil series either in gravel content (Series 4, 5, 7, 8, 10) or depth (Series 1, 2, 9).

(g) Series 7.

Series 7 consists of non gravelly soils with coarse textured topsoils extending to at least 30 cm depth. Topsoil textures vary from coarse sandy loam to coarse sand and the transition to the sandy clay loam subsoil is usually quite distinct. Subsoil colours are usually 7.5YR or 10YR although chromas must be high for the latter hue. Red ferruginous mottles and concretions are common in the subsoil, occasionally ferricrete sheets form the base of the profile. The profiles frequently contain quartz or ferruginous grit.

Series 7 soils are most commonly found on the middle to lower connecting slopes and overlie plinthite, weathered rock, ferricrete or sometimes dense quartz stone lines. They differ from Series 4 and 5 in their topsoil textures, and from Series 8 in overall profile texture. They are generally finer textured than Series 10, but are also darker or more brightly coloured. They differ from Series 9 in having a better developed subsoil, and from Series 6 by their lack of gravel.

(h) Series 8.

Series 8 consists of deep non gravelly coarse textured soils. Textures are coarse sandy loam or coarser to 60 cm depth. Subsoil colours are brighter or darker than 10YR 6/4. Significant quantities of quartz grit may be present. These soils usually occur in areas dominated by granite or gneiss but also occur in some cuirasse areas. They occupy the middle-to-lower connecting slope and occasionally lower slope positions and may be developed on fresh or partially weathered rock or on ferricrete. The coarse colluvium from which the soils are developed is typical of granite areas in West Africa.

Series 8 soils differ from all other soil series except Series 10, either in the coarseness of their texture, their lack of gravels or their depth. They differ from Series 10 in their stronger subsoil colours.

(i) Series 9.

Series 9 soils are of shallow to moderate depth and overlie only partially weathered rock. The boundary between soil and rock is often marked by a dense stoneline. The soil profile is poorly developed and often dark grey or brown. Textures are usually coarse sandy loam or loamy sand but may be finer. Gravel or quartz grit is sometimes present. These soils are usually readily distinguished from other series by their parent material, quartz stone line and poor profile development. They also typically occur on downcut lower slopes and in connecting slope areas that have been stripped and truncated due to surface erosion. This makes areas likely to contain Series 9 soils easy to recognise from aerial photographs, but interpretation is complicated by their frequent occurrence in association with Series 8 or 10 within the aerial photo unit.

(j) Series 10.

These are deep pale coloured and usually coarse textured soils that are often found on lower connecting slopes and downcut lower slopes. Subsoil hues are 10YR with chromas of 4 or less and values of 6 or more, or any colour of hue 2.5Y. There may or may not be weak to moderate rust mottling below 50 cm, which may have developed sufficiently to form fresh iron concretions. The solum is at least 60 cm deep to weathering rock, and is usually nore than 100 cm. Topsoil textures are invariably very coarse, and in most cases soils remain coarser than sandy clay loam to 100 cm.

These soils differ from those of Series 7 and 8 in that they are paler in colour.

The are deeper than the soils in Series 9. The soils of Series 11 are more hydromorphic, showing much more mottling.

(k) Series 11.

This series includes all the hydromorphic soils of the valley bottoms and the lower slopes. Matrix colours are predominantly grey, white or pale yellow. The depth distribution of rust mottling is erratic, but there is generally at least one strongly mottled horizon somewhere in the profile, often at depths of less than 50 cm. Because the parent material is often alluvial the textural stratification can be erratic and textures within this series are very heterogeneous.

These soils are found in the poorly drained valley bottoms. They also occur on lower sites with gradients of up to 5 per cent. Similar occasional erratic appearance of hydromorphic soils in places on slopes where drainage might be expected to be good has also been noted on the Ferke I sugar estate.

The only other soils with which the soils of this class might be confused are those of Series 9 and 10. The distinction is made on the hydromorphic nature of Series 11 soils and, in the case of Series 9, on their greater depth.

Some of these soils in the valley have a characteristic sedge vegetation cover or support a strong growth of riverain forest, but the lower slope sites often support open savanna.

(1) Series 12.

These are the soils of the Bandama terraces. They are generally fine textured, and have high silt and fine sand contents. They are well to imperfectly drained, and reddish yellow matrix colours usually persist to below one metre. Grey or yellow mottles are common, and may become co-dominant at one metre.

These soils carry a very distinctive vegetation of grass savanna, with *Loudetia arundaceae* dominant and rare isolated large trees.

They are distinguished from all other soils in the area by their relatively high silt and fine sand and their very low coarse sand contents. Their physiographic position is also unique.

The definitive properties of each soil series are outlined in Table 3.1, and typical profile forms are illustrated in Figure 3.1. Representative profiles are described in Appendix II.

### 3.2.2 Correlation with ORSTOM and International Systems of Classification

Although the soil classification system used was designed specifically for the study area, it was considered desirable to relate soil units to their approximate units in the ORSTOM system, which is used in Francophone Africa, and to the FAO and USDA systems which are widely used in other parts of Africa.

The main problem in relating our soil units to those of ORSTOM was the lack of chemical data as only relatively few sites were sampled since, as explained previously, the principal emphasis in classification was placed on soil physical factors important to the growth of sugar cane. Units could, however, be related to the mapping by SOGETHA and IRAT to the

# MODAL FORMS OF SOIL SERIES

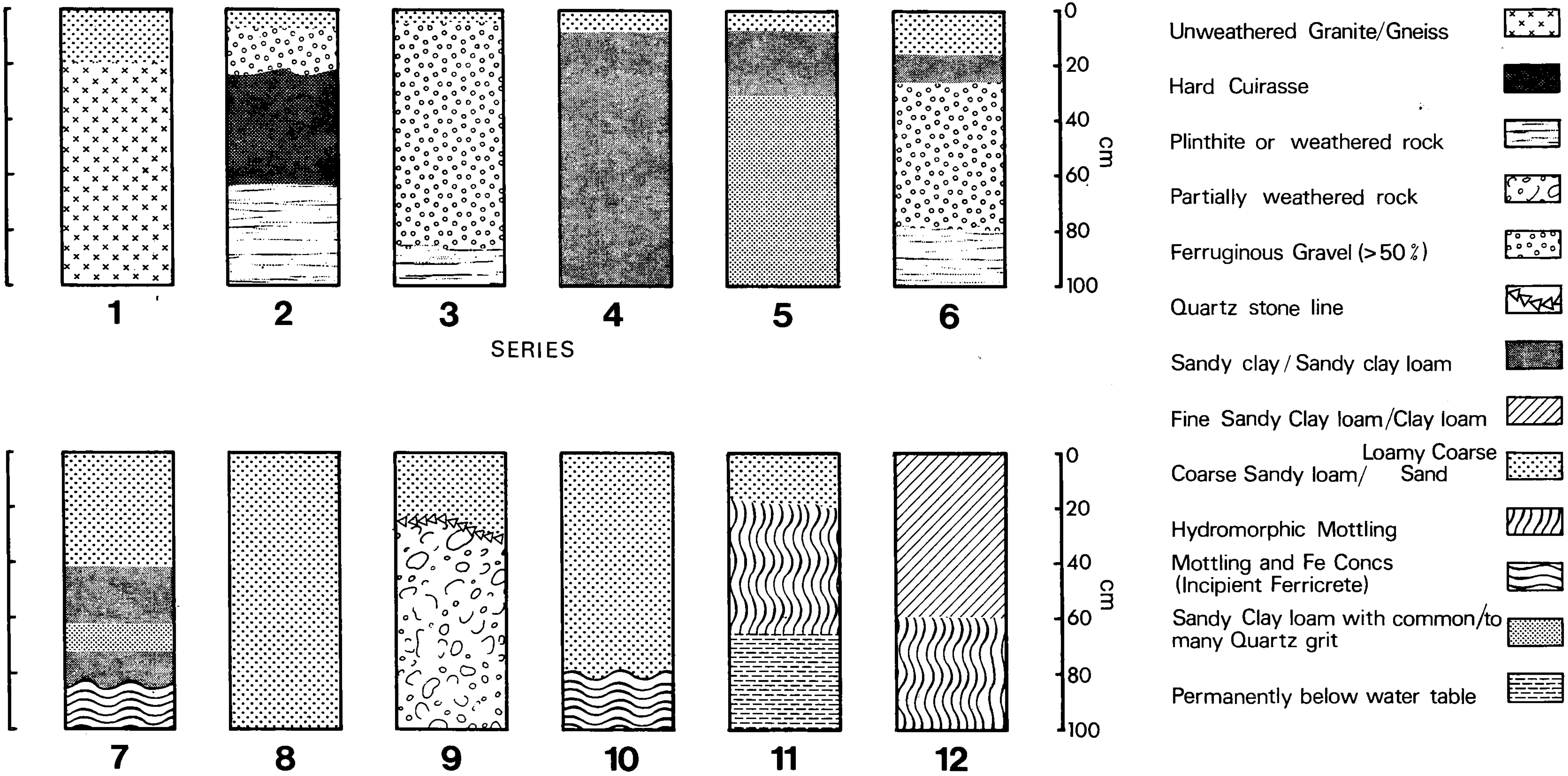



Figure 3·1

TABLE 3.1 Soil Classification

| Soil Series | Topographic Position | Parent Material | Phase | Diagnostic Properties |
|---|---|---|---|---|
| 1 | Anywhere, but crests of interfluves, lower slopes, and stream beds most common. | Consolidated unweathered granite or granitic gneiss, sometimes overlain by colluvium. | - | Depth 0-30 cm. Developed over granite or granitic gneiss. |
| 2 | Plateaux usually, but also locally on connecting slopes. | Hard consolidated cuirasse or ferricrete, or detrital ferruginous stones and gravel from cuirasse break up. | - | Depth 0-30 cm. Developed over cuirasse or ferricrete. |
| 3 | Plateaux and Upper connecting slopes. | Cuirasse, detrital stones and gravels, and sandy clay 'drift', derived from weathering of granite or gneiss. | - | Depth more than 60 cm. Gravel content (ferruginous) more than 50 per cent occuring uniformly through profile. Colour 2.5YR or redder within 30 cm surface. Texture SCL or finer within 30 cm surface. Occurs over cuirasse, plinthite or weathered rock. |
| | | | 3s | As above, except depth 30-60 cm. |
| 4 | Upper connecting slopes most common, but also on plateaux and occasionally on mid-lower connecting slopes. | 'Drift' derived from weathering of granite or granitic gneiss. | - | Depth more than 30 cm. Gravel content less than 25 per cent throughout profile. Texture SCL or finer by 30 cm depth. |
| | | | 4y | Subsoil colours 7.5YR - 10YR with Chromas 6-8 |
| 5 | Upper connecting slopes most common but also on plateaux and occasionally on mid-lower connecting slopes. Often close to granite or gneiss outcrops. | 'Drift' derived from weathering of granite or granitic gneiss. | - | Depth more than 30 cm. Gravel content less than 25 per cent throughout profile. Contains at least one horizon more than 30 cm thick with more than 25 per cent quartz or ferruginous grit. Texture SCL or finer by 30 cm depth. |
| 6 | Connecting slopes and plateaux. | Colluvium derived from weathered granite or granitic gneiss and detrital products of cuirasse. | - | Depth more than 30 cm. Gravel content more than 25 per cent in at least one horizon. Gravel is usually concentrated in one horizon of the profile, which occur within 40 cm soil surface. Colour is 5YR or yellower to more than 30 cm depth. Texture reaches SCL or finer by 60 cm. |
| | | | 6c | As above except texture which is SL or coarser to over 60 cm depth. |
| | | | 6b | As above except gravel layer commences at more than 40 cm depth. |
| 7 | Middle and lower connecting slopes, lower slopes. | Colluvium derived from weathered granite or granitic gneiss. | - | Depth more than 30 cm. Gravel content less than 25 per cent throughout profile. Textured SL or coarser to over 30 cm depth, but reaches SCL or finer by 60 cm depth. |
| 8 | Lower connecting slopes and lower slopes. Higher topographic positions in granite and gneiss areas. | Colluvium derived from weathered granite or gneiss. | - | Depth more than 60 cm. Gravel content less than 25 per cent throughout profile. Texture CoSL or coarser to over 60 cm depth. |
| 9 | Lower connecting slopes and lower slopes. | Colluvium and *in situ* weathering relatively fresh granite or gneiss. | - | Depth less than 60 cm. Generally only one horizon. Dense quartz stone line usual. Overlies only partially weathered rock. |
| 10 | Lower connecting slopes and lower slopes. | Colluvium, sometimes over alluvium. | - | Depth less than 60 cm. Gravel content less than 25 per cent throughout profile. Textures SL or coarser to 60 cm depth. Dominant colour 10YR 6/4 or paler. |
| 11 | Valley bottoms of streams | Alluvium | - | Depth more than 30 cm. Variable texture and gravel content. Low chroma colours dominant. Signs of seasonal waterlogging. (Hydromorphic mottling). |
| 12 | Bandama Terraces | Alluvium | - | Depth more than 30 cm. Gravel content less than 25 per cent throughout profile. Texture: Relatively high silt and fine sand content. Found only on Bandama Terraces. |

N.B. SC, SL and CoSL refer to standard texture classes as defined by FAO. Colours refer to standard Munsell (1954) notations.

south and north of the area. Both these surveys rely on ORSTOM derived units for their mapping.

The problem of relating our soil units to those of the FAO and USDA is in the reliance of these systems on the concept of diagnostic horizons. On the Africa sheet of the FAO/UNESCO soil map of the world (FAO/UNESCO, 1970), most of the upland soils of the area are mapped as Acrisols. Acrisols must, however, by definition have an argilluvic horizon and this was rarely apparent in the field as no cutans were observed in profile pits, and one reason for the textural difference between the upper and lower horizons was considered to be lateral removal of clay resulting from surface wash and colluviation. As profiles often contain weatherable minerals in the form of muscovite flakes they do not qualify for the Ferralsols of the FAO or the Oxisols of the USDA systems. The only alternative major groupings are the Cambisols (FAO) and Inceptisols (USDA) which usually refer to soils of more temperate regions. After discussions with Dr. Pecrot of FAO it was decided to class most of the soils as Acrisols, on the assumption that at least some clay illuviation had occurred and that, if thin sections were prepared the soils would show the one per cent cutans necessary for Acrisol definition.

Approximate ORSTOM, FAO/UNESCO and USDA equivalents to soil series are given in Table 3.2. The representative profile pits, described in Appendix I are also given an ORSTOM classification. ORSTOM units are based on Aubert (1965) and Aubert and Segalen (1967). FAO/UNESCO units are from the 1970 legend to the Soil Map of the World and USDA units are from the Seventh Approximation (USDA, 1960) and the 1964 supplement.

## 3.3 Land Classification

The land classification criteria are discussed fully in Chapter 4. However, at this stage it is useful to summarise the main points.

Land suitable for cane has been placed in three Classes I, II and III in descending order of suitability.

Some land which is considered suitable for cultivation but has at present a drainage problem due to a persistently high water table is placed in a special Class IV.

Land unsuitable for cane cultivation is placed in Class VI.

TABLE 3.2 Correlation of Soil Series with ORSTOM, FAO/UNESCO and USDA Systems of Classification

| Soil Series and Phases Utilised in Study | ORSTOM System | | | FAO/UNESCO System | USDA System |
|---|---|---|---|---|---|
| | Classe and Sous-classe | Groupe | Sous-groupe | | |
| 1 | Sols minéraux bruts d'origine non climatique | Sols bruts d'érosion | Lithosols (Famille sur roche en place) | Lithosols | Lithic Haplorthents |
| 2 | Sols minéraux bruts d'origine non climatique | Sols bruts d'érosion | Lithosols (Famille sur niveau cuirasse demantelé) | Lithosols | Durorthidic Haplorthents |
| 3,3s | Sols ferrallitiques fortement désaturés | Remanié | Modal | Orthic/Plinthic Ferralsols | Ustox |
| 4 | Sols ferrallitiques moyennement désaturés | Typique | Modal | Orthic, Ferric Plinthic and Acrisols | Ustults |
| 4y | Sols ferrallitiques moyennement désaturés | Typique | Jaune | | |
| 5 | Sols ferrallitiques moyennement désaturés | Typique | Modal/Jaune | | |
| 6,6b | Sols ferrallitiques moyennement désaturés | Remanié | Modal | | |
| 6c | Sols ferrallitiques moyennement désaturés | Remanié | Modal Faciès appauvris | | |
| 7 | Sols ferrallitiques moyennement désaturés | Appauvris | Modal/Jaune | | |
| 8 | Sols peu évolués d'origine non climatique | Sols peu évolués d'apport | Modal (Famille sur colluvion/alluvion | Dystric Regosols | Typic Normipsamments |
| 9 | Sols peu évolués d'origine non climatique | Sols peu évolués d'érosion | Régosoliques | Dystric Regosols | Typic/Lithic Haplorthents |
| 10 | Sols peu évolués d'origine non climatique | Sols peu évolués d'apport | Modal/Hydromorphe | Albic Arenosols | Typic Normipsamments |
| 11 | Sols hydromorphes minéraux | A gley | A gley d'ensemble/ à gley de profondeur | Dystric Gleysols | Typic Normaquepts |
| 12 | Sols hydromorphes minéraux | A gley | A gley de profondeur | Dystric Fluvisols | Typic Normaquepts |

Subscripts are used to indicate specific limitations as follows:-

d - effective depth (with permeable limiting horizon)

r - effective depth (with impermeable limiting horizon)

g - gravel or stone content

t - texture

p - surface boulders or outcrop

f - flood hazard

s - slope

w - soil drainage

e - gullied (eroded) land

More details are given in Sections 4.3 and 4.4.

### 3.4 Soil - Water Relationships

Two of the most important soil properties in determining suitability for irrigated agriculture are the infiltration rate and available water capacity. These determine firstly how much water the soil can accept in a given time, and secondly how much water the soil can store in a form available to the growing plant. Under the proposed irrigation scheme, which involves an application rate of 9.33 mm per hour and a net application of 56 mm every eight days, it is essential that soils classified as suitable for cane growing on their field characteristics should be able to accept this rate of water application, and be able to hold at least 56 mm of moisture in a form available to the growing plant.

Infiltration tests were carried out in the field at various selected sites. Available moisture capacity calculations were made from moisture retention measurements performed in the laboratory on soil cores, or disturbed samples taken from the ten profile pits described in Appendix II. The methods are described and the results are tabulated in Appendix III.

At two of the infiltration sites (profile pits 1 and 7), the tests were invalid because stones in the surface layer and coarse textured surface horizons resulted in a strong artesian effect with water bubbling to the surface outside the infiltration rings. Both these sites were in land which was classed as unsuitable. The basal rates of the three other infiltration investigations at the end of each day of the test are summarised in Table 3.3.

TABLE 3.3 Basal Infiltration Rates

| Site (Profile Pit No.) | Soil Unit | Land Class | Basal Infiltration Rates (mm/h) After 1 day | After 2 days | After 3 days |
|---|---|---|---|---|---|
| 10 | 6b | IIg | 46 | 36 | - |
| 40 | 4 | I | 20 | 16 | 14 |
| 41 | 5/6b | IIt | 24 | 19 | 19 |

From the above results it can be concluded that basal rates are generally adequate to accept irrigation water at the rate of 9.33 mm/hour. Although infiltration data is limited to these three sites, there is no reason to suspect an infiltration problem in soils of the project area. Where a sharp textural break occurs between topsoil and subsoil, as is often the case, the bulk of the water may, however, run off laterally through the subsoil and may constitute an erosion risk.

Available moisture capacities (AMC'S) were calculated as volume percentages for different horizons of the soils tested and these figures were used to calculate the number of mm of available moisture in the rooting zone (top 100 cm). The readily available moisture capacity (RAMC) is generally taken as being half the AMC. The results are summarised in Table 3.4.

TABLE 3.4 Available Water Characteristics

| Profile Pit | Soil Unit | Land Class | AMC (mm) | RAMC (mm) |
|---|---|---|---|---|
| 1 | 9 | VItg | 76 | 38 |
| 7 | 6 | VIg | 154 | 77 |
| 10 | 6b | IIg | 143 | 71 |
| 14 | 3 | IIIg | 115 | 58 |
| 18 | 10 | VIt | 136 | 68 |
| 21 | 6 | IIIg | 132 | 66 |
| 25 | 7 | VIt | 131 | 66 |
| 28 | 6 | VItg | 62 | 31 |
| 40 | 4 | I | 118 | 59 |
| 41 | 5/6b | IIt | 119 | 59 |

Profiles I and 28 which have less than 56 mm of readily available moisture have been classified as unsuitable for cane growth on their field characteristics. All the profiles classed as suitable appear to have adequate readily available water. In most cases a high proportion of this water was help in the top 50 cm, where efficiency of utilisation will be greatest because of a relatively high proportion of cane roots.

From these studies, one can conclude that the infiltration capacities and available water holding capacities of soils classed as suitable for cane are adequate to support the proposed irrigation system. They will not, however, be sufficient to cope with some of the bouts of heavy rain occurring between May and October, and conservation measures must be taken to protect land from excess run off.

Bulk densities were measured in the course of soil moisture retention studies. The results are shown in Table A3.2.

Bulk densities are very high in some of the profiles, particularly profiles 18, 40 and 41. The former is coarse textured and classed as unsuitable for cane anyway, but profiles 40 and 41 have been given high suitability ratings so the bulk density figures could give more cause for concern. These profiles did not appear excessively compact in the field, however, and no inhibition to root penetration was noticed. However, high bulk density resulting from unfavourable soil structure must be regarded as a possible problem in some of the otherwise suitable soils in the project area. Unfortunately this is a property that cannot be easily distinguished by a survey based on auger borings. It is recommended that attention is given to soil physical properties such as compaction in different moisture conditions during agronomic trials on the plantation. Soil compaction was also mentioned as a problem in growing cane in the area by M. Langellier, the pedologist at IRAT, Ferkéssédougou.

## 3.5 Discussion of the Analytical Data

The methods of analysis are described in Appendix I and detailed soil profile descriptions and related chemical data are given in Appendix II.

The general interpretation of results follows the work of Berger (1964) who compiled a series of classes for the principal chemical analyses based on topsoil samples from the Bouaké region.

TABLE 3.5 Interpretation Norms for the Principal Chemical Analyses (surface horizons)

| Determination | Interpretation Class 1 very poor | 2 poor | 3 average | 4 good | 5 very good |
|---|---|---|---|---|---|
| Total carbon % | 0.6 | 1.2 | 1.8 | 2.4 | |
| Total nitrogen % | 0.05 | 0.1 | 0.14 | 0.2 | |
| Total phosphorous mg/100g | 40 | 70 | 90 | 150 | |
| Exchangeable Ca me/100g | 1.0 | 4.0 | 8.0 | 18.0 | |
| Exchangeable Mg me/100g | 0.5 | 1.0 | 2.0 | 5.0 | |
| Exchangeable K me/100g | 0.1 | 0.2 | 0.4 | 0.6 | |
| Sum Bases me/100g | 2.0 | 6.0 | 12.0 | 24.0 | |
| CEC me/100g | 5.0 | 10.0 | 20.0 | 40.0 | |
| Base saturation % | 20.0 | 40.0 | 60.0 | 90.0 | |

The figures indicate the limiting values between the five classes.

The analytical data of representative soil profiles confirm that the soils are acid and generally deficient in nutrients, as one would expect on the basis of geology and the climatic and geomorphological regimes, both past and present, existing within this region.

Only a relatively small number of profiles have been analysed and therefore the results are discussed in general terms only.

### 3.5.1 Particle Size Analysis

The particle size analyses were carried out on the fine earth fraction (less than 2 mm) although a large proportion of ferruginous concretions was found in some soils. Particles greater than 2 mm were separated from the soil mass and weighed. This fraction was termed the gravel fraction and expressed as a percentage of the total weight of the soil.

The size limits used for the various particle size fractions depend upon the particular scheme used. The two main systems are the International and that of the United States Department of Agriculture.

The principal difference between the two systems and that used by scientists in the Ivory Coast, is in the size limits of the silt and sand fractions.

TABLE 3.6 Comparison of Particle Size Groupings

| Name of Separate | Effective Diameter (mm.) | | |
|---|---|---|---|
| | International | USDA | Ivory Coast |
| Very coarse sand | - | 2.0-1.0 | - |
| Coarse sand | 2.0-0.2 | 1.0-0.5 | 2.0-0.2 |
| Medium sand | - | 0.5-0.25 | - |
| Fine sand | 0.2-0.02 | 0.25-0.10 | 0.2-0.05 |
| Very fine sand | - | 0.10-0.05 | - |
| Coarse silt | - | - | 0.05-0.02 |
| Silt | 0.02-0.002 | 0.05-0.002 | 0.02-0.002 |
| Clay | below 0.002 | below 0.002 | below 0.002 |

The size fractions determined in the laboratory by Huntings were:

| | |
|---|---|
| Coarse sand | 2.0-0.2 mm |
| Fine sand | 0.2-0.05 mm |
| Coarse silt | 0.05-0.02 mm |
| Silt | 0.02-0.002 mm |
| Clay | less than 0.002 mm. |

The testural class names used in the soil profile descriptions are based on the USDA system and the USDA soil texture diagram.

The soil textures are varied, range from loamy coarse sands to clays and reflect the different parent materials, different topographic positions and the different soil forming processes which have operated.

Most soils show an increase in the clay content down the profile and then a decrease in the deep subsoil. The increase in clay content suggests that a certain amount of clay illuviation has taken place although very few signs of clay movement were recognised during field studies.

3.5.2 pH

The pH was measured in a 1:2½ soil water suspension using the following descriptive classes (Berger, 1964).

| pH Range | Description |
|---|---|
| less than 5 | Strongly acid |
| 5 - 6 | Acid |
| 5 - 7 | Slightly acid |
| greater than 7 | Alkaline |

The topsoil pH varied from 6.9 to 5.9 and that of the subsoils from 6.7 to 5.3.

These pH values are rather higher than one might expect for soils with low base saturation percentages. The pH was repeated using a suspension of soil in normal potassium chloride solution. A strong electrolyte such as potassium chloride, used on acid soils, prevents the buffering action which may occur by releases of hydroxyl ions from the clay lattice.

pH values measured in the potassium chloride suspension are lower by 0.3 to 1.0 unit than those measured in an aqueous suspension. This is a normal depression of pH values and indicates there are only small quantities, if any, of hydroxyl resulting from breakdown of the clay lattice under acid conditions and release of aluminium.

Generally the pH, base saturation percentage and the exchangeable aluminium values are related and a change in one factor is reflected by a similar change in the other two factors.

pH values are highest in the humic topsoils, reach minimum values in the subsoil and increase again in the deeper subsoil.

### 3.5.3 Exchangeable Aluminium

Exchangeable aluminium often occurs in soils with a low pH and the acid nature of the soil results from the hydrolysis of aluminium in the soil solution and release of hydrogen ions (Kamprath, 1972). An increase in the salt concentration of the soil solution increases the amount of aluminium in solution (by displacement of exchangeable aluminium) and therefore will lower the pH value. This reaction occurs when the pH is measured in a potassium chloride suspension. The magnitude of the change in pH is a measure of the amount of aluminium displaced. A change of pH between 0.5 and 1.0 unit is normal. A pH depression greater than 1.0 unit indicates that substantial quantities of aluminium exist in an exchangeable form on the soil colloids and have been released into the suspension.

Exchangeable aluminium was measured on all soils and values were less than one milliequivalent per 100g, soil except for the subsoil of profile P.14 where the value is somewhat high.

Significant quantities of aluminium may appear in the soil solution when the aluminium ion exceeds 60 per cent of the exchangeable cations. In general the aluminium saturation is less than 60 per cent and only approaches this level in two profiles P10 and P14.

Therefore exchangeable aluminium does not appear to reach toxic levels for most soils of the project area and even in the subsoil of profile P14 values are marginal.

### 3.5.4 Exchangeable Bases

The exchangeable forms of calcium, magnesium and potassium constitute the major sources for plant nutrition. The analyses show that there is a concentration of exchangeable bases in the surface horizons, associated with the organic material. Calcium is the dominant cation followed by magnesium, potassium and sodium in descending order. Values are highest in the topsoil and decline in the subsoil then increase in the deep subsoil. At best, levels are only average to poor in the topsoil and generally the subsoils have levels insufficient for adequate plant nutrition unless fertilisers are added.

The level at which potassium becomes deficient depends to a certain extent upon soil texture and also the plant. Boyer (1970) considered that for soils with medium to fine textures (clay and silt contents around 50 per cent) the critical value is around 0.3 me/100g soil whereas 1.0 me/100g soil may be the deficiency level in sandy soils.

Work on bananas (Dabin and Leneuf, 1960) and coffee and cocoa (Beley and Chezeau, 1954; Loue, 1961, 1962 and Moulinier, 1962) in the Ivory Coast indicated minimum levels which varied from 0.07 to 0.20 me/100g soil.

Studies in Hawaii (Baver, 1970; Humbert, 1958) indicated that sugar cane exhibits a deficiency if the exchangeable potassium is less than 0.18 me/100g soil and no response to potash fertilisers was obtained at soil exchangeable potassium values of 0.3 me/100g soil.

The relationship of exchangeable potassium to other nutrients is also important. It is generally found that exchangeable potassium should constitute at least two per cent of the sum of exchangeable bases and for intensive cultivation should constitute four per cent of the total exchange capacity (Chaminade, 1963).

Additionally the ratio of potassium to other exchangeable cations is important for plant growth. Boyer (1970) concluded that the ratio of magnesium to potassium should be less than 25 to avoid an induced potassium deficiency but greater than 2 to 3 to avoid a potassium induced magnesium deficiency in coffee.

Thus antagonisms may occur between nutrients and if the Mg/K ratio is less than 2 or Ca/K ratio less than 5 there is excessive absorption of potassium by the plant and an induced deficiency of calcium or magnesium occurs.

In Togo, Dabin (1956)showed that cotton yields decreased with potassium fertilisation when the Mg/K ratio is 3:1.

In soils with just sufficient potassium for plant requirements the application of nitrogenous fertilisers increase the plants demand for potassium and therefore nitrogen can bring about an induced potassium deficiency.

The absolute levels of exchangeable potassium are generally around 0.2 me/100g soil or less. Therefore potassium fertilisers will be needed for most crops.

The ratios of magnesium to potassium and calcium to potassium fall within acceptable ranges and cation induced deficiencies are unlikely to occur.

### 3.5.5 Cation Exchange Capacity and Base Saturation

The cation exchange capacity values are low particularly in the hydromorphic soils and other soils with coarse textures and vary between 1 and 9 me/100g soil. Values are highest in the surface horizons, except in certain profiles with a high clay content in the subsoil, which reflect the contribution made to the CEC by organic matter.

An indication of the nature of the clay minerals may be obtained by expressing the cation exchange capacity as milliequivalents per 100g of clay.

Values for subsoils give a range between 10 and 20 milliequivalents per 100g clay which suggest that kaolinite is the dominant clay mineral.

Kaolinite itself has a generally lower value for cation exchange capacity ranging from 5 to 15 milliequivalents per 100g clay material. However, there are reasons why the traditional method adopted for the measurement of CEC is not suitable for these soils. The CEC measured by the use of a buffered solution at a pH of 8.2 includes not only sites occupied by exchangeable cations but also pH dependent exchange sites associated with carboxyl groups and hydrated oxides of iron and aluminium.

Consequently Coleman (1959) suggested that the sum of the exchangeable calcium, magnesium, potassium and aluminium extracted with a neutral unbuffered salt solution be called the 'effective cation exchange capacity'. The 'effective CEC' can be considered to be the exchange sites that are participating in exchange reactions at the particular soil pH and is believed to be a much more realistic manner of expressing base saturation. On this basis most mineral soils will be 100 per cent base saturated at pH 6.0.

The main significance of the low CEC values is that the soils have a low capability for the retention of plant nutrients against leaching.

The aluminium saturation at the pH of the soil in the field is also important and the growth of sugar cane is severely depressed with an exchangeable aluminium saturation of 70 per cent of the effective CEC. Addition of lime to reduce the aluminium level to 30 per cent resulted in a four fold increase in growth (Abruna and Vicente-Chandler, 1967).

Most plants are relatively tolerant of low pH values, provided that the supply of nutrients is adequate. The depression of calcium and phosphorus uptake by aluminium can severely restrict root development. According to Kamprath (1972) there has been no evidence of aluminium toxicity to root development of sugar cane in acid soils in Hawaii even at pH values below 5.0. In Hawaii, calcium is added as a nutrient and adequate available calcium is assured.

Aluminium toxicity in sugar cane soils in Guyana did not occur unless the exchangeable aluminium saturation exceeded 60 per cent.

### 3.5.6 Organic Carbon and Total Nitrogen

Organic carbon and total nitrogen were determined on the top two horizons. Values for organic carbon range from 0.68 to 1.16 per cent in the topsoil and from 0.60 to 0.98 in the second layer. Organic matter may be obtained by multiplying the value for organic carbon by 1.72.

Values for both organic carbon and total nitrogen are only average to low and the ratio of organic carbon to total nitrogen varies from 15 to 25 with a mean around 20. These values indicate that the rate of humification is low and such low values for nitrogen indicate that nitrogenous fertilisers will be required by most crops.

Boyer (1970) considered that nitrogen was the most important single factor affecting crop yields in West Africa. Dabin (1961) stated that the fertility of a soil, in terms of the nitrogen content, varied according to the soil pH, assuming other factors were not limiting and provided a guide which is reproduced in Table 3.7.

Berger (1964) commented that this scale is very practical although rather optimistic when applied to diverse crops.

Soil organic matter is of importance to soil fertility due to its contribution to the soil exchange complex and sulphur status apart from its contribution to maintenance of soil structure and water holding characteristics.

TABLE 3.7 Soil Fertility Scale (Dabin, 1961)

| Fertility | Total Nitrogen % | | |
|---|---|---|---|
| | pH 4.5-5.0 | pH 5.0-5.5 | pH 5.5-6.0 |
| Very good | - | 0.30-1.00 | 0.15-1.00 |
| Good | 0.25-1.00 | 0.15-0.30 | 0.08-0.15 |
| Average | 0.12-0.25 | 0.08-0.15 | 0.04-0.08 |
| Mediocre | 0.06-0.12 | 0.04-0.08 | 0.03-0.04 |
| Very low | 0.01-0.06 | 0.01-0.04 | 0.01-0.03 |

### 3.5.7 Phosphorus

Phosphorus is probably the second most important plant nutrient after nitrogen and the majority of cultivated soils in the tropics are deficient in this nutrient.

Total reserves of phosphorus are often low but phosphorus is often converted in acid soils to a form which is not available to the plant. Loss of soil phosphorus by leaching is insignificant in tropical areas and most losses are due to removal by plants (cropping) and soil erosion.

Total phosphorus values decrease with increasing weathering and some mature upland soils may contain less than 20 mg/100g soil. (Bouyer and Damour, 1964).

Aluminium phosphate fixation increases with decreasing pH and iron phosphates form along with iron oxides as soils become ferruginous.

On the basis of Berger's (1964) scale all the soils are poorly supplied with total phosphorus.

Certain profiles were selected and analysed for 'available' phosphorus using a modified Truog extractant and also the phosphate adsorption capacity was measured.

The available phosphorus criteria used to predict crop response are:-

| | |
|---|---|
| less than 5ppm | extremely deficient |
| 5-15ppm | deficient |
| 15-25ppm | average |
| greater than 25ppm | adequate to high |

The available phosphorus values are highest in the topsoil and decrease rapidly in the subsoil. Subsoil values range from 3 to 10 ppm which indicate that the soils are deficient in available phosphorus. The topsoils are often moderately to well supplied with available phosphorus which is related to the organic matter content.

Fixation of phosphorus by the soil was effected by equilibrating the soil with a standard phosphate solution and measuring the amount of phosphate adsorbed after a certain period of time had elapsed.

Fixation of phosphorus is related to the clay mineralogy and the amorphous nature of the colloidal hydrated oxides of iron and aluminium. In Hawaii, Fox et alia (1968) ranked the fixation capacity in the descending order:-

amorphous hydrated oxides
gibbsite - goethite
kaolinite
montmorillonite

Dabin (1970) pointed out that fixation is particularly rapid on ferallitic soils high in goethite in West Africa.

The phosphate requirement of some tropical soils is so great that economic returns appear unlikely. Fixation of phosphate by iron and aluminium in soils is, however, not a one way process. Recent work (Younge and Plucknett, 1966; Fox et alia, 1968) has shown that the residual effects of phosphate applications are greater than expected even if the phosphate adsorption capacity is only partially satisfied.

Kamprath (1967) and Woodruff and Kamprath (1965) showed that phosphate added initially in large quantities to quench the fixation properties of acid tropical soils is not irretrievably lost but is available for plant growth in successive years.

Barrow and Shaw (1974) found that the effectiveness of phosphorus for plant nutrition decreased with an increase of temperature. This finding is of great importance for tropical soil conditions and indicates that the shorter the period between application and contact with plant roots the more effective is the result. The authors also found that the level of application of phosphorus did not affect the proportions of phosphorus changed which appears to contrast with the belief that heavy applications of phosphorus are neede to saturate the soil fixation sites. The phosphate adsorption values measured are given in Table 3.8.

The topsoils have generally low to medium phosphate adsorption characteristics which correlate quite well with the values for available phosphate. This generally satisfactory situation is restricted to the highly organic topsoil and a depth of soil which usually varies from 10 to 15 cm. Below this depth the adsorption capacity increases markedly and some extremely high values have been encountered.

TABLE 3.8 Phosphate Adsorption Capacities of Selected Soils

| Soil Series | Profile No. | Depth cm. | Exch. Al me% | Extract $Fe_2O_3$% | Total P ppm | Available P ppm | Phosphate Adsorption mg/100g | Phosphate capacity Kg/ha* |
|---|---|---|---|---|---|---|---|---|
| 6b | P10 | 2- 10 | 0.00 | 2.03 | 300 | 6.4 | 3.4 | 128 |
| | | 27- 34 | 0.82 | 3.29 | 310 | 3.2 | 26.3 | 986 |
| | | 50- 60 | 0.85 | 3.60 | 310 | 3.2 | 36.2 | 1358 |
| | | 80- 90 | 0.60 | 4.06 | 320 | 3.2 | 36.7 | 1376 |
| | | 120-125 | 0.26 | 9.95 | 480 | 3.2 | 37.5 | 1406 |
| 3 | P14 | 0- 10 | 0.02 | 7.44 | 670 | 17.2 | 9.6 | 360 |
| | | 30- 40 | 2.02 | 9.26 | 600 | 4.8 | 37.2 | 1395 |
| | | 80- 90 | 0.46 | 11.50 | 580 | 3.2 | 34.7 | 1300 |
| 6 | P21 | 0- 10 | 0.00 | 5.66 | 670 | 27.2 | 4.2 | 158 |
| | | 26- 33 | 0.73 | 7.20 | 360 | 6.4 | 26.0 | 975 |
| | | 70- 80 | 0.24 | 12.36 | 540 | 3.2 | 35.5 | 1330 |
| 4 | 40 | 0- 16 | 0.07 | 1.26 | 365 | 22.0 | 4.2 | 158 |
| | | 16- 35 | 0.20 | 2.03 | 405 | 8.8 | 17.8 | 668 |
| | | 35-115 | 0.08 | 3.40 | 465 | 4.8 | 37.4 | 1400 |
| | | 115-147 | 0.02 | 6.80 | 560 | 6.4 | 37.5 | 1400 |
| 6b | 41 | 0- 8 | 0.01 | 1.14 | 400 | 52.8 | 4.2 | 158 |
| | | 8- 25 | 0.36 | 1.80 | 470 | 10.4 | 18.6 | 698 |
| | | 25- 65 | 0.59 | 2.49 | 510 | 6.4 | 34.0 | 1275 |
| | | 65-110 | 0.14 | 4.29 | 470 | 4.8 | 37.8 | 1420 |
| | | 110-150 | 0.13 | 4.74 | 450 | 10.4 | 37.3 | 1400 |

* Calculations based on the quantity of phosphorus which would be adsorbed by soil contained in an area of one hecatre and a depth of 25 cm., assuming an average bulk density of 1.5 $g.cm^{-3}$.

Although both iron and aluminium are implicated in the role of phosphate adsorption, the results in Table 3.8 suggest a better relationship exists between the dithionite extractable iron and adsorption values than exchangeable aluminium and adsorption values.

Technical advice on the best methods of dealing with high phosphate adsorption capacities is sometimes contradictory. We believe a suitable approach would be to apply phosphorus based on an attempt to saturate 25 per cent of the adsorption capacity, utilising a granular form with slow release characteristics.

### 3.5.8 Sulphur

Most sulphur in soils of leached tropical soils is present in the topsoil in organic combination.

Studies on acid soils of eastern Australia (Barrow, 1960) showed that the presence of sulphur was closely related to the accumulation of soil nitrogen in the ratio ION: 1.2S. Although analyses were not carried out for sulphur we can use the above figures to assess the possible sulphur content. The highest value recorded for total nitrogen is 0.06 per cent or 600 ppm. Assuming a ration of ION: 1.2S then the sulphur content would be 72 ppm. in the best soil and considerably less in others.

The problems of sulphur deficiency appear to be associated especially with upland savanna (Greenwood, 1951) and the deficiency appears to be accentuated by drought (Dutt, 1962).

Responses to sulphur applications have been found on many acid soils in West Africa (Braud, 1969).

Therefore we conclude that sulphur is likely to be deficient in these soils and sulphates should be included in the fertiliser applications preferably in the form of potassium sulphate.

### 3.5.9 Silicon

In certain acid soils, particularly those developed from granites and those rich in iron and aluminium oxides, addition of silicates have increased crop yields. The main crops which have shown such responses are rice and sugar cane.

Kawaguchi and Kyuma (1969) stated that available silicon values less than 100 ppm in the plough layer of rice soils indicate deficiency conditions.

Studies in Hawaii (Fox et alia 1967) on sugar cane resulted in proposals for tentative levels of sulphuric acid extractable silicon in relation to deficiencies for cane production.

The levels assigned were:-

| | |
|---|---|
| Deficiency probably | less than 40 ppm available silicon |
| Deficiency questionable | 40 - 100 ppm available silicon |
| Deficiency unlikely | greater than 100 ppm |

Therefore a level of 100 ppm available silicon has been taken as the critical value.

Selected profiles were analysed for available silicon and values ranged from 100 to 600 ppm. Therefore we conclude that there will not be a silicon deficiency in these soils.

### 3.5.10 Total Potassium

Total potassium values cannot be satisfactorily correlated with crop yields according to the findings of Ollagnier and Prevot (1956) but the figures are a useful measure of the potassium reserves in the soil.

The analyses show that the soils have very variable reserves of potassium, the highest values are related to the presence of mica in the soil. In general reserves are only moderate to low and tend to vary directly with the clay content of the soil.

Topsoil content ranges from 18 to 45.9 mg/100g soil with one exceptional value of 298 mg/100g.

Subsoil values range 6 to 92.9 mg/100g soil with one exceptional value of 254 mg/100g soil.

Total potassium contents below 25 mg/100g soil are considered to be low. 25 to 50 mg/100g are average and more than 50 mg/100g are high.

### 3.5.11 Copper, Zinc and Manganese Contents

(a) Copper

Soils derived from acidic rocks are normally low in copper content. Deficiency symptoms in growing crops are frequent where total soil copper content is less than 5 ppm and sub-clinical deficiency symptoms may occur in grazing animals and plants at total soil copper contents between 5 and 10ppm.

Crop deficiency symptoms also occur when levels of available copper are less than 1.0ppm.

On this basis the total copper values indicate a marginal to adequate situation and the available copper values indicate a deficient to marginal situation (Table 3.9).

(b) Zinc

Zinc deficiencies are common on acid soils, particularly those derived from acidic rocks. Soils with total zinc contents below 25ppm are likely to produce deficiency symptoms in growing crops.

Crops also show deficiency symptoms when the available zinc values are less than 1.0ppm.

Consequently on the basis of the results quoted in Table 3.9 the soils are considered to be deficient in zinc and appropriate quantities of zinc need to be applied in the fertiliser programme.

(c) Manganese

A minimum value of 25ppm of total manganese is considered essential for normal crop growth. The critical level of available manganese for adequate crop growth lies between 10 and 15ppm. The analytical data given in Table 3.9 for manganese confirms there is sufficient for plant growth and it is unlikely that any nutritional problem will occur.

### 3.5.12 Summary

All the soils are acid in reaction and generally deficient in nutrients in commom with most West African soils formed under peneplain conditions.

The calcium and magnesium levels are low and potassium particularly so. The ratios between nutrients are adequate and cation induced deficiencies are unlikely to occur.

TABLE 3.9 Trace Elements in Selected Soils

| Land Suitability Class | Soil Series | Profile No. | Depth cm. | Total Mn ppm | Available Mn ppm | Total Cu ppm | Available Cu ppm | Total Zn ppm | Available Zn ppm |
|---|---|---|---|---|---|---|---|---|---|
| IIg | 6b | 10 | 2- 10 | 128 | 118 | 10 | 0.58 | 9 | 0.56 |
| | | | 27- 34 | 88 | 61 | 15 | 0.80 | 14 | 0.56 |
| | | | 50- 60 | 88 | 53 | 20 | 0.91 | 21 | 0.32 |
| | | | 80- 90 | 69 | 38 | 21 | 0.68 | 18 | 0.40 |
| | | | 120-125 | 58 | 14 | 25 | 0.46 | 17 | 0.32 |
| IIIg | 3 | 14 | 0- 10 | 500 | 223 | 10 | 0.58 | 14 | 0.88 |
| | | | 10- 40 | 340 | 148 | 16 | 0.68 | 21 | 0.48 |
| | | | 80- 90 | 71 | 26 | 15 | 0.68 | 12 | 0.72 |
| IIIg | 6 | 21 | 0- 10 | 133 | 65 | 12 | 0.58 | 11 | 0.72 |
| | | | 26- 33 | 129 | 65 | 18 | 1.02 | 20 | 0.40 |
| | | | 70- 80 | 63 | 18 | 24 | 0.68 | 16 | 0.72 |
| I | 4 | 40 | 0- 16 | 102 | 81 | 7 | 0.68 | 12 | 0.80 |
| | | | 16- 35 | 56 | 49 | 8 | 0.68 | 13 | 0.56 |
| | | | 35-115 | 45 | 26 | 13 | 0.58 | 19 | 0.40 |
| | | | 115-147 | 260 | 114 | 12 | 0.68 | 17 | 0.48 |
| IIt | 6b | 41 | 0- 8 | 160 | 144 | 6 | 0.58 | 12 | 0.80 |
| | | | 8- 25 | 90 | 57 | 10 | 0.91 | 18 | 0.40 |
| | | | 25- 65 | 55 | 53 | 10 | 0.80 | 18 | 0.80 |
| | | | 65-110 | 54 | 30 | 17 | 0.80 | 26 | 0.48 |
| | | | 110-150 | 26 | 6 | 13 | 0.46 | 18 | 0.40 |

Exchangeable aluminium values are only moderate although the percentage of exchange sites occupied by aluminium occasionally rises to a level where crop yields may be affected.

Nitrogen levels are low and sulphur levels are predicted to be low.

Total reserves of phosphorus are low and available phosphorus levels are vey variable, being adequate to average in the topsoil and deficient in the subsoil. Phosphate adsorption capacities are moderate in the topsoil and extremely high in the subsoil.

Silicon levels are adequate. Soil copper contents are only marginal and soil zinc contents are sufficiently low to produce deficiency symptoms in crops, whereas manganese levels are adequate.

The soils are non saline and there are no chemical toxicities present.

Although the soils are impoverished in nutrients and relatively infertile it is easy to overcome these chemical deficiencies by the application of fertilisers.

Suitable preliminary levels for fertiliser application are given below.

## 3.6 Fertiliser Requirements

Sugar cane removes large quantities of plant food elements from the soil and an adequate fertiliser programme will be necessary to sustain high crop yields.

Adequate early fertilisation is necessary for good yields and the plant has a high requirement for nitrogen, phosphorus and potassium during the early stages of growth.

### Nitrogen

An average requirement is around one kilogram of nitrogen per ton of cane for plant cane and 1.5 kg nitrogen per ton for ratoon cane. About half the nitrogen should be applied together with phosphate and potash in the furrow at planting followed by a top dressing two to three months after planting. The type of fertiliser to be applied will depend upon availability but on these acid soils ammonium nitrate/limestone, calcium cyananide or calcium nitrate would be preferable to the more commonly used ammonium sulphate.

Phosphorus

On soils with a high phosphate fixation capacity the availability of phosphorus is often improved by the application of super phosphates in combination with farm yard manure or compost.

An application of 100 to 120 kg per hectare as phosphorus pentoxide ($P_2O_5$) is often used for plant cane and 140 kg per hectare of $P_2O_5$ on the ratoon crop.

A phosphate fertiliser containing calcium and magnesium would be useful for the soils of the project area. Basic slag and calcium-magnesium phosphate both contain several percent of magnesium. The more commonly utilised super phosphates contain between 20 and 30 per cent calcium oxide (CaO) but only about 0.5 per cent of magnesium oxide (MgO).

Ordinary super phosphate, although low in magnesium content, contains considerable quantities (25 to 30 per cent) of sulphate and since sulphur is likely to be deficient, the ordinary super phosphate is prefereable to the double or triple varieties available.

Potassium

The potash requirements of cane are high and, because of the low potash status of the soils, applications around 300 kg per hectare of potash ($K_2O$) are suggested. The potash should be added as the sulphate and not the chloride form in order to minimise release of aluminium into the soil solution.

Calcium

Soil acidity may be a limiting factor to the growth of cane in certain areas. Liming would decrease the soil acidity but may prove expensive although field trials should be instituted to ascertain the economic levels required for improved cane growth. Considerable quantities of calcium (as CaO) are contained in ordinary super phosphate fertiliser.

Magnesium

Magnesium is probably most suitably applied either with the phosphate fertiliser (basic slag or as calcium-magnesium phosphate) or as a mixed fertiliser with potassium (potassium-magnesium sulphate). Magnesium content of leaves is around 0.1 per cent which suggests than an application rate of 100 kg/hectare of MgO will be needed.

Sulphur

Sulphur should be applied in the sulphate form. Healthy cane leaves contain a minimum of 0.2 per cent of sulphur therefore at a production rate of 80 tons cane/hectare the soil depletion will be 160 kg/hectare of sulphur which is equivalent to 480 kg/hectare of sulphate.

Trace Elements

Zinc deficiency should be corrected by the application of 35 kg/hectare of zinc sulphate.

Summary

Optimum fertiliser applications need to be determined by agronomic field trials. Soil analysis only indicates the likely gross deficiencies and the most suitable guide for the fertilisation of sugar cane is foliar diagnosis.

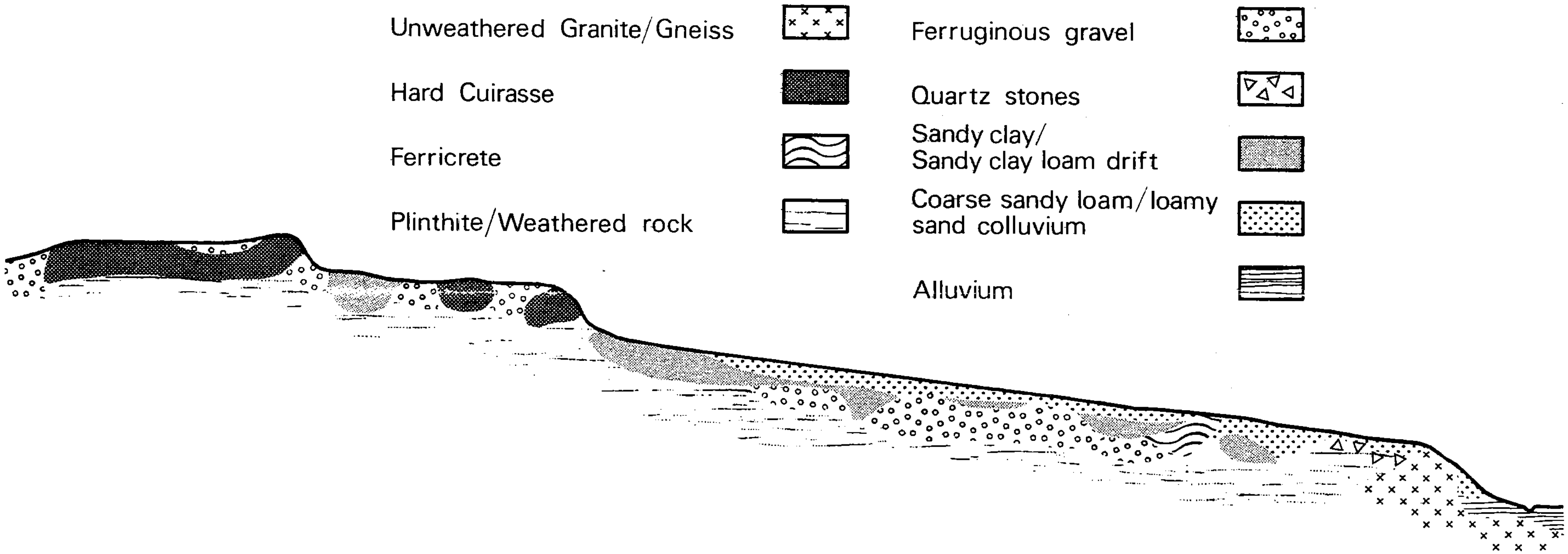
## 3.7 Soil Distribution and Mapping

The typical topographic situations of individual soil series are mentioned in Section 3.2.1 and typical toposequences are illustrated in Figures 3.2 and 3.3.

Figure 3.2 shows the relationship between parent material, soil and vegetation in a toposequence typical of the eastern or southern part of the project area. Soils of Series 2 and 3 are dominant on the two levels of cuirasse plateaux although Series 4 occurs in a pocket of sandy clay just below the upper scarp. A belt of Series 4 soils is also present on the upper connecting slope immediately below the lower scarp, and it is covered by a dense growth of vine forest. Going down the connecting slope, Series 4 soils give way to Series 6, which is the dominant connecting slope soil. The band of Series 6 soil is interrupted when the ferruginous gravel layer dips temporarily below 100 cm and is covered by sandy clay drift, giving rise to

# IDEALISED TOPOSEQUENCE IN A CUIRASSE DOMINATED AREA

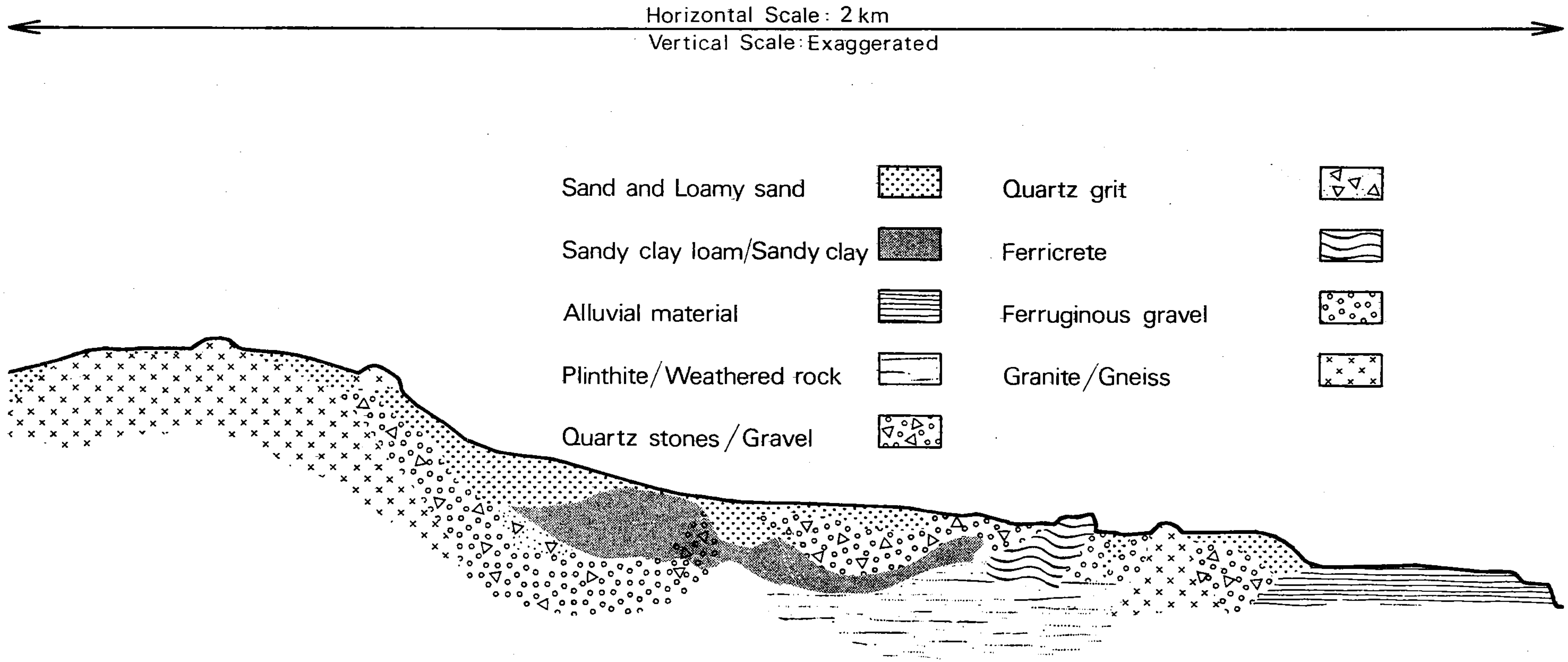
Horizontal Scale: 1km
Vertical Scale: Exaggerated




| Topographic Unit | PLATEAU | | | | | | | | Scarp | CONNECTING SLOPE | | | | | | | | | Lower Slope | | Valley Bottom |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower | UPPER | | | LOWER | | | | | UPPER | | MIDDLE | | LOWER | | | | | | | |
| Slope % | 1-5 | 0-2 | | 8-25 | 0-2 | | | | 8-30 | 1-5 | | | | | | | | | 4-8 | | 0-2 |
| Vegetation | Thicket Savanna | Grassland | Thicket Savanna | | Medium Woodland Savanna | | Grass-land | Thicket Savanna | | Vine Forest | Dense Woodland Savanna | | Thicket Savanna | | Open Savanna | | | | | | Riverain Forest |
| Soil Series | 3 | 2 | 3s | 2 | 4 | 3 | 2 | 3 | 2 | 4 | 6 | 4 | 6 | 7 | 2 | 7 | 10 | 9 | 1 | 9 | 11 |
| Parent Material | Cuirasse and Detrital Products | | | | Sandy Clay Drift | Cuirasse and Detrital Products | | | | Sandy Clay Drift | Colluvium derived from Granite/Gneiss and break up Cuirasse | | | | | | | Unweathered and partly weathered Granite/Gneiss | | | Alluvium |
| Land Class | IIIg | VIr | | | I | IIIg | VIr | IIIg | VIr | I | VI gt | II t | IIIg | VIg | IIIt | VIr | III t | VIt | VIdt | III dt | VIr | VIt | IVw |

Figure 3.2

# IDEALISED TOPOSEQUENCE IN A GRANITE/GNEISS DOMINATED AREA




| Topographic Unit | GRANITE DOME AND HIGH LEVEL OUTCROPS | | | | | CONNECTING SLOPE: UPPER | | | CONNECTING SLOPE: MIDDLE | | | | CONNECTING SLOPE: LOWER | | | | | BANDAMA TERRACES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slope % | 0 – > 15 | | | | | 1 – 5 | | | 1 – 5 | | | | 1 – 5 | | | | 4–8 | 0 – 1 |
| Vegetation | Grassland/Bare Rock | | Thicket Savanna | Grassland | Thicket Savanna | | Medium Wood-land Savanna | Thicket Savanna | | Dense Wood-land Savanna | | Thicket Savanna | | Grassland, Bare Rock | | Open Savanna | | Grassland |
| Soil Series | 8 | 1 | 8 | 1 | 8 | 7 | 4 | 9 | 7 | 6 | 4 | 6 | 2 | 8 | 1 | 9 | 10 | 12 |
| Parent Material | Unweathered and partly weathered Granite, Granitic Gneiss and Gneiss | | | | | Colluvium derived from Granite, Gneiss and Sandy Clay drift | | | Colluvium derived from Granite/Gneiss and break up Cuirasse and Sandy Clay drift | | | | | Unweathered and partly weathered Granite/Gneiss | | | Coll-uvium | Alluvium |
| Land Class | VI t | VI r | VI t | VI r | VI t | III t | II t | VI g | VI t / III tg | III g | II d | VI r | | VI t | VI r | VI d | VI t | III f |

BANDAMA RIVER

Figure 3.3

a thin band of Series 4. The Series 6 eventually grades to Series 7 when the gravels give way to a coarse and fine textured colluvium, and this abuts directly onto a band of indurated ferricrete which outcrops at the surface giving rise to a band of shallow Series 2 soils. Series 10 soils are developed in the coarse textured colluvium of the lower connecting slope. A small outcrop of granitic gneiss occurs at the upper boundary of the lower slope, giving rise to Series 9 soils both slightly upslope and on the downcut lower slope, and shallow Series 1 soils around the outcrop. These soils grade into alluvium and Series 11 soils in the valley bottom.

Figure 3.3 shows the relationship between parent material, soil and vegetation in an area dominated by granite or gneiss crested interfluves which are typical of the western part of the project area, bordering the Bandama river. The dome shaped summit consists of outcrops of granite with pockets of shallow Series 1 soils and sometimes deeper Series 8 soils where the quartz rich weathering products have been able to accumulate. The coarse textured material, with many quartz stones, continues down to the upper connecting slope, which is covered by a sandy clay drift formed during a much older weathering cycle. This fine drift results in finer textured soils of Series 7 and eventually Series 4. A broken residual quartz vein breaks the sequence producing a soil best classed as Series 9, although it lacks the partially weathered rock at shallow depth. On the middle connecting slope a layer of ferruginous gravels approaches the surface resulting in Series 6 soil, although this is interrupted by Series 7 and Series 4 when the gravel is replaced by colluvium. The lower connecting slope has outcrops of ferricrete and granitic gneiss, which produce shallow soils of Series 1 and 2 respectively. They are separated by a coarse textured colluvium forming Series 8. Downslope of the gneiss, Series 9 shallow soils are developed over partially weathered rock with a characteristic quartz stone line. These give way to coarser soils of Series 10 which are succeeded by the medium textured Series 12 soils developed in the alluvium of the terraces.

Although these two toposequences are fairly typical of certain parts of the project area, there is a lot of local variation, especially in soil type, so while one can make general statements such as 'Series 6 soils are the most common on connecting slopes' or 'Series 4 soils are most likely to occur on upper connecting slopes', one cannot necessarily predict the soil from the topographic position except in cases like terrace and valley bottom where the soil series definition is partially physiographic. The variation in soil type on connecting slopes is discussed in Section 3.8. The extent of soil variation was such that in the final mapping, most units were complexes of two or three series, rather than discrete series. Table 3.10 shows the soil series which occurred in association and were mapped as complexes.

TABLE 3.10 Soil Series Forming Complexes

| Soil Series and Phase | 1 | 2 | 3 | 3s | 4 | 4y | 5 | 6 | 6b | 6c | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | | | | | | | x | | x | x | x | x | x | | |
| 2 | | - | x | | | x | | x | | | | | x | | | |
| 3 | | x | - | x | | | | x | | | | | | | | |
| 3s | | | x | - | | | | | | | | | | | | |
| 4 | | | | | - | x | x | x | x | | x | | | | | |
| 4y | | x | | | x | - | x | x | x | x | x | x | | | | |
| 5 | | | | | x | x | - | x | | | x | | | | | |
| 6 | x | x | x | | x | x | x | - | | | x | x | x | x | | |
| 6b | | | | | x | x | | | - | | | | | | | |
| 6c | x | | | | | x | | | | - | x | x | x | x | | |
| 7 | x | | | | x | x | x | x | | x | - | x | x | x | | |
| 8 | x | | | | | x | | x | | x | x | - | x | x | | |
| 9 | x | x | | | | | | x | | x | x | x | - | x | | |
| 10 | x | | | | | | | x | | x | x | x | x | - | x | |
| 11 | | | | | | | | | | | | | | x | - | |
| 12 | | | | | | | | | | | | | | | | - |

x = complex mapped between two units.

Series 4 often occurs in association with Series 4y, 5, 6 and 6b in a complex typical of upper connecting slopes. Series 6c, 7, 8, 9 and 10 commonly occur as complexes on the lower connecting slopes and lower slopes and also in areas dominated by granite or gneiss. Series 6 may occur in complexes in any upland topographic position.

Sixty four units were finally mapped of which forty eight were complexes of two or three series. The total and percentage areas of each mapping unit are shown in Table 3.11. Areas were measured planimetrically.

TABLE 3.11 Soil Mapping Units: Gross and % Areas in Project Area

| Mapping Unit (Series or Complex) | Area hectare | Area percentage |
|---|---|---|
| 1 | 201 | 1.0 |
| x 1.5.10 | 128 | 0.6 |
| x 1.6c.7 | 60 | 0.3 |
| x 1.7.8 | 158 | 0.8 |
| x 1.7.9 | 129 | 0.6 |
| x 1.8 | 98 | 0.5 |
| 2 | 57 | 0.3 |
| x 2.3 | 1074 | 5.4 |
| x 2.3.6 | 652 | 3.3 |
| x 2.6 | 53 | 0.3 |
| 3 | 51 | 0.3 |
| x 3.3s | 138 | 0.7 |
| 4 | 267 | 1.3 |
| x 4.4y | 93 | 0.5 |
| x 4.5 | 86 | 0.4 |
| x 4.6 | 109 | 0.5 |
| x 4.6b | 88 | 0.4 |
| 4y | 639 | 3.2 |
| x 4y.5 | 368 | 1.9 |
| x 4y.6 | 148 | 0.7 |
| x 4y.7 | 53 | 0.3 |
| 5 | 210 | 1.1 |
| x 5.6 | 348 | 1.8 |
| 6 | 8303 | 41.8 |
| x 6.6b | 244 | 1.2 |
| x 6.8 | 163 | 0.8 |
| 6b | 361 | 1.8 |
| 6c | 73 | 0.4 |
| x 6c.7.10 | 103 | 0.5 |
| x 6c.8.9 | 123 | 0.6 |
| x 6c.8.10 | 56 | 0.3 |
| 7 | 367 | 1.9 |
| x 7.8 | 507 | 2.6 |
| x 7.10 | 164 | 0.8 |
| 8 | 723 | 3.6 |
| x 8.9.10 | 89 | 0.4 |
| x 8.10 | 278 | 1.4 |

continued....

TABLE 3.11 (continued)

| Mapping Unit (Series or Complexes) | Area hectare | percentage |
|---|---|---|
| 9 | 139 | 0.7 |
| 10 | 235 | 1.2 |
| 11 | 1706 | 8.6 |
| 12 | 537 | 2.7 |
| Rock outcrops | 64 | 0.3 |
| Minor Units (complexes <50 ha) | 411 | 2.1 |
| Total | 19,854 | 99.9 |

Table 3.11 shows that Series 6 is by far the dominant soil mapping unit, covering over 40 per cent of the project area and occurring mainly in connecting slope sites. Series 4, 4y, 5 and 6b all occur in significant amount and typify the upper connecting slope soils, which generally have high land suitability ratings. Complexes of Series 2, 3 and 6, occupying over 8 per cent of the project area, are typical of plateau sites and cuirasse outcrops. Series 8 and 10, and their complexes with Series 1, 7 and 9, occupying about 10 per cent of the project area, typify the poorer soils of lower slopes. Hydromorphic soils of Series 11 cover 8.6 per cent of the area surveyed, and the alluvial terrace soils of Series 12 cover 2.7 per cent.

## 3.8 Soil Variability

Figures 3.2 and 3.3 give an impression of the extreme variability of soil types, particularly on the connecting slopes. Local variability resulted in a large number of units being mapped as complexes, and even within one unit soil types may occur as minor constituents which are not indicated in the unit annotation on the final map. The level of purity of mapping units was not always high because of this variation, but the situation is typical of this part of West Africa, where soils have experienced a number of cycles of weathering and erosion (Section 3.1) resulting in local sites of erosion and deposition within a single unit of the present day landscape. Disturbance by treefall and insect activity is also instrumental in redistributing gravel layers and bringing subsoil material to the surface.

In order to obtain a measure of soil variability and hence purity of final mapping units on the connecting slope, two profile pits were chosen, one on the middle connecting slope and one on the lower connecting slope, and a total of 27 bores were augered within a 100 x 200 m grid around each pit. Both pits were in Series 6, the most common connecting slope soils, which is characterised by a layer of ferruginous gravels. The depth to the upper boundary of the gravel layer (with 50 per cent or more gravels) is plotted for both sites in Figure 3.4.

During a routine survey, the probability of an auger boring being made in any such area measuring 100 x 200 m is only 0.5, assuming an overall survey density of 1 bore every 4 hectares. In the two blocks illustrated, pits 7 and 21 give a reasonable representation of the dominant soil type of the blocks, but in both cases the depth to gravel layer varies from less than 15 cm to more than 85 cm over a very short distance, and the soil series vary from 6, through 6b, to 4. The implications of this variation in the resulting land suitability classification are discussed in Section 4.6.

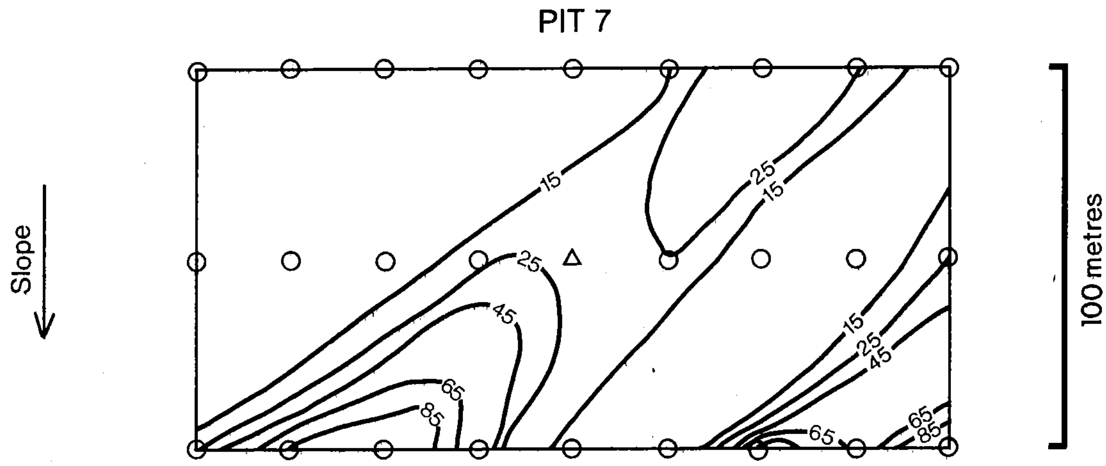
In addition to the two grid surveys described above, soil sequences were observed on open drain lines on connecting slope sites on the Sodesucre sugar cane plantation, which is adjacent to the project area, to the north of the Waha river. Two variability sequences were examined and both showed sharp changes in the depth of the gravel layer which were unrelated to any variation in the slope. The results of one of these variability trials are illustrated in Figure 3.5, which shows the change from a soil which is extremely gravelly (more than 75 per cent gravels) to the surface, to a soil with only a few gravels in ths subsoil, in the space of 20 m. This sequence is sometimes repeated several times on the connecting slope.

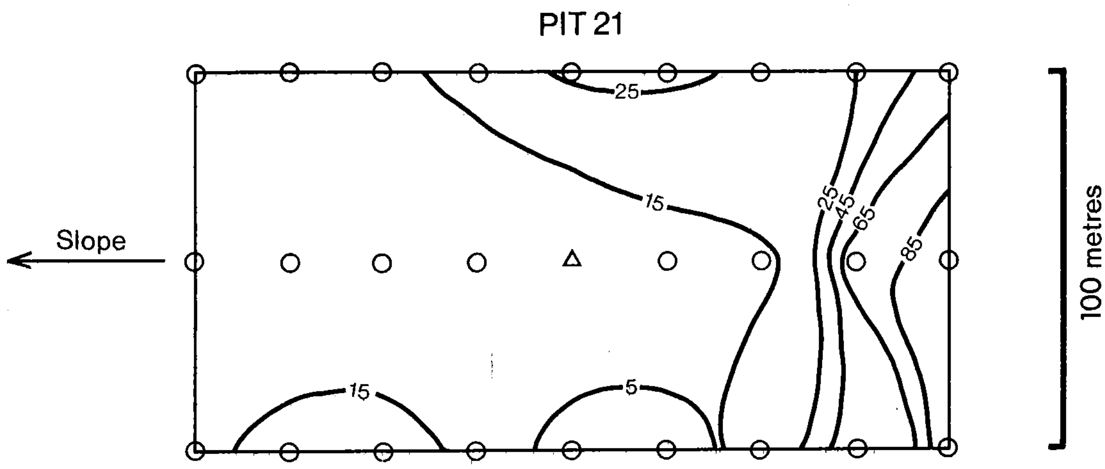
From the studies conducted on soil variability one could conclude that soil mapping units will rarely be homogenous, and that a certain percentage of observations will be unrepresentative. It must be borne in mind, however, that these studies were carried out on areas where the ferruginous gravel soils of Series 6 were dominant and these are the most subject to

# VARIATION IN DEPTH TO GRAVEL LAYER

Scale 1:2000

Auger bores ○
Pits △
Contours represent depth in cm to layer with over 50% gravel



# SOIL VARIABILITY TRIAL

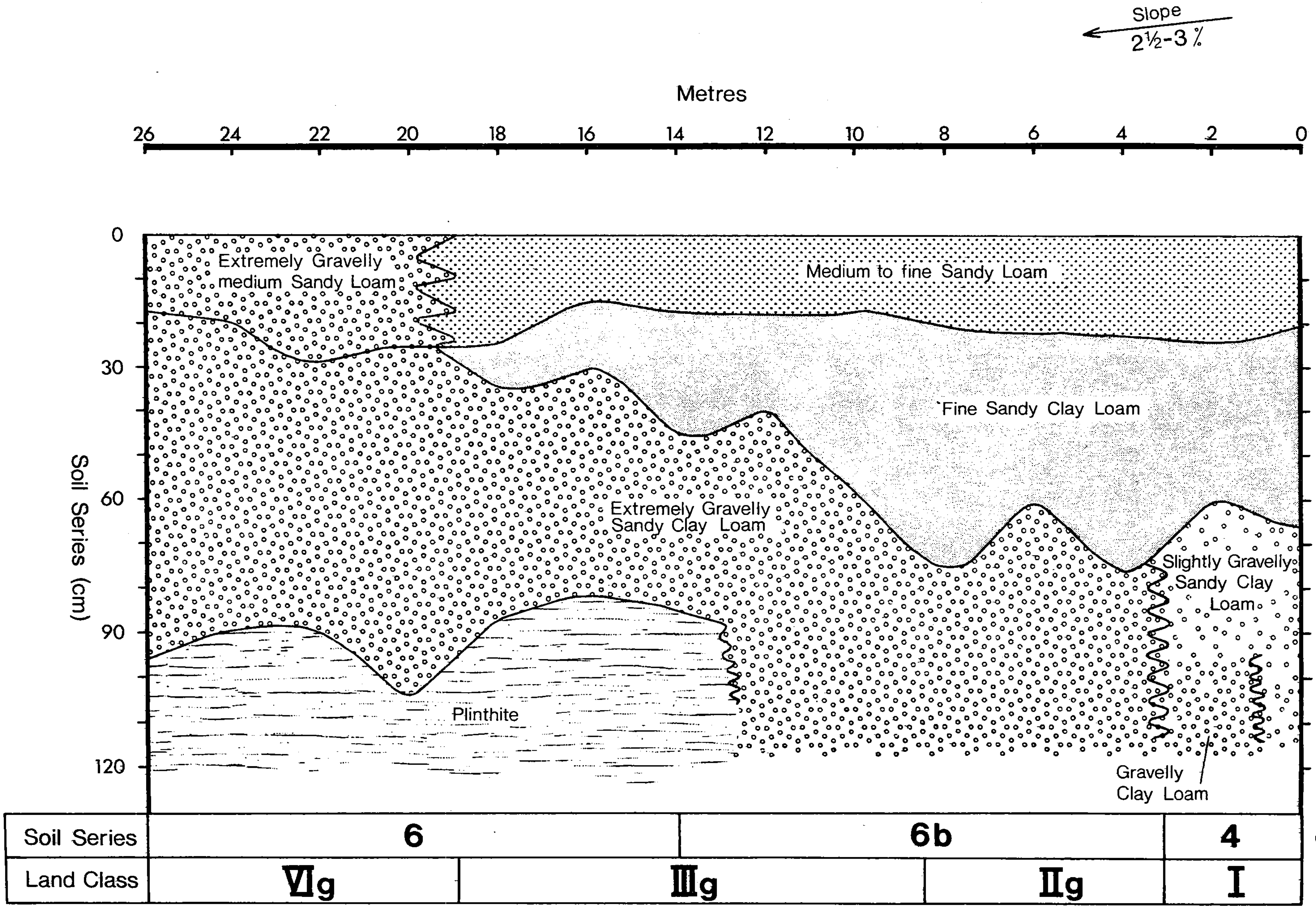



Figure 3.5

variations likely to affect suitability for cane production. Other areas, such as upper connecting slopes underlain by sandy clay drift, and coarse textured colluvial areas are not considered to show the same degree of variability. Errors due to unrepresentativeness of point observations are reduced when certain units are mapped as complexes, and because the soil classification is related to the topography and geomorphology, odd observations which occur in unexpected circumstances can be interpreted in relation to their position in the topographic sequence. Although attempts have been made to reduce errors in mapping units to a minimum, a high degree of variability does exist in some units and this variability must be taken into account when the units are laid out for irrigation.

# CHAPTER 4

# LAND SUITABILITY FOR SUGAR CANE

## 4.1 General Principles

The land suitability classification used has been developed with particular reference to sustained cultivation of sugar cane under project conditions. The classes are defined on the assumption that a high level of management, including an extensive fertiliser program and a thorough soil conservation plan, is inherent to project development. The criteria used to define land suitability classes are selected and evaluated strictly with project conditions in mind, and the land suitability classes are really potential classes under the proposed level of management.

## 4.2 Criteria for Land Suitability Definition

The criteria used for definition of soil units were stable properties of the soil or site, which would not be easily modified by ameliorative practices during the establishment of the plantation. All these properties were readily recognisable from routine auger observations. The major criteria used were effective soil depth, gravel content, texture, percentage surface cover by outcrop and boulders, and flood hazard. In one or two specific areas, moderate to severe gullying due to erosion was also a major limiting factor. Minor criteria are slope and drainage. The importance and limiting values of these criteria are discussed below.

### 4.2.1 Effective Soil Depth

The depth of soil that can be effectively exploited by plant roots is a critical factor in determining suitability for all crops. In the project area, as in many areas of the humid and subhumid tropics, this physiological rooting depth often differs from the depth of the 'solum', because horizons limiting to soil depth may be composed of soil derived materials, such as cuirasse, and some materials still recognisable as weathered rock may allow adequate penetration by roots. In this survey the effective depth was measured on the basis of penetrability by a 10 cm Jarrett auger. The validity of this estimate was often confirmed by observations of roots in soil pits, and the only circumstances when estimates are unlikely to be borne out are when a thin but dense stoneline impedes the auger but allows passage of the roots. Such occurrences are considered rare, and augerings were duplicated if the initial bore was stopped at less than 60 cm. The correlation between augerable depth and physiological rooting depth is thus a valid one. It must be added that the soil survey was done in the months June to October when the soils were relatively moist and that augerability may be reduced as the soils dry out. A dry season soil survey may have to operate with slightly altered criteria.

Soil depth, as well as being important as a medium for normal root growth and development, also has a direct bearing on available water capacity, total pore space and total nutrient holding capacity, as well as influencing infiltration rate. These properties are also influenced by the gravel content and texture and are discussed in Section 4.2.8.

The nature of the horizon limiting to soil depth is relevant to the definition of suitability classes because minimum suitable soil depths are shallower if the limiting horizon is permeable and there is no waterlogging hazard. The limiting horizons and their estimated permeabilities are listed below.

| Limiting Horizon | Permeability |
| --- | --- |
| Cuirasse | Impermeable |
| Indurated Ferricrete (Secondary Cuirasse) | Very slowly permeable |
| Indurated Plinthite | Very slowly permeable |
| Unweathered rock | Impermeable |
| Partially weathered rock (stony) | Permeable |
| Extremely gravelly or stony layer | Permeable |
| Quartz stone line | Permeable |

If the limiting horizon is permeable the minimum depth for a suitable soil is 30 cm, assuming adequate texture and low gravel content. Adequate cane yields can be expected from 30 cm of good soil provided it is carefully managed to minimise further soil losses.

For a very slowly permeable or impermeable limiting horizon the minimum depth is 50 cm. This depth is considered sufficient to sustain cane yields without danger of waterlogging provided that the soils are medium textured or coarser.

75 cm and 50 cm are taken as the absolute minimum depths for Class I and Class II respectively. These depths must be related to other factors in defining the land class, as discussed in Section 4.2.8.

### 4.2.2 Gravel Content

The majority of soils in the project area contain varying amounts of gravels and stones, which are either ferruginous or quartzose in nature. These gravels and stones may occur throughout the profile or in a specific horizon. Soil gravel contents were estimated and put into one of the following four categories:-

| Categories | Gravel Content | |
|---|---|---|
| Non or slightly gravelly | None to few | 0 - 25 |
| Gravelly | Common | 25 - 50 |
| Very gravelly | Many | 50 - 75 |
| Extremely gravelly | Very many | 75 -100 |

Although a little gravel within the soil can be considered beneficial for the improvement of structure and profile drainage, the main effect of gravel and stones is to reduce the volume of soil that can be effectively exploited by plant roots and, in the case of a dense stone or gravelly layer, to restrict root penetration. A high content of stones or gravel at or near the surface may also result in damage to or extensive wear on agricultural machinery.

The available water capacity and potential nutrient holding capacity will be reduced in a stony or gravelly soil. The effect of gravel content on minimum effective depth is discussed in Section 4.2.8. When a stony or gravelly horizon is so dense that it is not augerable it constitutes a limiting horizon to effective soil depth, but some extremely gravelly horizons could be penetrated by auger. In this case the limiting depths and thicknesses for each land class are defined in Table 4.3.

Problems of compaction of dense gravel layers should be at least partially alleviated by the proposed ripping to 50 cm by a D8 tractor prior to planting of the cane. For land suitability Classes I and II extremely gravelly layers are excluded unless they occur below the minimum permissible depth of a soil eligible for Class I or II allocation (i.e. 75 cm or 50 cm respectively). Limitations due to stone or gravel content are denoted 'g' in the classification.

### 4.2.3 Texture

Texture is very important factor in determining land suitability because of its effect on soil structure, drainage, available water capacity, cation exchange capacity, infiltration rate and erodibility. It is also a prime factor in determining susceptibility to attack by nematodes.

The ideal texture is probably a clay loam or sandy clay loam, provided it is friable and of good structure. Textures of sandy clay loam are very common in the project area, especially in the subsoil, although topsoils are usually coarser.

Heavy clay soils are virtually absent from the project area therefore no restriction was placed on clay content in the determination of the suitability classes.

Although soils as light as loamy sand could be expected to give adequate cane yields initially under project conditions, the possibility of nematode buildup is considered limiting and soils with a dominant texture of coarse sandy loam or coarser in the top 100 cm are excluded for this reason. Coarse textured soils are often pale coloured and may be highly leached. This could lead to problems in the retention of nutrients after fertiliser application.

Many of the soils have a coarse sandy loam or loamy sand topsoil about 10 to 15 cm thick. This has to be accepted although soils with a loamy sand topsoil cannot be placed in suitability Class I. Class I and II soils are also required to reach a texture of sandy clay loam or finer by 30 cm depth. Soils which do not satisy these criteria are placed in subclasses denoted by 't' indicating a textural limitation.

### 4.2.4 Surface Cover by Boulders and Outcrops

Outcrops and boulders of cuirasse and granitic gneiss occur locally throughout the project area. Cuirasse is most common on the 'plateau' geomorphic unit, particularly near the plateau edges and on the scarps. Outcrops of parent rock, mainly granite in various states of metamorphosis, are most common in the western part of the project area.

The limitations of outcrops and boulders are obvious on a plantation type of development. They will reduce the amount of soil in a plantation unit and if their irrigation cannot be avoided, valuable water will be lost. They are also a considerable hazard to agricultural machinery and expensive damage could result.

A surface cover of 10 per cent outcrop and boulders is considered severely limiting, and soils with more than 10 per cent cover are considered unsuitable. Land must have less than 5 per cent cover to qualify for Class II and outcrops and boulders must be virtually absent in Class I. These figures are based purely on visual estimates made during the course of field work.

A subscript 'p' is used to indicate a limitation due to surface boulders and outcrops.

#### 4.2.5 Flood Hazard

A relatively small percentage of land in the project area is susceptible to flooding. The valley bottoms of small stream were often flooded in August and September, as were many parts of the Bandama terraces. When the level of the Bandama river rises after construction of the barrage the risk of inundation is likely to be increased slightly and the lower Bandama terraces are excluded for this reason. The upper terrace, which often has promising soils is provisionally included, with a subscript 'f' indicating inundation hazard. Further information should be obtained on the proposed maximum flood level of the Bandama before these soils are included in the plantation layout.

#### 4.2.6 Slope

For a sprinkler irrigation system, slope is of reduced importance in the determination of land suitability.

Slope is an important factor in determining erodibility and sheet, rill and gully erosion were observed on fairly moderate slopes (less than 5 per cent) in the project area. The suitability classification, however, assumes that adequate soil conservation measures will be incorporated into plantation development and only relatively severely gullied areas were excluded on erosion grounds.

Apart from scarps on the edge of cuirasse plateaux which may have slopes of over 25 per cent and a few downcut lower slope bounding valley bottoms, slopes rarely exceed 6 per cent in the area surveyed. Scarp slopes are often excluded for other reasons, such as surface boulders or outcrops, but the area covered by the scarp is often too narrow to constitute a mappable unit at the mapping scale used.

No absolute limit is placed on slope as it is felt that small areas of scarp, which are otherwise suitable, could be incorporated into irrigated cane units without substantial losses. For Class I and Class II land, the maximum allowed slope is 5 per cent. Slopes over 5 per cent will have a greater erosion risk and may require careful management, particularly if topsoils are very light. These steeper slopes are not extensive, however and did not constitute mappable units.

### 4.2.7 Drainage

Drainage is not considered by itself a major limiting factor, although many poorly drained soils are subject to flooding hazard, or have textures too coarse to be classified as suitable. Poorly or imperfectly drained soils with adequately fine texture (dominant texture sandy loam or finer) are put into a special Class IVw. Soils with only slightly imperfect drainage may be classed as IIw or IIIw. Small areas of this land could be used to complete an irrigation unit although further investigations may have to be carried out on the soils first. On the other hand, the amount of land falling into this category is probably too small to economically justify further investigations.

### 4.2.8 Erosion Gullying

In a few localities in the project area, generally on the steeper lower connecting slopes and lower slopes, moderate to severe erosion gullies were observed, giving rise to an unfavourable microtopography and a high risk of further erosion if cultivation is implemented.Gullies were occasionally 10 m deep, and were considered a serious limitation when over 10 per cent of the land surface was covered by gullies more than one metre deep. This gullying only occurred in a few localities, where it was well marked. It was not considered an important limiting factor at a minor level in other areas.

### 4.2.9 Criteria Interelationship

The interdependence of the various criteria in determining land suitability classes must be stressed. For example, the minimum effective depths mentioned in Section 4.2.1 assume a gravel content of less than 25 per cent. If the gravel content is greater than 25 per cent the effective soil volume per unit depth will be reduced and the minimum depth must be increased. If the dominant texture is sandy loam rather than sandy clay loam the water holding capacity will be lower and minimum acceptable depths have again to be increased to compensate. The relationship between these three factors in determining land class is shown in Table 4.1.

TABLE 4.1 The Relationship between Effective Depth, Texture and Gravel Content in Determining Land Suitability Class

1. Texture SCL or finer

| Gravel content / Depth | % 0-25 | % 25-50 | % 50-75 | % 75-100 |
|---|---|---|---|---|
| 0- 30 | VId | VId | VIdg | VIdg |
| 30- 50 | IIId | VId | VIdg | VIdg |
| 50- 75 | IId | IIId | VIg | VIg |
| 75-100 | I | I | IIIg | VIg |

2. Texture SL

| Gravel content / Depth | % 0.25 | % 25-50 | % 50-75 | % 75-100 |
|---|---|---|---|---|
| 0- 30 | VIdt | VIdt | VIdtg | VIdtg |
| 30- 50 | VIdt | VIdt | VIdtg | VIdtg |
| 50- 75 | IIIt | IIIt | VItg | VItg |
| 75-100 | IIIt | IIIt | VItg | VItg |

Subscripts: d = effective depth
or r if limiting horizon is impermeable
t = texture
g = gravel content

The effective soil volume is a more critical factor than the effective depth and the above classes have been allocated so as to ensure that soil selected for development has an adequate water and nutrient holding capacity.

Under the proposed irrigation scheme a gross application of 70 mm of water will be made every eight days. It is estimated that 56 mm of this will be utilised by the plant, and it is important that the soil can absorb this amount of water and drain off any water in excess of field capacity. Using the estimates of Salter and Williams (1967) as a rough guide and assuming a surface texture in the range coarse sandy loam to sandy clay loam the calculated available water capacity (AWC) of 30 cm of soil is only 42 mm. For this reason a soil of this depth is only classed as suitable if the horizon limiting to soil depth is permeable to water, so that excess water can be drained off through the soil, avoiding waterlogging or run off and associated erosion problems. This means that 30 cm of soil over cuirasse or hard rock is unsuitable because either one or both of these problems may occur. The Salter and Williams estimate for the AWC of 50 cm of soil is

70 mm. After making allowance for dilution by a little gravel (not more than 25 per cent), this soil depth is just adequate to cope with irrigation water applications.

Soils with a limitation in effective soil volume, unless they are very well drained, are likely to be very susceptible to run off and/or waterlogging during the rainy season when falls of over 100 mm in one day are not unusual. Extra care must be given to implement soil conservation measures when using these soils or soil loss will result. Soils in the depth range 30-60 cm are considered fairly marginal anyway and a comparatively small further soil loss would render them unsuitable.

#### 4.2.10 Chemical Factors

Chemical criteria were not used in the definition of land suitability classes because an overall low level of fertility of the soils was assumed. It was also assumed that, where texture was adequate, this deficiency would be ameliorated by the application of fertilisers.

### 4.3 Definition of Limitations

As shown in Table 4.2 subscripts are used to indicate specific limitations. These are used to define subclasses in the suitability units. The subscripts used are listed below:-

| | |
|---|---|
| d | effective depth (with permeable limiting horizon) |
| r | effective depth (with impermeable limiting horizon) |
| g | gravel or stone content |
| t | texture |
| p | surface boulders and outcrops |
| f | risk of flooding |
| s | slope |
| w | soil drainage |
| e | erosion gullying |

The values of each factor that can be considered as constituting a limitation are summarised in Table 4.2.

TABLE 4.2 Limiting Values of Land Suitability Criteria

| Subscript | Minor limitation Class II and III | Major limitation Class VI |
|---|---|---|
| d | < 75 cm soil | < 30 cm soil |
| r | < 75 cm soil | < 50 cm soil |
| g | (i) Any very gravelly soil (50-75%) with an upper boundary within 75 cm surface layer. | An extremely gravelly layer with an upper boundary within 30 cm of the surface, < 20 cm thick. |
| | (ii) Any extremely gravelly layer. | An extremely gravelly layer with an upper boundary below 30 cm depth, more than 40 cm thick, unless soil above the layer qualifies for a suitable class. |
| t | (i) More than 5 cm of loamy sand. | A dominant texture of coarse sandy loam or coarser in the top 100 cm. |
| | (ii) More than 15 cm of coarse sandy loam or more than 30 cm of medium or fine sandy loam at the soil surface. | |
| p | More than 1 per cent outcrop and boulders on the land surface. | More than 10 per cent outcrop and boulders on the land surface. |
| f | Risk of inundation for one or two weeks per year. | Risk of inundation for periods longer than 2 weeks per year. |
| s | More than 5 per cent slope. | No limitation |
| w | Drainage slightly imperfect to poor. | No limitation, unless water table is permanently above 100 cm. |
| e | - | Gullies > 1 m deep. |

### 4.4 Definition of Classes and Subclasses

Classes are grouped according to the number and severity of the limitations outlined in Section 4.3. Subclasses are defined by the specific limiting factors.

Classes and subclasses are defined in Table 4.3.

TABLE 4.3 Definition of Classes and Subclasses

| Class | Subclasses | Definition |
|---|---|---|
| I | | Effective depth more than 75 cm, if gravel content is 0-25 per cent. |
| Excellent for cane | | Effective depth more than 100 cm if gravel content is 25-50 per cent. |
| | | No very gravelly (50-75%) layer within 75 cm of soil surface. |
| | | No extremely gravelly (> 75%) layer. |
| | | Topsoil texture sandy loam or finer ( 5 cm of loamy sand is not limiting). Only 15 cm of coarse sandy loam is allowed. |
| | | Subsoil texture sandy clay loam of finer, commencing by 30 cm. |
| | | Less than 1 per cent surface boulders and outcrops. |
| | | No hazard of flooding. |
| | | Slopes less than 5 per cent. |
| | | No drainage restriction, no toxic chemicals. Good infiltration characteristics. |
| II | | Effective depth more than 50 cm if gravel content is 0-25%. |
| Good for cane | | Effective depth more than 75 cm if gravel content is 25-50 per cent. |
| | | No very gravelly (50-75%) layer within 50 cm of surface. |
| | | No extremely gravelly layer. |
| | | Topsoil texture loamy sand or finer. |
| | | Subsoil texture sandy clay loam or finer commencing by 30 cm. |
| | | Less than 1 per cent surface boulders and outcrops. |
| | | No hazard of flooding. |
| | | Slope less than 5 per cent. |
| | II r or d | Effective depth 50-75 cm if gravel content is 0-25 per cent. or effective depth 75-100 cm if gravel content is 25-50 per cent. |
| | IIg | Very gravelly layer, with an upper boundary between 50 and 75 cm depth. |
| | IIt | More than 5 cm of loamy sand at the surface, but reaching SCL or finer by 30 cm depth, slope or drainage as defined in Table 4.2 are allowed on Class II land. |
| | IIw | Slightly imperfect drainage. |

continued....

TABLE 4.3 (continued)

| Class | Subclasses | Definition |
|---|---|---|
| III Moderate for cane | | Land without major limitations, but failing by the nature, number or degree of its major limitations to qualify for a higher suitability class. |
| | IIIr or d | Effective depth 30-50 cm if limiting horizon is permeable and gravel content is 0-25 per cent, or effective depth 50-75 cm if gravel content is 25-50 per cent. |
| | IIIg | Very gravelly (50-75%) layer, commencing within 50 cm of soil surface.<br>or extremely gravelly layer (> 75%) commencing within 30 cm of soil surface, less than 20 cm thick.<br>or extremely gravelly layer (>75%) commencing deeper than 30 cm, and <40 cm thick.<br>or extremely gravelly layer commencing deeper than 30 cm more than 40 cm thick if the soil above the layer satisfies criteria of suitability. |
| | IIIt | Dominant texture sandy loam<br>or more than 30 cm of sandy loam ot loamy sand at soil surface, assuming the dominant texture of the top 100 cm is finer than coarse sandy loam. |
| | IIIp | 1-10 per cent surface cover by boulder and outcrop. |
| | IIIf | Risk of inundation for one or two weeks per year. |
| | IIIs | Slope more than 5 per cent. |
| | IIIw | Drainage slightly imperfect, with other limitations. |
| | IIIdg, IIIts, ) IIItsp ) | Any combination of limitations is allowed up to a maximum of three. |
| IV special | IVw | Drainage imperfect to poor, if water table is not permanently less than 100 cm from surface.<br>Must satisfy the requirements of Class III land. |
| VI unsuitable | Any number and combination of subscripts e.g. VIdt, VItspf etc. | Any major limitation as defined in Table 4.2 and/or more than three minor limitations and/or a water table less than 100 cm from surface throughout the year. |

## 4.5 Relationship between Soil Series and Land Class

Land suitability mapping was carried out with reference to the soil maps and the soil and land class often share common boundaries. The relationship between soil series and land suitability Class is illustrated in Table 4.4.

TABLE 4.4 Relationship between Soil Series and Land Class

| Soil Series and phase | Usual Land Class and Subclass. | Range of Land Classes |
|---|---|---|
| 1 | VIr | VI |
| 2 | VIr | VI |
| 3 | IIIg | II - VI |
| 3s | VIt | VI |
| 4 | I | I - III |
| 4y | IIt | I - III |
| 5 | IIg | I - III |
| 6 | IIIg | II - VI |
| 6b | IIg | I - VI |
| 6c | VItg | VI |
| 7 | IIIt | III - VI |
| 8 | VIt | VI |
| 9 | VId | III - VI |
| 10 | VIt | VI |
| 11 | IVw | IVw - VI |
| 12 | IIIf | III - VI |

From the table, one can conclude that the best land for cane production is associated with soil series 4, 4y, 5 and 6b, and that any land with soil series 1, 2, 3s, 6c, 8 or 10 dominant is automatically placed in suitability Class VI.

## 4.6 Distribution and Mapping of Land Suitability Classes

The variation of land suitability classes along typical toposequences is illustrated in Figures 3.2 and 3.3 from which it can be observed that most of the suitable land occurs on the upper to middle connecting slopes. Discontinuous strips also occur, however, on the plateaux, lower connecting slopes and lower slopes. Class I land is most commonly found on the upper connecting slopes, directly below the scarps. Suitable land is also found on the terraces.

Considerable variation in land suitability class can be noticed going down both sequences. This reflects local changes in soil type and is typical of the project area. Such local variation, in the same way as the soil mapping, leads to irregular boundaries between land class units and makes the exclusion of unsuitable land from irrigation blocks very difficult.

In order to obtain a more quantitative estimate of short range variability of land suitability, land classes were assigned to the soil bores made in the soil variability study described in Section 3.8. The results were mapped and are illustrated in Figure 4.1.

Both series of observation show considerable variation within the studied areas of two hectares. In one case the land suitability varies from Class I to Class VI and in the other case from Class II to Class VI. Pit 7 is representative of the soils of the surrounding two hectares but Pit 21 is not.

It is very important that the extent of local variability of soils and hence of land suitability is borne in mind when blocks of cane are irrigated. It is probable that small unmappable areas of Class VI land may occur within units mapped as suitable, and these areas may only support restricted cane growth. Variation is most marked in the gravelly soils of the connecting slopes (Series 6), where dense gravel layers may occur at very different depths within a horizontal distance of only a few metres (see Section 3.6).

Table 4.5 shows the land suitability units, consisting of classes and subclasses, which were mapped, and their relative proportions in the project area. Areas were measured planimetrically from the final land suitability maps.

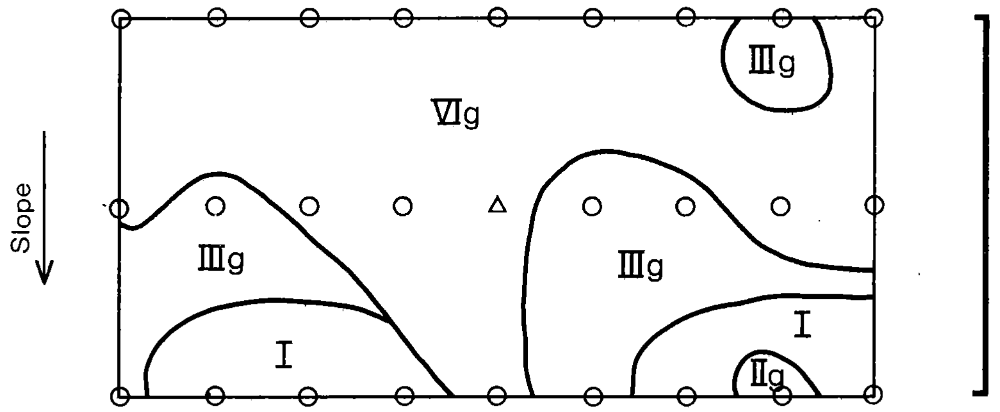
Table 4.5 shows that approximately 10,900 hectares of land in the project area has been classified as suitable. Allowing for irregular boundaries and impurities in mapping due to soil heterogenity, the amount of suitable land is sufficient for the proposed plantation development to be viable. If Class VI land has to be taken in to square off plantation blocks, it is recommended that Class VI land with the relatively more severe limitations due to solid rock on cuirasse at shallow depth (subscript r), surface cover by outcrops or boulders (subscript p) or gully erosion resulting in unfavourable topography (subscript e), be avoided.

# VARIABILITY IN LAND SUITABILITY CLASS

Scale 1:2000

Auger bores ○
Pits △

PIT 7




PIT 21

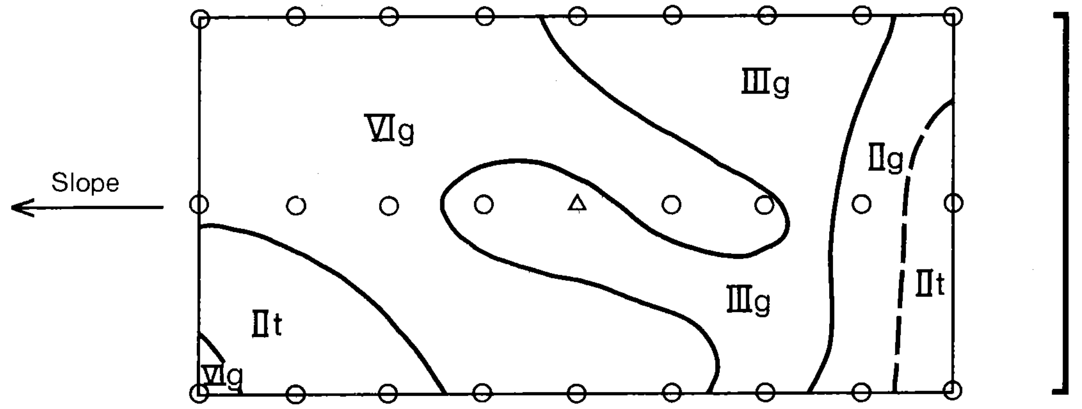


TABLE 4.5 Land Suitability: Mapping Units

| Unit (Land Class and Subclass) | Area hectare | | Project Area percentage | |
|---|---|---|---|---|
| I | | 1557 | | 7.7 |
| I-IIg | | 105 | | 0.5 |
| IIg | 383 | | 1.9 | |
| IIt | 893 | | 4.4 | |
| IIrt | 57 | | 0.3 | |
| IIdt | 97 | | 0.5 | |
| IIgt | 104 | | 0.5 | |
| Total II | | 1534 | | 7.6 |
| IIg-IIIg | | 71 | | |
| IIIg | 6281 | | 31.1 | |
| IIIt | 323 | | 1.6 | |
| IIIf | 345 | | 1.7 | |
| IIIgt | 102 | | 0.5 | |
| IIIgp | 169 | | 0.8 | |
| Total III | | 7220 | | 35.7 |
| IVw | | 154 | | 0.8 |
| Minor Units (<50 ha) Suitable: | | 270 | | 1.3 |
| Total Suitable Land: | | 10,911 | | 53.6 |
| VIr | 643 | | 3.2 | |
| VIg | 795 | | 3.9 | |
| VIt | 1168 | | 5.8 | |
| VIrg | 1860 | | 9.2 | |
| VIrt | 1347 | | 6.7 | |
| VIdt | 60 | | 0.3 | |
| VIdg | 130 | | 0.6 | |
| VIgt | 1159 | | 5.7 | |
| VIgp | 416 | | 2.1 | |
| VItw | 1239 | | 6.1 | |
| VIrgt | 284 | | 1.4 | |
| VIrtw | 74 | | 0.4 | |
| VIdgt | 55 | | 0.3 | |
| VItfw | 230 | | 1.1 | |
| VIgtw | 122 | | 0.6 | |
| Minor Units with r,p,or e subscripts | 135 | | 0.7 | |
| Minor Units without r,p, or e subscripts | 28 | | 0.1 | |

continued....

TABLE 4.5 (continued)

| Unit (Land Class subclasses) | Area hectare | Project Area percentage |
|---|---|---|
| Total VI with r,p or e subscripts | 4759 | 23.6 |
| Total VI without r,p or e sub- script | 4986 | 24.7 |
| Total Unsuitable Land | 9745 | 48.3 |
| Total | 20,656 | 101.9 |

4.7 Summary

The most extensive areas of suitable land are situated north of the Fahalogo river, although these areas are much dissected by Class VI land resulting from cuirasse plateaux (VIrg), granite outcrpps with resulting coarse textured soils (VIrt),and streams with associated coarse textured soils and/or eroded lower slopes (VItw, VIg, VIrgt).

Between the Fahalogo and the Korhogo - Badikaha road the plateaux are more extensive, and the areas affected by stripping are wider, giving rise to a more fragmented pattern of suitable land and consequently making irrigation blocks more difficult to lay out.

Between the road and the Farakwo river a smaller percentage of land is excluded on the cuirasse plateaux, but the area is dissected by valleys with broad lower slopes of coarse textured colluvium, (VItw, VIgt, VIg, VIt), especially in the area fringing the Bandama in the west of the project area.

Throughout the project area layout of irrigation blocks on areas of suitable land is hindered by irregular boundaries and fragments of Class VI land interrupting units that would otherwise be utilisable.

Although VIr, VIp and VIe land should preferably be avoided as the subscripts indicate relatively very severe limitations (solid rock or cuirasse at shallow depth, surface outcrops and unfavourable topography resulting from erosion gullying), small areas of VId, VIg and VIt land could be taken in to round off irrigation blocks if necessary. Some depression of yields however, could be expected.

Suitable land is at a premium, therefore it is important to plan irrigation blocks to maximise the potential of good land, even if it involves taking in a few small areas which are unsuitable. This is the only way the cane growing potential of the area can be fully exploited.

## GLOSSARY

Acrisol (FAO/UNESCO, 1970) - A soil having an argillic horizon with a base saturation of less than 50 per cent.

Argillic Horizon (USDA, 1960) - A horizon containing a significant amount of clay transported from upper horizons by illuviation, The presence of clay cutans on pores and ped faces is a diagnostic feature.

Arkosic Schist - A foliated metamorphic rock rich in sand sized grains of quartz and feldspars originally resulting from the weathering of granite.

Available Water Capacity - The amount of water held by the soil in a form available to the plant. This corresponds to the amount of water held between the Field Capacity and the Permanent Wilting Point.

Base Saturation - The degree of saturation of the soil exchange complex by basic metallic cations.

Boulders - Large stones of greater than 25 cm diameter.

Cation Exchange Capacity - The total amount of exchangeable cations that can be retained on the soil exchange complex.

Colluvium - Material formed from weathering of rocks which moves downslope under the influence of gravity, and accumulates near the base of the slope.

Complex, Soil - A mapping unit comprising two or more Soil Series which occur in a complicated pattern and cannot be mapped separately at the scale used.

Concretions - Granules or nodules of various sizes, shapes and colours formed from local concentrations of material within the soil, and associated with hardening. Iron oxides are common constituents of these concretions.

Cuirasse - A sheet of indurated material formed by accumulation and irreversible hardening of iron oxides.

Cutan - A thin layer of clay coating the surface of soil aggregate or pores.

Drainage, Soil - Also called internal drainage. The rate at which water percolates through the soil and the frequency and duration of any periods of waterlogging. Can often be assessed from soil colour.

Erosion, Soil - Breakup and removal of material from the land surface by the action of wind or water, usually resulting in irregular topography.

Exchange Complex, Soil - The sites associated mainly with clay or organic matter on which soil cations and anions are held.

Ferricrete - Compact semi indurated material containing iron oxide concretions. Often found in the subsoil on lower slopes where fluctuating water tables are encountered.

Ferruginous Gravel - Hard gravel rich in iron oxides. Often rounded, in which case it is termed 'Pisolitic Gravel'.

Fertility - The capacity of the soil to supply mineral nutrients for plant growth.

Field Capacity - Soil water content after saturation and drainage of free water.

Flood Plain - Land with low relief, composed of river alluvium and subject to seasonal flooding and deposition of alluvium unless artificial protection measures are implemented.

Gneiss - A coarse grained banded metamorphic rock. Often similar to granite in mineralogical composition but possessing finer grained, frequently micaceous bands, interbedded with coarser material.

Gravel - Cohesive rock fragments having a diameter between two millimetres and eight centimetres. In the Ivory Coast most of the gravel consists of angular quartz or rounded ferruginous gravel.

Horizon - A layer of soil with boundaries roughly parallel to the soil surface having properties differing from adjacent layers, and having distinctive characteristics reflecting its genesis.

Hue, Value and Chroma - These terms refer to the colour notation used in the Munsell Soil Color Charts (Munsell Color Company, 1954). The hue refers to the relative dominance of red and yellow in the soil colour. The value refers to the darkness of the colour (darker colours have lower values) and the chroma refers to its brightness (brighter colours have higher chromas).

Illuviation - The movement of clay from an upper soil horizon and its redeposition in a lower soil horizon under the influence of percolating water.

Inceptisol (USDA, 1960) or Cambisol (FAO/UNESCO, 1970) - A soil with a medium to fine textured subsoil containing significant amounts of weatherable mineral, and lacking the significant amounts of illuvial clay necessary to characterise an argillic horizon. Normally found in more temperate conditions than those of the project area.

Inselberg - An isolated hill composed of relatively resistant rock, which has weathered and eroded less than the surrounding land. Often dome shaped.

Laterite - A term originally applied to soft red or mottled clay which hardened irreversibly on exposure to the atmosphere. The term has since been used to refer to a variety of indurated or semi indurated iron rich materials, and its use has been avoided as far as possible in this report.

Leaching, Soil - Transport of soluble constituents of soil by percolating water.

Mapping Unit - Relatively homogenous areas delineated on a map having the soils or land suitability classes defined in the annotation.

Micas - A group of aluminosilicate minerals having a sheet structure in which a layer of silicate alternates with a layer of aluminate. They often break apart in the form of 'booklets'.

Morphology, Soil - The overall constitution of the soil, comprising texture, structure, colour and other physical,chemical and biological properties of the various horizons which make up the soil profiles.

Mottling - Patches or streaks of a colour other than the dominant colour, occurring in the soil.

Oxisol (USDA, 1960) or Ferralsol (FAO/UNESCO, 1970) - A soil with a medium to fine textured subsoil containing no more than traces of weatherable minerals and having a low cation exchange capacity. Lacking illuvial clay in significant amounts.

Pedogenesis - The formation of a soil, with particular reference to the processes leading to the formation of a particular profile type.

Plinthite - An iron rich, humus poor, mixture of clay with quartz and other diluents, which commonly occur as red mottles, usually in platy polygonal or reticulate patterns, and which changes irreversibly to an ironstone hardpan or to irregular aggregates on exposure to repeated wetting and drying.

Porosity, Soil - The amount of space occupied by pores and cavities in the soil. Usually expressed as a volume percentage of a particular soil horizon.

Profile, Soil - The vertical succession of soil horizons from the soil surface down to the parent material.

Run-off - The flow of water along the land surface, or the total volume of water which flows off a given surface in a given time.

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## ACKNOWLEDGEMENTS

We are grateful to the following for assistance and cooperation:-

Dr. B. Silver, M. J.P. Terninck, M. A. Bema, M. G. Castaing and other members of the staff at the SODESUCRE complex, Ferkéssédougou.

M. R. Langellier, pedologist, of the IRAT sugar research station, Ferkéssédougou.

Dr. G.M. Higgins and Dr. A. Pecrot of FAO, Rome for discussions on land evaluation and soil classification.

Dr. J.B. Hall, Department of Forest Resources Management, University of Ibadan, Nigeria for discussions on the vegetation of the area.

# APPENDIX I

## Laboratory Methods of Analysis

# APPENDIX I

## LABORATORY METHODS OF ANALYSIS

### A1.1 Particle Size Analysis

40 g of soil were dispersed by shaking overnight with sodium hexametaphosphate solution. The suspension was then transferred to a one litre cylinder, made up to volume and stirred. A bouyoucos hydrometer was used to take readings after the following settling times:

(a) 46 seconds, to give silt plus clay content.

(b) 4 minutes 48 seconds to give fine silt plus clay.

(c) 5 hours to give clay content.

The readings were corrected for temperature and dispersing agent content. The soil suspension was then washed through an 80 mesh (0.2 mm) sieve and the coarse sand fraction weighed after drying.

### A1.2 pH 1:2½ Soil/Water Suspension

50 ml of deionised water were added to 20 g of soil. The suspension was stirred and allowed to settle. After one hour the pH of the supernatant liquid was measured.

### A1.3 pH 1:2½ Soil/Potassium Chloride Suspension

50 ml of normal potassium chloride solution were added to 20 g of soil. The suspension was stirred and allowed to settle. After one hour the pH of the supernatant liquid was measured.

### A1.4 Exchangeable Cations

4 g of soil were extracted by shaking with 20 ml of N ammonium acetate solution.

Calcium and magnesium were determined by atomic absorption spectroscopy using strontium chloride as a releasing agent to overcome interference by aluminium or phosphate.

Sodium and potassium were also determined using atomic absorption methods, utilising strontium chloride as an ionisation buffer.

A similar weight of soil was extracted by shaking with 20 ml of deionised water. Soluble cations were determined as above, and the exchangeable cations values were corrected to allow for the soluble salts.

### A1.5 Exchangeable Aluminium

4 g soil were shaken for one hour with normal potassium chloride solution (20 ml). The aluminium was determined colorimetrically on this extract using Aluminon (tri-ammonium aurine-tricarboxylate) as the complexing agent.

### A1.6 Cation Exchange Capacity

4 g of soil were shaken twice with triethanolamine buffered barium chloride solution, pH 8.2, in order to replace all exchangeable cations with barium. Excess barium was removed by shaking with water. The sample was then shaken with a solution of magnesium sulphate of known concentration. This replaced the exchangeable barium of magnesium, at the same time removing barium from solution by precipitating barium sulphate. Magnesium remaining in solution was determined by titration against EDTA. The cation exchange capacity is calculated from the difference between the amount of magnesium added and the amount remaining in solution.

### A1.7 Total Potassium and Phosphorus

A weighed finely ground sample of soil was digested with 8 N. hydrochloric acid for two hours at 95°C. After digestion the sample was centrifuged to obtain a clear extract.

Potassium was determined on this extract using atomic absorption techniques in the presence of strontium chloride.

Phosphorus was determined colorimetrically using the Vanadate/molybdate method.

### A1.8 Total Nitrogen Content

A weighed sample of finely ground soil was digested with concentrated sulphuric acid, containing potassium sulphate to raise the temperature, and selenium as a catalyst. After digestion the sample was made alkaline and the ammonia released was steam distilled into boric acid containing a mixed indicator of bromocresol green/methyl red. After distillation the ammonia dissolved in the boric acid was black-titrated against standard sulphuric acid and the result expressed as per cent total nitrogen.

## A1.9 Organic Carbon Content - Walkley-Black Method

A weighed sample of finely ground soil was digested with a known amount of potassium dichromate and concentrated sulphuric acid. Excess dichromate, remaining after digestion was complete, was titrated against standard ferrous ammonium sulphate using ferroin as indicator. In the calculation of the result, expressed as per cent organic carbon, it was assumed that only 77 per cent of the organic carbon had been oxidised.

## A1.10 Phosphorus Absorption Capacity

The soil was placed in contact with a standard phosphate solution in 0.02 molar calcium chloride solution. The suspension was then shaken for thirty minutes, morning and evening, for five days. The suspension was then centrifuged and an aliquot of the supernatant liquid taken for phosphorus analysis using the sulphuric acid molybdenum blue method, with stannous chloride as the reducing agent. The result was expressed as mg P absorbed per 100g soil.

## A1.11 Available Phosphorus and Silicon

5g of soil were extracted with 0.02 normal sulphuric acid (100 ml) by shaking together for thirty minutes. Phosphorus was determined in the extract by the reduced molybdenum blue method. Silicon was determined in the extract by the molybdosilicic acid method.

## A1.12 Total Copper, Zinc and Manganese

A weighed, finely ground sample of soil was digested using a 4:1 mixture of nitric and perchloric acids followed by evaporation to dryness. The residues were leached with 5M hydrochloric acid and copper, zinc and manganese determined in the leachate using atomic absorption techniques.

## A.1.13 Available Copper and Zinc

Copper and zinc were extracted by shaking with 0.1M hydrochloric acid. Atomic absorption methods were used to determine copper and zinc in the extract.

## A1.14 Available Manganese

Manganese was extracted from the soil using neutral normal ammonium acetate containing 0.2 per cent hydroquinone. Manganese was determined in the extract using atomic absorption techniques.

# APPENDIX II

Soil Profile Descriptions and Analytical Data

TABLE AII.1 Additional Results: Available Silicon and Phosphorus

| Lab Nos: | Pit no. | Depth (cm) | Available Silicon ppm | Available Phosphorus ppm |
|---|---|---|---|---|
| 31181 | 10 | 2- 10 | 170 | 6.4 |
| 82 | 10 | 27- 34 | 320 | 3.2 |
| 83 | 10 | 50- 60 | 400 | 3.2 |
| 84 | 10 | 80- 90 | 360 | 3.2 |
| 85 | 10 | 120-125 | 432 | 3.2 |
| 86 | 14 | 0- 10 | 248 | 17.2 |
| 87 | 14 | 30- 40 | 608 | 4.8 |
| 88 | 14 | 80- 90 | 320 | 3.2 |
| 89 | 21 | 0- 10 | 320 | 27.2 |
| 90 | 21 | 26- 33 | 248 | 6.4 |
| 91 | 21 | 70- 80 | 360 | 3.2 |
| 31914 | 40 | 0- 16 | 196 | 22.0 |
| 15 | 40 | 16- 35 | 258 | 8.8 |
| 16 | 40 | 35-115 | 516 | 4.8 |
| 17 | 40 | 115-147 | 560 | 6.4 |
| 18 | 41 | 0- 8 | 314 | 52.8 |
| 19 | 41 | 8- 25 | 100 | 10.4 |
| 20 | 41 | 25- 65 | 196 | 6.4 |
| 21 | 41 | 65-110 | 286 | 4.8 |
| 22 | 41 | 110-150 | 350 | 10.4 |

Pit No.: 1 — Date: 13.6.1975

Soil Series: 9

Land Suitability Class: VItg

ORSTOM Classification: Sols minéraux bruts d'érosion. Sous groupe regosols.

Location: 70 m S of river Fahalogo, on base line.

Parent Material: Colluvium over in situ weathering granitic gneiss.

Geomorphic Unit: Lower slope. — Slope: 3% N

Microrelief at Site: Slight grass tussocks.

Surface Features: Mica deposited on ground between tussocks.

Vegetation Class: Open savanna.

Profile Drainage: Good. — Water Table: >80 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0-12 | Dark brown (10YR 3/3) light coarse sandy loam with weak fine crumb structure; moist, firm; many medium and fine interstitial pores; many fine roots; many mica flakes. Gradual smooth transition to:- |
| 12-28 | Dark yellowish brown (10YR 3/4) slightly gravelly coarse sandy loam with weak subangular blocky structure; moist, friable; common fine interstitial and few fine tubular pores; common fine roots; 10-25 per cent angular quartz and cuirasse gravel, many mica flakes. Clear smooth transition to:- |
| 28-60 | Dark yellowish brown (10YR 4/4) extremely stony gritty loam with stony structure; moist, many fine interstitial pores; occasional roots; some cuirasse stones down to 40 cm. Gradual wavy transition to:- |
| 60-80 | Yellowish brown (10YR 5/6) very stony sandy clay loam with weak fine subangular blocky and stony structure; common fine interstitial and few fine tubular pores; 50-75 per cent quartz and partially weathered gneiss stones. |

PIT NO. 1

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31174 | 0-10 | 48 | 17 | 8 | 9 | 18 |
| 31175 | 41-50 | 58 | 12 | 5 | 7 | 18 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH Al me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.6 | 6.1 | 3.81 | 1.24 | 0.05 | 0.16 | 5.26 | 0.00 | 6.3 | 83 |
| 6.0 | 5.0 | 1.75 | 0.32 | 0.01 | 0.07 | 2.15 | 0.08 | 2.7 | 80 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 24 | 298 | 0.065 | 0.98 | 15 |
| 49 | 254 | 0.046 | 0.98 | 21 |

Pit No.: 7 Date: 16.6.1975

Soil Series: 6

Land Suitability Class: VIg

ORSTOM Classification: Sols ferrallitiques moyennement désaturés, Groupe remanié, sous groupe modal.

Location: 1.3 km S of Fahalogo river, along base line.

Parent Material: Colluvium derived from granitic gneiss and cuirasse.

Geomorphic Unit: Middle connecting slope. Local flat area. Slope: 0%

Microrelief at Site: Slightly uneven, with grass tussocks.

Surface Features: None

Vegetation Class: Open savanna.

Tree Species: *Terminalia laxiflora, Butyrospermum paradoxum, Syzygium guineense.*

Grass Species: *Elymandra audrophila, Hyperthelia, Cymbopogon.*

Profile Drainage: Good Water Table: >110 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0- 6 | Dark yellowish brown (10YR 3/4) loamy medium sand with common medium faint yellowish brown (10YR 5/4) mottles and a compound structure of weak medium subangular blocky and weak fine crumb; moist, friable; many fine interstitial pores; many fine and medium roots; rare fine round ferruginous gravels and ferruginous grit. Gradual smooth transition to:- |
| 6-20 | Brown (7.5YR 4/4) gravelly medium sandy loam with a compound structure of weak medium subangular blocky and fine crumb; moist, friable; many fine interstitial and common medium and fine tubular pores; many fine and common medium roots; 25-50 per cent round ferruginous gravels, few angular quartz stones. |
| 20-45 | Yellowish red (5YR 5/8) extremely gravelly sandy clay loam; structure and consistence dominated by gravel content; common fine interstitial and tubular pores; common fine roots; over 75 per cent ferruginous gravel, few gneiss and quartz stones. Diffuse transition to:- |

| | |
|---|---|
| 45- 90 | Yellowish red (5YR 5/8) gravelly sandy clay with weak subangular blocky-gravelly structure; moist, indurated; common fine tubular and interstitial pores; few fine roots; 25-50 per cent ferruginous gravel and gneiss fragments. Gradual wavy transition to:- |
| 90-110 | Yellowish red (5YR 5/8) clay loam with common medium distinct red and dark red mottles and very weak fine subangular blocky structure; slightly moist, firm; abundant fine tubular pores; very few fine roots; consists mainly of rock weathering in situ. |

PIT NO. 7

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31176 | 0-5 | 43 | 30 | 5 | 7 | 15 |
| 77 | 17-22 | 49 | 19 | 5 | 4 | 23 |
| 78 | 28-36 | 46 | 16 | 5 | 8 | 25 |
| 79 | 54-62 | 28 | 17 | 5 | 7 | 43 |
| 80 | 90-95 | 21 | 19 | 7 | 13 | 40 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.9 | 6.5 | 2.93 | 1.24 | 0.01 | 0.18 | 4.36 | 0.00 | 5.5 | 79 |
| 5.7 | 4.8 | 1.15 | 0.33 | 0.01 | 0.05 | 1.54 | 0.22 | 5.0 | 31 |
| 5.4 | 4.6 | 0.83 | 0.15 | 0.01 | 0.04 | 1.03 | 0.44 | 4.9 | 21 |
| 5.7 | 4.8 | 1.57 | 0.18 | 0.01 | 0.05 | 1.81 | 0.56 | 5.6 | 32 |
| 5.7 | 5.0 | 1.73 | 0.25 | 0.01 | 0.03 | 2.02 | 0.13 | 5.1 | 40 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 30 | 33 | 0.064 | 1.16 | 18 |
| 70 | 16 | 0.044 | 0.85 | 19 |
| 63 | 21 | | | |
| 42 | 26 | | | |
| 48 | 22 | | | |

| | |
|---|---|
| 78-130 | Red (2.5YR 5/8) extremely gravelly sandy clay with massive structure; dry, hard; many fine tubular pores; rare fine roots; over 75 per cent ferruginous gravel. Diffuse transition to:- |
| 130-150 | Red (2.5YR 4/8) slightly gravelly sandy clay loam with common distinct yellow and strong brown mottles and massive structure; dry, hard; few fine tubular pores; much weathered rock material and many mica flakes. |

Pit No.: 10 Date: 16.6.1975

Soil Series: 6b

Land Suitability Class: IIg

ORSTOM Classification: Sols ferrallitiques moyennement désaturés. Groupe remanié sous groupe modal.

Location: 1.75 km S of Fahalogo river, on base line.

Parent Material: Colluvium derived from cuirasse and granitic gneiss.

Geomorphic Unit: Upper connecting slope. Just below scarp. Slope 0.5% N

Microrelief at Site: Slightly uneven due to grass tussocks.

Surface Features: None

Vegetation Class: Thicket savanna. Site is in thicket.

Tree Species: *Pterocarpus sp., uapaca togoensis, Afzelia sp.*

Grass Species: *Hyparrhenia welwichiae, H. smithiana, Andropogon tectorum, Schizachyrium sanguineum.*

Profile Drainage: Good Water Table: >150 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0-12 | Brown (7.5YR 4/4) light coarse sandy loam with weak fine crumb structure; moist, friable; many fine tubular and interstitial pores; common fine roots; occasional fine ferruginous gravel. Abrupt smooth transition to:- |
| 12-40 | Red (2.5YR 5/8) gritty sandy clay loam with weak medium subangular blocky tending to massive structure; dry and very hard; many coarse and medium tubular pores due to termites; common medium and fine roots; common ferruginous grit. Gradual smooth transition to:- |
| 40-78 | Red (2.5YR 5/8) gravelly sandy clay with weak fine subangular blocky structure; dry, hard; many medium and fine interstitial and tubular pores; few medium and fine roots; common ferruginous gravels. Clear smooth transition to:- |

PIT NO. 10

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31181 | 2-10 | 60 | 22 | 0 | 5 | 13 |
| 82 | 27-34 | 46 | 14 | 2 | 5 | 33 |
| 83 | 50-60 | 40 | 12 | 3 | 5 | 40 |
| 84 | 80-90 | 38 | 14 | 3 | 5 | 40 |
| 85 | 120-125 | 41 | 18 | 2 | 6 | 33 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.5 | 5.7 | 2.05 | 0.33 | 0.01 | 0.09 | 2.4 | 0.00 | 2.4 | 100 |
| 5.4 | 4.4 | 0.40 | 0.18 | 0.02 | 0.04 | 0.64 | 0.82 | 4.6 | 14 |
| 5.4 | 4.6 | 0.33 | 0.15 | 0.03 | 0.05 | 0.56 | 0.85 | 4.9 | 11 |
| 5.7 | 4.6 | 0.45 | 0.18 | 0.03 | 0.07 | 0.73 | 0.60 | 5.0 | 15 |
| 5.6 | 4.8 | 0.50 | 0.13 | 0.05 | 0.05 | 0.73 | 0.26 | 4.1 | 18 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 30 | 18 | 0.037 | 0.68 | 18 |
| 31 | 23 | 0.029 | 0.53 | 18 |
| 31 | 24 | | | |
| 32 | 26 | | | |
| 48 | 18 | | | |

Pit No.: 14 Date: 20.6.1975

Soil Series: 3

Land Suitability Class: IIIg

ORSTOM Classification: Sols ferrallitiques moyennement désaturés. Groupe remanié sous groupe modal.

Location: 2.2 km S of river Fahalogo, along base line.

Parent Material: Cuirasse, derived from granitic gneiss.

Geomorphic Unit: Plateau. Near centre. Slope: Flat 0%

Surface Features: Common ferruginous gravels, few cuirasse boulders nearby.

Vegetation Class: Medium savanna.

Profile Drainage: Good Water Table: >115 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0- 15 | Brown (7.5YR 4/4) slightly gravelly loamy coarse sand with gravelly, tending towards fine granular structure with depth; moist, friable; many fine interstitial pores; common medium and many fine roots; common subrounded ferruginous gravel. Clear smooth transition to:- |
| 15- 57 | Red (2.5YR 4/8) gravelly sandy clay loam with medium subangular blocky and gravelly structure; moist, gravelly; many fine interstitial and few fine tubular pores; common medium and fine roots; many ferruginous gravels up to 2 cm diameter. Diffuse transition to:- |
| 57-100 | Red (2.5YR 4/8) very gravelly sandy clay loam with massive and stony gravelly structure; moist, gravelly; many fine interstitial pores; common fine and few medium roots; many ferruginous gravels and cuirasse stones (to 3 cm diameter). |
| 100-115 | Red hard cuirasse. |

PIT NO. 14

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31186 | 0-10 | 60 | 17 | 3 | 6 | 14 |
| 87 | 30-40 | 44 | 13 | 2 | 6 | 35 |
| 88 | 80-90 | 56 | 16 | 3 | 5 | 20 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.3 | 5.6 | 3.45 | 0.91 | 0.05 | 0.21 | 4.62 | 0.02 | 6.2 | 75 |
| 5.4 | 4.4 | 0.13 | 0.08 | 0.05 | 0.07 | 0.33 | 2.02 | 5.8 | 6 |
| 5.9 | 4.6 | 0.13 | 0.05 | 0.05 | 0.05 | 0.28 | 0.46 | 4.5 | 7 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 67 | 18 | 0.061 | 1.12 | 18 |
| 60 | 23 | 0.034 | 0.60 | 18 |
| 58 | 6 | | | |

Pit No.: 18 Date: 3.7.1975

Soil Series: 10

Land Suitability Class: VIt

ORSTOM Classification: Sols peu évolués d'apport. Sous groupe modal.

Location: 11.4 km E of Bandama river on Korhogo-Badikaha road.

Parent Material: Colluvium derived from granitic gneiss.

Geomorphic Unit: Lower connecting slope Slope: 2%

Microrelief at Site: Grass tussocks.

Surface Features: Few quartz pebbles.

Vegetation Class: Open savanna woodland.

Tree Species: *Daniellia oliveri, Butyrospermum paradoxum, Parinari sp.*

Grass Species: *Hyperthelia sp., Hyparrhenia smithiana, Andropogon ascinodis, Ctenium sp.*

Profile Drainage: Good Water Table: >148 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0- 10 | Very dark greyish brown (10YR 3/2) loamy coarse sand with weak medium subangular blocky structure; slightly moist, friable; many tubular and interstitial pores; many fine roots; few ferruginous and quartz gravel. Gradual smooth transition to:- |
| 10- 34 | Dark yellowish brown (10YR 3/4) coarse sandy loam with moderate medium subangular blocky structure; slightly moist, friable; common tubular and interstitial pores; common fine and few medium roots; few ferruginous and quartz gravel. Gradual smooth transition to:- |
| 34- 63 | Dark yellowish brown (10YR 4/4) loamy coarse sand with moderate medium subangular blocky structure; moist, friable; common tubular and interstitial pores; common fine and few medium roots; few ferruginous and quartz gravel. Clear wavy transition to:- |

| | |
|---|---|
| 63-140 | Dark yellowish brown (10YR 4/4) loamy coarse sand with moderate medium subangular blocky structure; moist, firm; common tubular and interstitial pores; common fine roots; common quartz and ferruginous gravel to 1 cm diameter. Gradual smooth transition to:- |
| 140-148 | Pale brown (10YR 6/3) coarse sand with weak medium subangular blocky structure; moist, friable; few fine roots. |

PIT NO. 18

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31192 | 0.12 | 62 | 20 | 3 | 7 | 8 |
| 93 | 12-34 | 59 | 21 | 4 | 6 | 10 |
| 94 | 34-63 | 63 | 19 | 2 | 6 | 10 |
| 95 | 63-140 | 68 | 14 | 3 | 5 | 10 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.5 | 5.9 | 2.50 | 0.57 | 0.03 | 0.11 | 3.21 | 0.04 | 3.6 | 89 |
| 6.3 | 6.0 | 1.16 | 0.32 | 0.03 | 0.08 | 1.59 | 0.02 | 2.4 | 66 |
| 6.5 | 6.0 | 0.91 | 0.20 | 0.03 | 0.08 | 1.2 | 0.00 | 1.1 | 100 |
| 6.7 | 6.3 | 0.75 | 0.15 | 0.03 | 0.05 | 0.9 | 0.00 | 0.8 | 100 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 31 | 27 | 0.044 | 0.08 | 18 |
| 21 | 25 | 0.027 | 0.63 | 23 |
| 18 | 31 | | | |
| 14 | 38 | | | |

Pit No.: 21 Date: 15.9.1975

Soil Series: 6

Land Suitability Class: IIIg

ORSTOM Classification: Sols ferrallitiques moyennement désaturés. Groupe remanié. Sous groupe modal.

Location: 1.1 km S of river Waha on base line.

Parent Material: Colluvium derived from cuirasse and granitic gneiss.

Geomorphic Unit: Middle connecting slope. Slope: 2%

Microrelief at Sites: Very slight tussocks.

Surface Features: Common ferruginous gravel.

Vegetation Class: Open savanna.

Profile Drainage: Good. Water Table: >110 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0- 12 | Dark brown (7.5YR 3/2) slightly gravelly, coarse sandy loam with a moderate fine subangular blocky structure breaking down to moderate fine crumb; moist, friable; many fine tubular and interstitial pores; many fine and medium roots. Common ferruginous gravel, few quartz gravel. Clear smooth transition to:- |
| 12- 48 | Yellowish red (5YR 4/6) very gravelly sandy clay loam, gravelly structure; moist, firm; many fine tubular and interstitial pores; common fine and medium roots. Many ferruginous gravel, few angular quartz stones, few cuirasse fragments. |
| 48-110 | Plinthite - sandy clay loam with many coarse distinct, red, red-yellow, yellow, and strong brown mottles; massive structure; moist, very firm; many fine and medium tubular pores. |

PIT NO. 21

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31189 | 0-10 | 60 | 20 | 4 | 5 | 11 |
| 90 | 26-33 | 46 | 16 | 4 | 6 | 28 |
| 91 | 70-80 | 48 | 19 | 4 | 9 | 20 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.7 | 6.1 | 2.62 | 0.84 | 0.05 | 0.21 | 3.72 | 0.00 | 4.7 | 79 |
| 5.8 | 4.7 | 0.37 | 0.33 | 0.05 | 0.29 | 1.04 | 0.73 | 5.4 | 19 |
| 5.8 | 4.8 | 0.74 | 0.38 | 0.01 | 0.14 | 1.27 | 0.24 | 5.9 | 22 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 67 | 26 | 0.037 | 0.95 | 25 |
| 36 | 38 | 0.027 | 0.53 | 20 |
| 54 | 19 | | | |

Pit No.: 25 Date: 8.7.1975

Soil Series: 7

Land Suitability Class: VIt

ORSTOM Classification: Sols ferrallitiques moyennement désaturés. Groupe typique, sous groupe modal, faciès appauvris.

Location: 400 m. N. of river Fahalogo on base line.

Parent Material: Colluvium derived from granitic gneiss.

Geomorphic Unit: Middle connecting slope Slope: 3%

Microrelief at Site: Tussock grass.

Surface Features: Cuirasse boulders 40 metres away.

Vegetation Class: Open savanna woodland.

Profile Drainage: Fair Water Table: >180 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0-19 | Dark brown (10YR 3/3) coarse sandy loam with a compound structure of weak fine subangular blocky and granular; moist, friable; many tubular and interstitial pores; many fine and medium roots. Clear smooth transition to:- |
| 19-35 | Dark yellowish brown (10YR 4/3) coarse sandy loam with a compound structure of moderate medium subangular blocky and granular; moist, friable; many tubular and interstitial pores; many fine and common medium roots. Clear smooth transition to:- |
| 35-51 | Dark yellowish brown (10YR 4/4) coarse sandy loam with a compound structure of moderate medium subangular blocky and granular; moist, friable; few tubular and common interstitial pores; common fine and common medium roots. Clear smooth transition to:- |
| 51-82 | Yellowish brown (10YR 5/8) sandy clay loam with a moderate medium to coarse subangular blocky structure; moist, friable; few tubular and common interstitial pores; few fine roots. Clear smooth transition to:- |

| | |
|---|---|
| 82-120 | Strong brown (7.5YR 5/6) gritty sandy clay loam with a moderate medium subangular blocky structure; moist, slightly hard; common interstitial pores; few fine roots; few round pisolite gravels. |
| 120-140 | Hard secondary cuirasse. |

PIT NO. 25

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31196 | 0-19 | 55 | 20 | 2 | 9 | 14 |
| 97 | 19-35 | 58 | 17 | 4 | 7 | 14 |
| 98 | 35-51 | 55 | 17 | 3 | 7 | 18 |
| 99 | 51-82 | 50 | 14 | 2 | 9 | 25 |
| 31200 | 82-120 | 48 | 13 | 3 | 7 | 29 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.2 | 5.5 | 1.46 | 0.57 | 0.03 | 0.08 | 2.14 | 0.04 | 3.6 | 59 |
| 5.9 | 4.9 | 0.72 | 0.23 | 0.03 | 0.07 | 1.05 | 0.16 | 2.4 | 44 |
| 5.6 | 4.7 | 0.67 | 0.18 | 0.03 | 0.04 | 0.92 | 0.26 | 2.3 | 40 |
| 5.5 | 4.6 | 1.00 | 0.37 | 0.03 | 0.09 | 1.49 | 0.28 | 3.4 | 44 |
| 5.6 | 4.7 | 0.97 | 0.45 | 0.03 | 0.11 | 1.56 | 0.27 | 3.5 | 45 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 21 | 34 | 0.046 | 1.15 | 25 |
| 18 | 32 | 0.029 | 0.60 | 21 |
| 25 | 46 | 0.019 | 0.45 | 24 |
| 32 | 79 | 0.024 | 0.55 | 23 |
| 35 | 87 | | | |

Pit No.: 28 Date: 10.7.1975

Soil Series: 6

Land Suitability Class: VItg

ORSTOM Classification: Sols ferrallitiques moyennement désaturés. Groupe remanié. Sous groupe appauvris.

Location: 1.5 km N of river Fahalogo along base line.

Parent Material: Colluvium derived from granitic gneiss.

Geomorphic Unit: Lower connecting slope. Slope: 2½%

Microrelief of Site: Slightly uneven due to tussock grass.

Surface Features: Quartz grit in between tussocks.

Vegetation Class: Open savanna.

Profile Drainage: Good Water Table: >125 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0-30 | Very dark greyish brown (10YR 3/2) coarse sandy loam with a compound structure of weak medium subangular blocky and crumb; moist, friable; common interstitial and few fine tubular pores; many fine and common medium roots; few ferruginous gravels. Gradual wavy transition to:- |
| 30-50 | Dark brown (7.5YR 4/4) gravelly coarse sandy loam, moderate medium angular blocky structure; moist, friable; common fine interstitial and tubular pores; common fine roots; few ferruginous gravels and common quartz stones. Gradual wavy transition to:- |
| 50-75 | Brown (7.5YR 5/4) very gravelly sandy clay loam, moderate medium angular blocky structure, moist, friable; few interstitial and common tubular pores; few fine roots; few ferruginous gravels; many quartz stones up to 2.5 cm. Gradual irregular transition to:- |
| 75-95 | Strong brown (7.5YR 5/8) extremely gravelly sandy clay loam; moderate medium angular blocky structure; moist, friable; common fine tubular roots; few fine roots; many quartz gravels up to 2 cm. Gradual irregular transition to:- |

95-125 Weathered rock with common quartz pebbles to 5 cm diameter. The boundary of weathered rock is very irregular varying between 95 and 75 cm from the surface.

PIT NO. 28

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31201 | 0-30 | 61 | 16 | 3 | 7 | 13 |
| 02 | 30-50 | 63 | 12 | 4 | 6 | 15 |
| 03 | 50-75 | 58 | 14 | 3 | 5 | 20 |
| 04 | 75-95 | 60 | 12 | 3 | 4 | 21 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.1 | 5.6 | 1.56 | 0.44 | 0.03 | 0.08 | 2.11 | 0.00 | 3.9 | 54 |
| 5.9 | 5.2 | 0.91 | 0.23 | 0.03 | 0.07 | 1.14 | 0.06 | 2.1 | 54 |
| 5.9 | 5.2 | 1.24 | 0.29 | 0.03 | 0.10 | 1.66 | 0.13 | 2.5 | 66 |
| 6.0 | 5.0 | 1.06 | 0.20 | 0.10 | 0.08 | 1.44 | 0.09 | 2.1 | 69 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 31 | 15 | 0.034 | 0.95 | 28 |
| 28 | 16 | 0.020 | 0.71 | 35 |
| 21 | 20 | | | |
| 21 | 21 | | | |

Pit No.: 40 Date: 15.9.1975

Soil Series: 4

Land Suitability Class: I

ORSTOM Classification: Sols ferrallitiques moyennement désaturés. Groupe typique. Sous groupe modal.

Location: On Trace line 15S. 300 m west of base line.

Parent Material: Colluvium derived from granitic gneiss.

Geomorphic Unit: Upper connecting slope (convex) Slope: 2½% E/W

Microrelief of Site: Even

Surface Features: None

Vegetation Class: Open Guinea savanna.

Tree species: *Uapaca togoensis, Terminalia laxiflora.*

Grass Species: *Hyperthelia subplumosa, H. smithiana.*

Profile Drainage: Good. Water Table: >147 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0- 16 | Dark yellowish brown (10YR 3/4) medium sandy loam with weak fine subangular blocky structure breaking down to weak fine granular; moist, friable; porous; many fine common medium roots. Clear smooth transition to:- |
| 16- 35 | Yellowish red (5YR 4/6) medium to coarse sandy clay loam with moderate medium subangular blocky structure; slightly moist, firm; few fine to medium pores; common fine few coarse roots; few quartz grit. Gradual smooth transition to:- |
| 35-115 | Yellowish red (5YR 5/8) clay loam with moderate medium subangular blocky structure; slightly moist, firm; few fine and medium pores; signs of forming laterite. Gradual irregular transition to:- |
| 115-147 | Red (2.5YR 5/6) and strong brown (7.5YR 5/8) clay loam with massive structure; slightly moist, slightly hard; some lateritic and quartz gravel in pockets, some black concretions. Plinthite. |

PIT NO. 40

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31914 | 0-16 | 59 | 18 | 5 | 4 | 14 |
| 15 | 16-35 | 50 | 16 | 5 | 3 | 26 |
| 16 | 35-115 | 30 | 9 | 2 | 6 | 53 |
| 17 | 115-147 | 31 | 9 | 5 | 7 | 48 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 5.9 | 5.4 | 1.65 | 0.56 | 0.03 | 0.12 | 2.36 | 0.07 | 5.9 | 40 |
| 5.5 | 4.7 | 1.18 | 0.40 | 0.03 | 0.11 | 1.72 | 0.20 | 4.5 | 38 |
| 5.7 | 5.0 | 1.98 | 0.58 | 0.01* | 0.17 | 2.73 | 0.08 | 7.9 | 35 |
| 5.8 | 5.2 | 2.05 | 0.83 | 0.09 | 0.19 | 3.16 | 0.02 | 9.1 | 35 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 36.5 | 38.3 | 0.04 | 0.90 | 22 |
| 40.5 | 67.4 | | | |
| 46.5 | 117.3 | | | |
| 56.0 | 115.3 | | | |

* Less than

Pit No.: 41 Date: 19.9.1975

Soil Series: 5/6b

Land Suitability Class: IIt

ORSTOM Classification: Sols ferrallitiques moyennement désaturés. Groupe typique. Sous groupe modal. Faciès à taches et concrétions.

Location: On trace line 16. 120 m west of base line.

Parent Material: Colluvium from weathered granite or granitic gneiss.

Geomorphic Unit: Upper connecting slope. Slope: 3%

Microrelief of Site: Grass tussocks.

Surface Features: None.

Vegetation Class: Open savanna woodland.

Tree Species: *Butyrospermum paradoxum, Ostryoderis sp., Paleostigma sp.*

Grass Species: *Hyperthelia sp., Hyparrhenia subplumosa, Schizachyrium sanguineum.*

Profile Drainage: Good Water Table: >150 cm

| Depth (cm) | Horizon Description |
|---|---|
| 0- 8 | Dark brown (10YR 3/3) loamy coarse sand with a fine granular structure; moist, friable; porous; common and fine medium roots; few ferruginous gravel. Gradual smooth transition to:- |
| 8- 25 | Brown (7.5YR 5/4) coarse sandy loam with a weak medium subangular blocky structure; moist, firm; common tubular and interstitial pores; common fine medium and coarse roots; clear smooth transition to:- |
| 25- 65 | Yellowish red (5YR 5/8) slightly gritty sandy clay loam with a weak medium subangular blocky structure; moist, firm; common tubular pores, common fine medium and coarse roots; common Fe and quartz grit. Gradual wavy transition to:- |
| 65-110 | Yellowish red (5YR 5/8) gravelly and gritty sandy clay with common medium distinct red and common medium prominent yellow mottling; weak medium angular blocky structure; moist, slightly indurated; common tubular pores, few fine roots; common Fe and quartz grit and common ferruginous gravels. Diffuse smooth transition to:- |

110-150 Yellowish red (5YR 5/8) gritty sandy clay (weathered rock) with many coarse prominent yellow, white and red mottling; massive structure; moist; indurated; few pores; rare roots. Common Fe and quartz grit.

PIT NO. 41

| LAB NO. | DEPTH (CM) | SOIL PARTICLES % | | | | |
|---|---|---|---|---|---|---|
| | | COARSE SAND | FINE SAND | COARSE SILT | FINE SILT | CLAY |
| 31918 | 0-8 | 63 | 16 | 1 | 7 | 13 |
| 19 | 8-25 | 45 | 9 | 2 | 5 | 39 |
| 20 | 25-65 | 46 | 10 | 4 | 6 | 34 |
| 21 | 65-110 | 56 | 9 | 5 | 6 | 24 |
| 22 | 110-150 | 46 | 9 | 6 | 10 | 29 |

| pH water | pH KCl | EXCHANGEABLE CATIONS me/100g | | | | TEB me% | EXCH AL me/100g | CEC me% | % BASE SATURATION |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | | | |
| 6.8 | 6.2 | 2.30 | 0.60 | 0.01* | 0.12 | 3.02 | 0.01* | 4.5 | 67 |
| 5.3 | 4.5 | 1.03 | 0.33 | 0.03 | 0.08 | 1.47 | 0.36 | 5.9 | 25 |
| 5.4 | 4.5 | 1.10 | 0.32 | 0.04 | 0.10 | 1.56 | 0.59 | 7.4 | 21 |
| 5.6 | 4.8 | 1.18 | 0.60 | 0.01 | 0.12 | 1.91 | 0.14 | 7.6 | 25 |
| 5.6 | 4.8 | 1.16 | 0.47 | 0.01 | 0.13 | 1.77 | 0.13 | 6.0 | 30 |

| TOTAL P mg % | TOTAL K mg % | TOTAL N % | ORGANIC CARBON % | C/N RATIO |
|---|---|---|---|---|
| 40.0 | 45.9 | 0.04 | 0.70 | 18 |
| 47.0 | 70.4 | | | |
| 51.0 | 92.9 | | | |
| 47.0 | 87.0 | | | |
| 45.5 | 70.4 | | | |

* Less than

# APPENDIX III

## SOIL MOISTURE CHARACTERISTICS

### A.III.1 Infiltration Rates

#### A.III.1.1 Method

The tests were carried out in the rainy season when the soils were in a moist state and because of this no pre-flooding was considered necessary. It is the infiltration characteristics of the soil in a moist irrigated state that are of practical importance.

Four pairs of 31.9 and 63.8 cm diameter rings were used for each site. The rings were driven into the soil to a depth of 15 cm where possible - the larger concentrically outside the smaller - however, shallow stony or gravelly layers prevented this depth of penetration at some sites. The rings were filled with water and the rate of fall of the water level in the inner ring was measured. The inner ring was topped up at intervals to avoid differences of hydrostatic head. Readings were continued until a fairly constant rate of infiltration was achieved. Although 5 tests were carried out, 2 were invalid due to high run-off through the coarse textured topsoil. Results are only presented for the remaining three tests.

#### A.III.1.2 Results

In the results that follow in Table AIII.1 it should be noted that the 'time elapsed' column refers to the time of measurement. Infiltration rates and accumulative rates are given for each ring as well as mean values for the four rings.

Infiltration rates are plotted in the accompanying graphs (Figures A.III.1 - 3).

Table AIII.1

Site 10

Soil Series 6

Land Class IIg

Infiltration Rate cm/hour

| | Time elapsed hours | Replicate 1 | | Replicate 2 | | Replicate 3 | | Replicate 4 | | Mean Rate* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | ΣI | I | ΣI | I | ΣI | I | ΣI | I | ΣI |
| Day 1 | 1 | 6.9 | 6.9 | 6.6 | 6.6 | 6.9 | 6.9 | 21.6 | 21.6 | 6.7 | 6.7 |
| | 2 | 5.3 | 12.2 | 4.9 | 11.5 | 4.2 | 11.1 | 20.8 | 42.4 | 4.8 | 11.6 |
| | 3 | 5.1 | 17.3 | 4.8 | 16.3 | 3.6 | 13.9 | 20.6 | 63.0 | 4.5 | 15.8 |
| | 4 | 6.5 | 23.8 | 3.9 | 20.2 | 3.3 | 18.0 | | | 4.6 | 20.6 |
| Day 2 | 1 | 6.4 | 6.4 | 4.8 | 4.8 | 4.2 | 4.2 | 28.4 | 28.4 | 5.0 | 5.0 |
| | 2 | 5.6 | 12.0 | 3.5 | 8.3 | 3.5 | 7.7 | 30.4 | 58.8 | 4.5 | 9.3 |
| | 3 | 4.1 | 16.1 | 3.1 | 11.4 | 2.9 | 10.6 | | | 3.6 | 12.7 |

* These results were based on the mean values of replicates 1, 2 and 3 only.

The test was terminated after day 2 because of heavy rain.

Table AIII.1 (continued)

Site 40

Soil Mapping Unit 4

Land Class I

Infiltration Rate cm/hour

| | Time elapsed hours | Replicate 1 | | Replicate 2 | | Replicate 3 | | Replicate 4 | | Mean value* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | Σ | I | Σ | I | Σ | I | Σ | I | ΣI |
| Day 1 | 1 | 2.0 | 2.0 | 8.7 | 8.7 | 1.0 | 1.0 | 9.2 | 9.2 | 3.9 | 3.9 |
| | 2 | 2.1 | 4.1 | 4.9 | 13.6 | 0.5 | 1.5 | 15.1 | 24.3 | 2.5 | 6.4 |
| | 3 | 1.9 | 6.0 | 5.7 | 19.3 | 0.5 | 2.0 | 16.2 | 40.5 | 2.7 | 9.0 |
| | 4 | 1.5 | 7.5 | 4.3 | 23.6 | 0.5 | 2.5 | 17.7 | 58.2 | 2.4 | 16.2 |
| Day 2 | 1 | 1.9 | 1.9 | 3.5 | 3.5 | 0.2 | 0.2 | 1.8 | 1.8 | 2.46 | 2.46 |
| | 2 | 2.1 | 4.0 | 3.2 | 6.7 | 0.2 | 0.4 | 2.5 | 4.3 | 2.66 | 5.28 |
| | 3 | 1.2 | 5.2 | 2.3 | 9.0 | 0.2 | 0.6 | 1.9 | 6.2 | 1.86 | 7.0 |
| | 4 | 1.4 | 6.6 | 2.2 | 11.2 | 0.3 | 0.9 | 1.7 | 7.9 | 1.86 | 5.53 |
| Day 3 | 1 | 3.2 | 3.2 | 2.7 | 2.7 | 0.3 | 0.3 | 1.9 | 1.9 | 2.7 | 2.7 |
| | 2 | 2.0 | 5.2 | 3.3 | 6.0 | 0.5 | 0.8 | 1.87 | 3.77 | 2.55 | 5.25 |
| | 3 | 2.1 | 7.3 | 2.1 | 8.1 | 0.2 | 1.0 | 1.67 | 5.44 | 2.29 | 7.28 |
| | 4 | 2.1 | 9.4 | 2.0 | 10.1 | 0.4 | 1.4 | 1.22 | 6.66 | 1.90 | 9.18 |

* 1st day results were based on the mean value of replicates 1, 2 and 3 only.

Table AIII.1 (continued)

Site 41

Soil Mapping Unit 5/6b

Land Class IIt

Infiltration Rate (cm/hour)

| | Time elapsed hours | Replicate 1 | | Replicate 2 | | Replicate 3 | | Replicate 4 | | Mean Values | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | ΣI | I | ΣI | I | ΣI | I | ΣI | I | ΣI |
| Day 1 | 1 | 3.5 | | 1.1 | | 1.6 | | 5.8 | | 4.0 | 4.0 |
| | 2 | 2.3 | 5.8 | 0.6 | 1.7 | 0.7 | 2.3 | 3.8 | 9.6 | 2.46 | 6.46 |
| | 3 | 1.9 | 7.7 | 0.8 | 2.5 | 1.2 | 3.5 | 3.5 | 13.1 | 2.46 | 8.93 |
| | 4 | 1.9 | 9.4 | 0.6 | 3.1 | 1.0 | 4.5 | 2.7 | 15.8 | 2.0 | 10.93 |
| Day 2 | 1 | 2.2 | 2.2 | 1.1 | 1.1 | 1.6 | 1.6 | 4.4 | 4.4 | 3.1 | 3.1 |
| | 2 | 3.5 | 5.7 | 0.3 | 1.4 | 0.6 | 2.2 | 2.0 | 6.4 | 2.13 | 5.23 |
| | 3 | 3.2 | 8.9 | 0.3 | 1.7 | 0.4 | 2.6 | 2.0 | 8.4 | 1.96 | 7.2 |
| | 4 | 2.6 | 11.5 | 0.5 | 2.2 | 0.6 | 3.2 | 1.8 | 10.2 | 1.89 | 9.0 |
| | 5 | 2.0 | 13.5 | 0.4 | 2.6 | 0.5 | 3.7 | 1.9 | 12.1 | 1.6 | 9.96 |
| Day 3 | 1 | 2.1 | 2.1 | 1.4 | 1.4 | 1.1 | 1.1 | 2.4 | 2.4 | 2.99 | 2.99 |
| | 2 | 1.6 | 3.7 | 1.4 | 2.8 | 1.3 | 2.4 | 2.1 | 4.5 | 2.16 | 4.46 |
| | 3 | 1.1 | 4.8 | 1.4 | 4.2 | 0.7 | 3.1 | 2.0 | 6.5 | 1.73 | 6.20 |
| | 4 | 1.0 | 5.0 | 1.3 | 5.5 | 0.7 | 3.8 | 1.7 | 8.2 | 1.56 | 7.5 |
| | 7 | 2.7 | 7.7 | 4.3 | 9.8 | 3.7 | 7.5 | 4.1 | 12.3 | 3.99 1.33 | 12.43 |
| | 8 | 1.0 | 8.7 | 1.4 | 11.2 | 0.9 | 8.4 | 1.6 | 13.9 | 1.69 | 14.6 |
| | 9 | 1.0 | 9.7 | 1.3 | 12.5 | 0.7 | 9.1 | 1.3 | 15.2 | 1.4 | 15.5 |

## A.III.2 Moisture Retention Characteristics

### A.III.2.1 Method

Soil samples were collected in the field using a special core sampling device. The dry weight of the undisturbed soil in the core was determined and the bulk density calculated.

Subsequently, the cores were saturated with water, placed in a porous plate apparatus, and subjected to a pressure of 1/10 of an atmosphere. When the moist sample and pressure reached equilibrium water ceased to flow from the pressure chamber. The sample was then removed and weighed to determine the moisture content.

The determinations were repeated at pressures of 1/3 and 1 atmospheres.

The samples were then transferred to the high pressure chamber and the soil moisture content determined when in equilibrium with a pressure of fifteen atmospheres.

It was not possible to take core samples in stony or gravelly soils. Consequently, a known volume of disturbed soil was collected and, following bulk density determination, analyses were carried out on the fine earth (>2 mm) soil size fraction following the standard method for core samples.

### A.III.2.2 Results

The results of the soil moisture retention investigations are presented in Table AIII.2. Water contents are expressed as volume percentages and, if the sample was a disturbed rather than a core sample, figures are corrected for gravel content. Figures therefore refer to whole soil horizons, including stones and gravels. As the survey team had a slight tendency to overestimate stones and gravels and they were estimated on a 'range' basis, (e.g. common gravels = 25-50 per cent), the lower figure defining the range was taken as the correction factor.

Table A.III.2

Soil Moisture Retention Characteristics

| Profile Pit | Depth of Horizon Sampled | Type of sample | Gravel content | Texture | Bulk Density | Moisture Content (% volume) at suction (atm) 0 | 1/10 | 1/3 | 1 | 15 | RAC | RAMC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0- 12 | U | - | LS | 1.37 | 49.1 | 29.7 | 22.3 | 19.6 | 8.2 | 21.5 | 10.7 |
| 1 | 12- 28 | D | 75 | L | 1.42 | 20.2 | 7.7 | 5.5 | 4.7 | 2.6 | 5.1 | 2.6 |
| 7 | 0- 6 | U | - | LMS | 1.43 | 47.9 | 29.7 | 23.0 | 20.0 | 11.2 | 18.5 | 9.2 |
| 7 | 45- 90 | D | 25 | SC | 1.50 | 76.2 | 39.0 | 29.1 | 26.1 | 20.4 | 18.6 | 9.3 |
| 10 | 0- 12 | U | - | CoSL | 1.49 | 46.6 | 24.4 | 14.2 | 12.1 | 5.8 | 18.6 | 9.3 |
| 10 | 12- 40 | D | 25 | SCL | 1.51 | 54.7 | 27.4 | 16.6 | 14.3 | 10.6 | 16.8 | 8.4 |
| 10 | 40- 78 | D | 25 | SC | 1.55 | 67.4 | 32.3 | 21.9 | 19.8 | 15.7 | 16.6 | 8.3 |
| 14 | 0- 15 | D | - | SCL | 1.30 | 74.0 | 30.8 | 22.1 | 20.8 | 15.9 | 14.9 | 7.4 |
| 14 | 15- 57 | D | 50 | SCL | 1.35 | 37.2 | 13.8 | 10.8 | 9.5 | 7.8 | 6.0 | 3.0 |
| 18 | 0- 10 | U | - | LCoS | 1.65 | 51.2 | 23.9 | 14.4 | 12.2 | 3.1 | 20.8 | 10.4 |
| 18 | 10- 34 | U | - | CoSL | 1.83 | 40.1 | 21.8 | 13.9 | 11.9 | 4.8 | 17.0 | 8.5 |
| 18 | 34- 63 | U | - | LCoS | 1.95 | 36.5 | 18.5 | 14.6 | 12.3 | 4.9 | 13.6 | 6.8 |
| 18 | 63-140 | U | - | LCoS | 1.96 | 32.7 | 13.7 | 11.2 | 8.8 | 4.3 | 9.4 | 4.7 |
| 21 | 0- 12 | U | - | CoSL | 1.60 | 47.2 | 23.4 | 18.7 | 16.5 | 8.6 | 14.8 | 7.4 |
| 21 | 12- 48 | D | 50 | SCL | 1.60 | 37.5 | 15.5 | 11.0 | 9.6 | 7.0 | 8.5 | 4.2 |
| 25 | 0- 19 | U | - | CoSL | 1.55 | 49.9 | 27.7 | 20.3 | 18.0 | 6.8 | 20.9 | 10.4 |
| 25 | 19- 35 | U | - | CoSL | 1.79 | 38.8 | 24.2 | 17.7 | 15.9 | 7.2 | 17.0 | 8.5 |
| 25 | 35- 51 | D | - | CoSL | 1.80 | 77.2 | 20.3 | 14.6 | 12.8 | 9.2 | 11.1 | 5.5 |
| 25 | 51- 82 | U | - | SCL | 1.80 | 28.4 | 21.8 | 18.9 | 17.5 | 11.2 | 10.6 | 5.3 |
| 25 | 82-120 | D | 25 | SCL | 1.81 | 61.8 | 26.3 | 17.8 | 14.9 | 11.7 | 14.6 | 7.3 |
| 28 | 0- 30 | D | - | CoSL | 1.20 | 48.8 | 15.1 | 10.3 | 8.8 | 5.3 | 9.8 | 4.9 |
| 28 | 30- 50 | D | 25 | CoSL | 1.27 | 33.4 | 14.6 | 9.9 | 7.9 | 7.0 | 7.6 | 3.8 |
| 28 | 50- 75 | D | 50 | SCL | 1.26 | 24.1 | 7.6 | 4.9 | 4.0 | 2.6 | 5.0 | 2.5 |
| 28 | 75- 95 | D | 75 | SCL | 1.30 | 10.9 | 4.0 | 2.7 | 2.1 | 1.9 | 2.1 | 1.0 |
| 40 | 0- 16 | U | - | mSL | 1.97 | 28.8 | 27.0 | 24.2 | 23.0 | 14.2 | 12.8 | 6.4 |
| 40 | 16- 35 | U | - | SCL | 1.79 | 36.5 | 22.7 | 18.4 | 17.2 | 8.4 | 14.3 | 7.1 |
| 40 | 35-115 | U | - | CL | 1.85 | 38.5 | 37.4 | 35.7 | 35.0 | 26.5 | 10.9 | 5.4 |
| 41 | 0- 8 | U | - | LCoS | 1.43 | 41.2 | 24.0 | 19.7 | 18.3 | 8.2 | 15.8 | 7.9 |
| 41 | 8- 25 | U | - | CoSL | 1.71 | 38.5 | 30.8 | 27.0 | 25.7 | 13.2 | 17.6 | 8.8 |
| 41 | 25- 65 | U | - | SCL | 1.75 | 42.3 | 34.3 | 29.9 | 28.5 | 21.9 | 12.4 | 6.2 |

AMC = Available Moisture Capacity

RAMC = R-adily Available Moisture Capacity

U = Undisturbed core sample

D = Disturbed sample of known volume

Figure A 3.1

# SITE 10 INFILTRATION

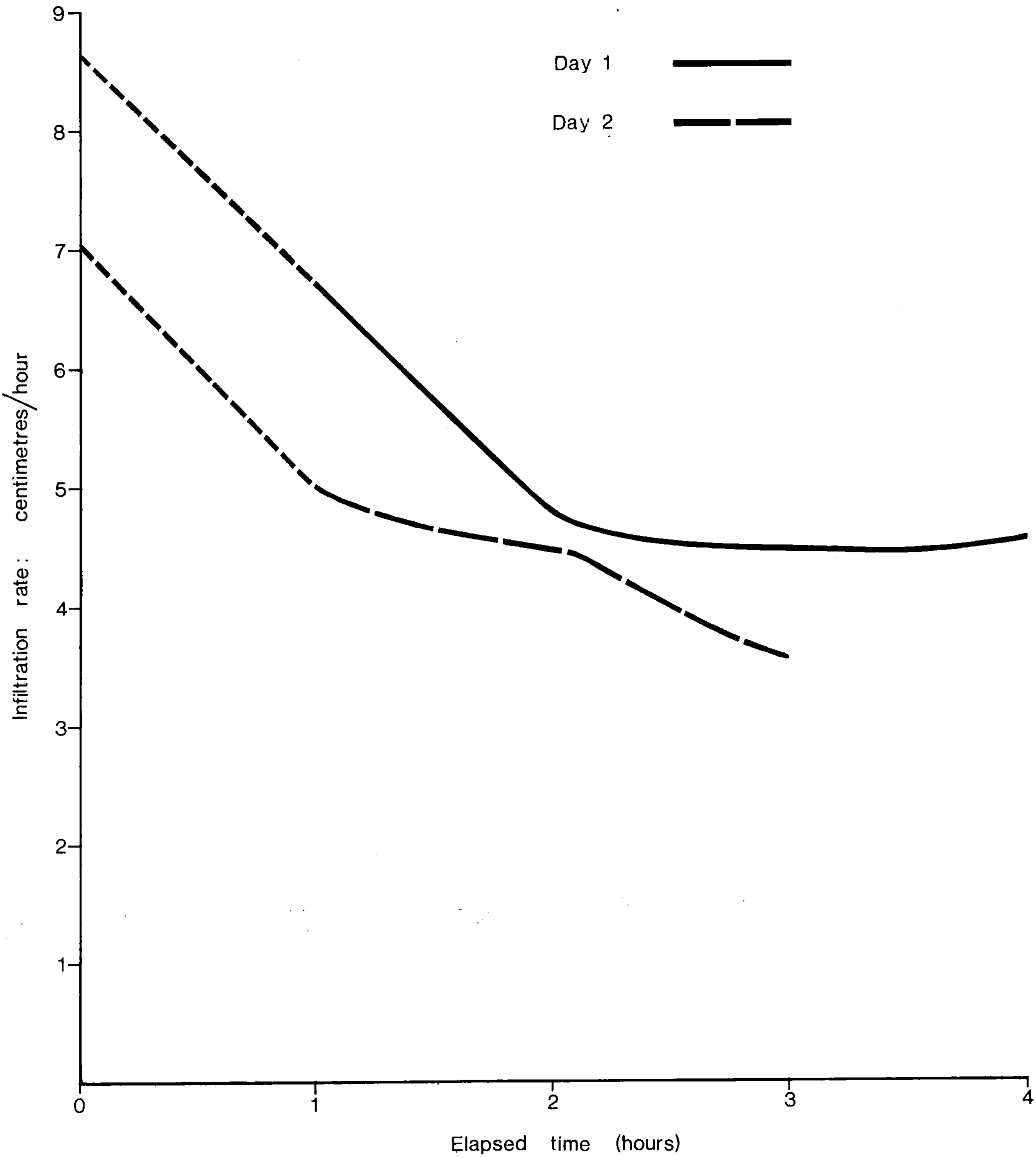


Figure A 3.2

# SITE 40 INFILTRATION

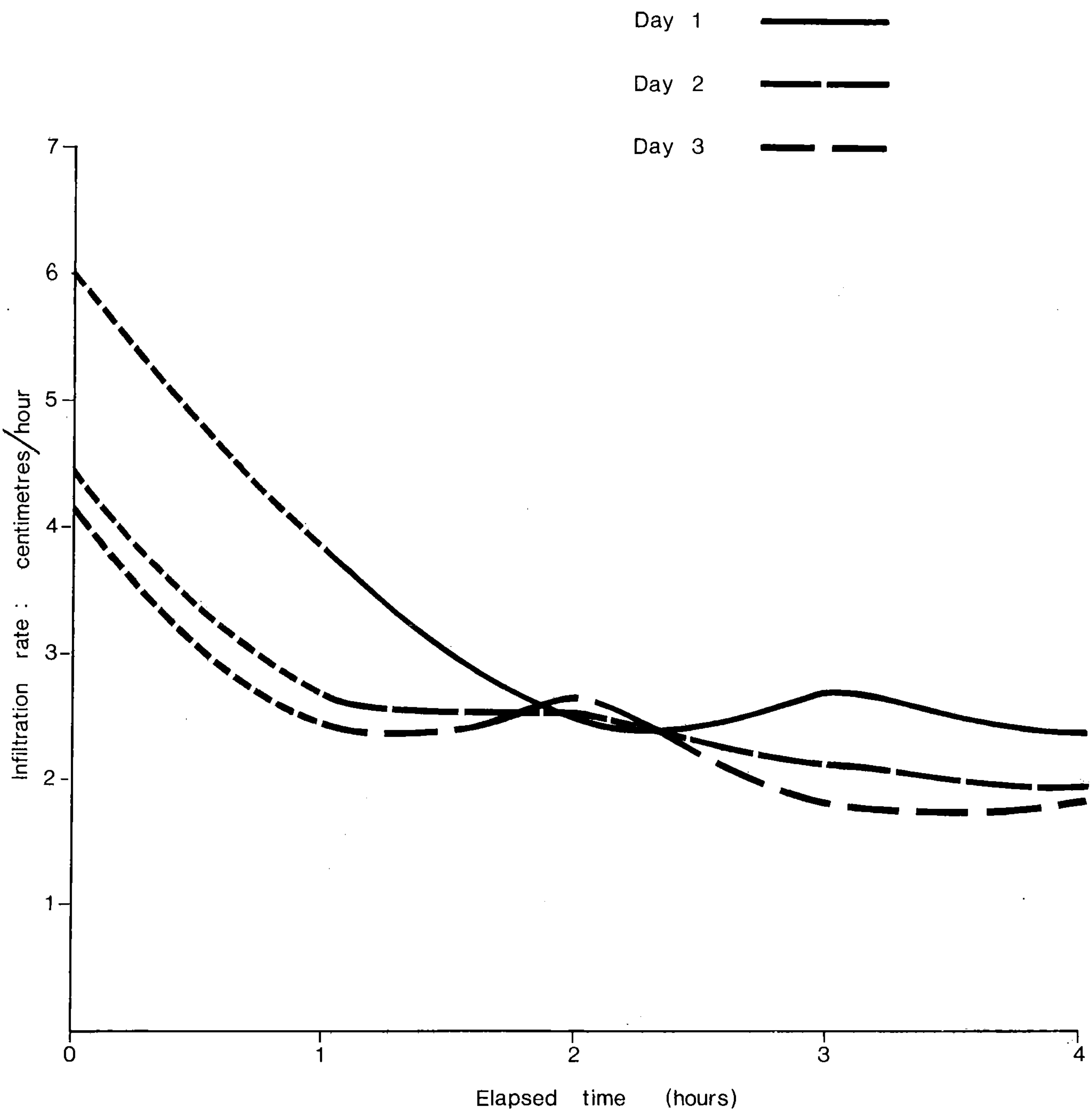
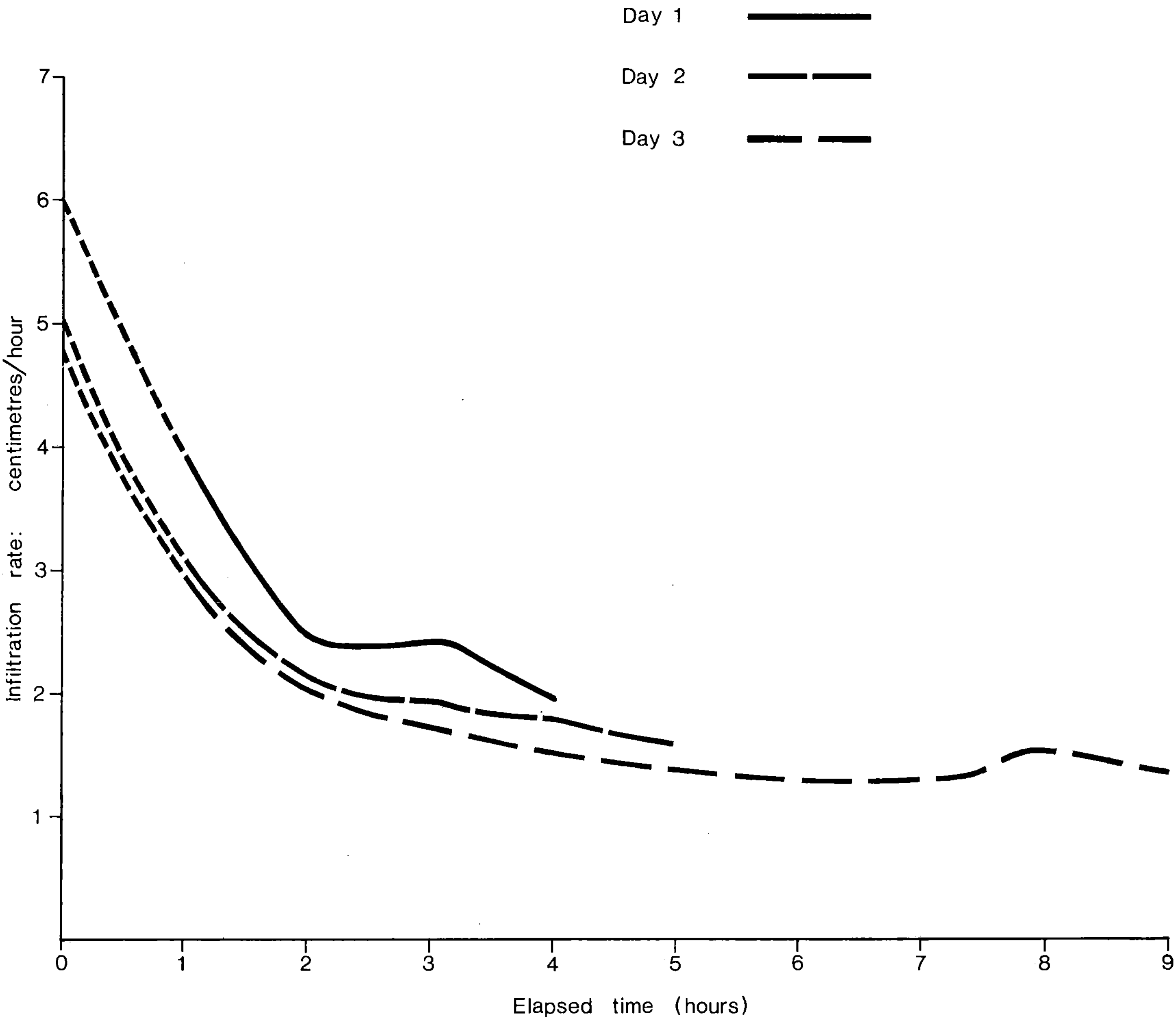


Figure A3.3

# SITE 41 INFILTRATION



## APPENDIX IV

## RECONNAISSANCE SOIL SURVEY, JUNE 1975

### A.IV.1 Introduction

The detailed soil survey area was originally chosen on the basis of the findings of the April 1975 appraisal mission and those of a BNETD reconnaissance study concluded in 1974. However, during the initial marking out of the central north-south base line for the detailed survey, considerably more cuirasse was encountered than was shown on the original map. In order to ensure that a detailed soil survey was justified, a brief reconnaissance of the area between the Waha river and the Korhogo-Badikaha road was carried out June 20th-30th, 1975.

For the description of the area etc., reference should be made to the main report.

### A.IV.2 Methods of Study

#### A.IV.2.1 Field

Using the aerial photographs for navigation and location, field traverses were made throughout the area. Considerable difficulty was experienced in navigation because of the age and moderate quality of some of the photographs. This was particularly true in the centre of the area, some of which is covered only on the margin of the end frames of flight runs, so that there is no stereoscopic cover. The soils were examined at points in major landform/aerial photograph interpretation (API) units. A 10 cm head Jarret auger was used and the soils were examined to a depth of one metre where possible. In addition to the 175 auger observations, 15 soil profile pits were dug and described. The pits were sited along a crest-valley toposequence to the south of the river Fahalogo.

#### A.IV.2.2 API and Mapping

The mapping material available was the same as for the detailed soil survey and the 1:20,000 uncontrolled photomosaic was used as the base map. The landform/API units were placed on the individual prints using the data gathered in the field and interpretation of the photographs, stereoscopically where possible.

### A.IV.3 Results

#### A.IV.3.1 API Units

It proved impossible to distinguish the major soil types by API, so the final units were basically physiographic. However, vegetation was used as a subsidiary aid, particularly where high trees tended to mask minor breaks of slope. Four landform/API units were demarcated.

Granite Area:

This is a block of land in the western part of the area covering about 1180 hectares. The crests of the interfluves are characterised by small convex hills, flat 'boiler plate' weathering surfaces, or long strike-aligned rocky ridges. The connecting slopes are usually gently graded and rectilinear, but are frequently interspersed with rock outcrops of varying size. The vegetation is tree savanna,usually sparse or moderate and rarely thick.

Cuirasse Plateau:

This unit forms the crests of the interfluves in the eastern part of the area and covers about 2060 hectares. The plateaux are low and either flat or slightly concave, with areas of restricted internal drainage in the centres. The plateaux are bounded by scarp features, but these are so low in places that they could not be distinguished by API.

The vegetation on the plateaux is variable but consists of fairly open savanna, often with dense thickets, or open savanna woodland. Vine forests and dense savanna woodland often extend right to the plateaux edges but rarely occur on the plateaux tops. Where solid cuirasse outcrops over a significant area, there may be no vegetation at all or only a sparse grass cover.

Bandama Terrace:

There are two terraces distinguishable along the Bandama, the upper of which is by far the most extensive. They cover about 300 hectares. They have a very distinctive photo image as they are virtually flat and covered with a thick grass savanna, with rare large scattered trees.

Connecting Slopes:

This is the most extensive unit and covers about 8100 hectares. For this reconnaissance it refers to the landscape lying below cuirasse escarpments. The connecting slopes in the granite area to the west were not demarcated separately.

The slopes are mostly gently graded and rectilinear in form, except for very small concave sections at the highest points just under the scarp, and more extensive convex sections at the foot of the slope, where recent downcutting by streams has stripped off slopewash deposits.

Included in this area are small patches of hydromorphic soils in valley bottoms. These have a distinct photo image but are too small to warrant demarcation at reconnaissance level.

A.IV.3.2 Soils and Cane Suitability of API Units

In assessing the cane suitability of the API units, a fairly generalised four class rating was used. The approximate correspondence between the reconnaissance assessments and those used in the detailed soil survey are shown in Table A.IV.1. It must be borne in mind that reconnaissance land suitability units were defined on the assumption that 100 per cent mechanical harvesting would be undertaken from the start of the project.

TABLE A.IV.1 Reconnaissance and Detailed Survey Cane Suitability Ratings

| Reconnaissance | | Detailed | |
|---|---|---|---|
| A | Good | I | Excellent |
| B | Moderate | II | Good |
| C | Marginal | III | Moderate |
| D | Unsuitable | VI | Unsuitable |
| | | IVw | Special Class |

For each of the API units the soils and cane ratings are as follows:-

Granite Area

This unit contains a varied assemblage of soils. There are numerous rock outcrops, some of which are quite extensive. There are some deep, gravel-free, well drained, medium textured soils but there are also extensive areas of shallow and stony soils. Because of the high incidence of surface stones and rock, this unit was assessed as unsuitable and given a Class D rating.

Cuirasse Plateau

Much of this unit consists of sheet cuirasse or very stony or rocky land. The intervening areas have red very gravelly clay soils, some of which are very shallow overlying hard cuirasse or very compact plinthite. Because of the high incidence of surface stones and rocks this unit was also considered unsuitable and given a Class D rating.

Bandama Terrace

The soils in this unit are generally medium-heavy textured, with high silt and fine sand contents. Drainage is good or imperfect. Because of the suspect drainage and the possible flood hazard, the land in this unit was rated as moderate and given a Class B rating.

Connecting Slopes

This unit contains a wide variety of soils. The most extensive soils have dark coloured coarse textured topsoils over a thick stone line of rounded ferruginous gravel set in a reddish sandy clay loam to sandy clay matrix. This gravel layer overlies a colluvial mixture of well weathered rock and soil.

Another common soil consists of moderately deep to deep non gravelly reddish sandy loam-sandy clay over intensely weathered rock. On the downcut lower slopes soil colours tend to be paler and deep coarse textured yellow coloured soils and also shallow grey coarse textured soils over slightly weathered rock predominate. The soil rock boundary in the latter case is often marked by a quartz stone line. Lower slopes are often interrupted by rock and secondary cuirasse and surface quartz stones also occur in places.

Because of the heterogeneous soil cover it was not possible to assign this extensive unit to a single suitability class. Taking our 146 auger inspections in this unit as a sample, we estimated that 60 per cent of the unit consisted of moderate or marginal land and 40 per cent was unsuitable. In the light of our later findings, this estimate appears to be pessimistic, possibly due to an over sampling of sites near streams because of the need to return to stream lines for position confirmation.

The areas and suitability assessment of the API units are summarised in Table A.IV.2.

TABLE A.IV.2 Areas and Cane Suitability of API Units

| API Unit | Area | | Cane Suitability Rating | |
|---|---|---|---|---|
| | hectares | % survey area | | |
| Granite Area | 1180 | 10.4 | D | Unsuitable |
| Cuirasse Plateaux | 2060 | 17.5 | D | Unsuitable |
| Bandama Terrace | 300 | 2.7 | B | Moderate |
| Connecting Slope | 8100 | 69.4 | 60% B or C<br>40% D | Moderate to marginal<br>Unsuitable |

The areas of the land Classes are summarised in Table A.IV.3.

TABLE A.IV.3 Areas of Cane Suitability Classes

| Suitability Class | | Area | |
|---|---|---|---|
| | | hectares | % survey area |
| A | Good | 0 | 0 |
| B | Moderate | 300 | 2.7 |
| B-C | Moderate to marginal | 4,860 | 41.8 |
| D | Unsuitable | 6,480 | 55.7 |
| | Total | 11,640 | 100.0 |

These estimates erred on the side of pessimism by the blanket exclusion of the granite and cuirasse plateau areas and by the lower slope bias in the sampling of the connecting slope unit. However, the assignment of the Bandama terraces to Class B may be optimistic in that the flood hazard may turn out to be quite severe.

## A.IV.4 Conclusions

The reconnaissance estimates that there are 5100 hectares of land suitable for irrigated cane development. Given the cursory nature of the survey, this is close enough to the minimum required area of 6000 hectares to justify continuing with the detailed soil survey.

## APPENDIX V

## ALTERNATIVE CROPS

The main emphasis on the assessment of land quality was its suitability or otherwise for the sustained production of sugar cane under irrigation and on an estate basis.

Although with good management sugar cane is not a crop which places high demands on soil quality, there are factors in this area which have led us to classify some land as unsuitable for cane cultivation which would otherwise be suitable for general cropping.

Soils otherwise suitable for cultivation have been excluded because:

(a) They occur in small non-contiguous units which it would be uneconomic to irrigate.

(b) They occur in larger units containing an unacceptably high percentage of unsuitable material e.g. cuirasse and rock outcrops.

(c) They are sufficiently coarse textured to lead to grave risks of nematode infestation.

(d) They suffer from impeded drainage which it would be uneconomic to ameliorate.

If one consideres other climatically suitable crops to be grown on a smallholder basis, then much of the land considered as unsuitable for sugar cane production for the above reasons could be brought into cultivation.

Many of the cuirasse plateaux areas which have been mapped as Class VI do contain a significant area of better quality soils occurring as small scattered units. The delineation of such small units is beyond the scope and scale of this study. However, the percentages of suitable and unsuitable land within such areas can be deduced.

In terms of suitability for smallholder cultivation, 14,400 hectares of the 20,656 hectares surveyed can be considered suitable for this purpose. Of these 14,400 hectares of cultivable land, some 6,200 hectares will be developed initially for cane production, with the possibility of some further expansion of this area. Nevertheless a significant area of cultivable land will not be put under cane. Indeed, some 3,500 hectare of the area mapped as Class VI on the cane suitability map could be used for smallholder production.

With a 5 to 6 month period without a marked moisture deficit; uniformly high but not excessively high temperatures; and adequate insolation there is a wide range of crops which are climaticlly suited to the area. The choice of specific crops will be dictated to some extent by soil conditions, although economic factors and local preference are more important. Soil volume is the major limiting factor in the area and, as a result, crops requiring a large soil volume cannot be recommended.

Hydromorphic soils are unsuitable for many crops without major improvement in drainage but are frequently well suited to rice cultivation with minor improvements. Coarse textured soils have low moisture holding capacities and are not suitable for crops with a high moisture requirement especially when such crops are of a shallow rooting habit.

In all soils of the area nutrient reserves are low, and specific problems like high phosphate retention capacity in the cuirasse soils and possible aluminium toxicity in the same soils occur. Consequently, sustained cropping to give reasonable yields can only be achieved with adequate fertiliser use or with an adequate fallow period in the rotation combined with management techniques designed to conserve fertility.

The suitable soils of the area can be divided roughly into four categories:

(1) Red ferralsols with high gravel content occurring on the plateaux; they have a rather scattered distribution with intervening areas of cuirasse at or near the surface.

(2) Reddish acrisols with variable gravel content occurring on plateaux and connecting slopes.

(3) Coarse textured regosols associated with granite and gneiss outcrops or lower slope positions.

(4) Hydromorphic soils of valley bottoms and terraces.

The soils of group (1) and (2) are essentially similar in their suitability for cropping. The fine earth fraction of both contains moderate to high clay contents and their physical properties in terms of structure and consistence are favourable. Exceptions occur where erosion has restricted the solum depth and compact highly weathered rock parent material occurs within rooting depth. However, the main limitation inherent in these soils is their variable, but generally high, gravel content which effectively limits soil volume. Consequently, they are unsuitable for crops which require large soil volumes, but are moderately suited for most of the crops commonly grown in the surrounding area.

Cropping practices which would accelerate soil erosion must be avoided to prevent reduction of the already limited soil volume. The soils are very abrasive and would very quickly wear away the light hand cultivation implements used by smallholders.

Soil conditions are generally suitable for the cultivation of maize, sorghum, millet and cotton. Groundnuts are of more limited suitability because of the very low calcium reserves and high phosphate fixation capacity of the most highly weathered soils. Yams and sweet potatoes can be recommended, especially if grown on ridges or mounds to increase effective soil volume. These crops are generally less demanding of phosphate status then are groundnuts; they have a considerable requirement for potash, but this element is better represented in many of the soils than the other macronutrients. Castor bean might also be a possible crop, but it does require soils of at least moderate fertility and has a moderately high requirement for phosphorus. Therefore it should be restricted to the more fertile soils. Inadequate soil volume and excess subsoil aluminium will render many of these soils unsuitable for cotton.

The coarse textured regosols have been considered unsuitable for sugar cane because of the risk of nematode damage. However, a large proportion of these soils is suitable for agriculture, except that in close association with granite and gneiss outcrops where the coarse texture is further enhanced by high quartz gravel and grit. The coarse textured soils are of low fertility and have limited water holding capacity, but are generally deep and root development is unrestricted.

With reasonable management, adequate yields of the relevant crops could be expected on these soils. They will require fertiliser application. Sorghum and millet could be grown successfully on most soils and maize on the medium textured soils. Groundnuts are quite well suited to these soils. Yams and sweet potatoes are less well suited, although adequate yields could be obtained with fertiliser. Yams and potatoes have a fairly high potassium uptake, but require only limited nitrogen. However, sweet potatoes are susceptible to nematode damage, and for this reason should not be grown on sandysoils if a high nematode population is suspected.

Cotton should be suitable for the better of the coarse textured soils, especially those with a good rooting volume. Where the water holding capacity is low, rainfall distribution will be critical in yield determination. Tobacco and sunflower are reasonably well adapted to sandy soils. Tobacco has a low nitrogen requirement and is a suitable crop provided the soil moisture status is adequate.

Soil moisture is likely to be limiting on most of these soils, unless irrigation is practised, and a dry spell after germination of seeds may lead to serious crop losses.

Hydromorphic soils occupy a significant total area, but have a very scattered distribution within relatively small valley bottoms and drainage lines. Only on the lower Bandama terraces do larger blocks of land occur. Within the smaller valleys, the hydromorphic soils are generally coarse textured and could be drained for general cropping. However, it may be more economical to use these lands for rice production with some levelling and water control by bunding. Interceptor drains will be required to remove surface run-off originating from the upper slopes.

Along the valley edges where the soils are subject to a rising water table but not to overflow, yams and sweet potatoes could be grown on raised beds.

On the lower Bandama terrace the soils frequently are finer textured and irrigated rice cultivation could be practised. Other possible crops for hydromorphic soils are the root crops *Colocasia esculenta* (taro) and *Xanthosoma sagittifolium* (tania or yam des angiosaxons) both of which have high moisture requirements. However, these crops are not, at present, much cultivated in the area.

Apart from the major crops mentioned above, fruit trees and vegetables would be regarded as garden crops to be cultivated around dwellings.

There is a conflict of requirements between estate type agriculture typified by cane cultivation and the type of agriculture likely to be practised by small holders.

Sugar cane cultivation demands large blocks of cultivable land and intensive management systems with close control of irrigation, fertiliser application and pests and diseases to ensure optimum crop yields and a product suitable for export from the area. Smallholder cultivation is likely to be at a subsistence level and would mainly comprise crops for home consumption and animals - cattle, sheep and goats.

Estate and smallholder cultivation are not compatible and the agricultural practices of smallholders will conflict with the requirements for sugar cane.

Cultivation of many smallholder crops, particularly if practised without an adequate rotation system, leads to a build up of pests and weeds which are deleterious to cane. The cultivation of the staple cereal crops of maize and sorghum leads to a build up of borers. Kenaf plantings result in an increase in nematodes. Serious crop damage would result if borers or nematodes spread to the cane areas.

Also animal husbandry is not acceptable on an estate because of damage to cane perpetrated by grazing animals.

Without irrigation, crops are likely to suffer if a dry period occurs, after seed has germinated. With irrigation the soils will rapidly lose fertility unless fertilisers are applied.

Therefore if the area is to be used for a sugar cane plantation then smallholder agriculture must be excluded.

# IVORY COAST

SCALE : APPROX 1:20,000

Interim copy only.

Boundaries derived from uncontrolled mosaics and subject to revision.

**LAND SUITABILITY LEGEND**

| LAND CLASS | SUITABILITY |
|---|---|
| I | Excellent |
| II | Good |
| III | Moderate |
| IVw | Special class for soils with restricted drainage. |
| VI | Unsuitable |

**LIMITATIONS**

| | |
|---|---|
| Effective soil depth (with impermeable limiting horizon) | r |
| Effective soil depth (with permeable limiting horizon) | d |
| Stone or gravel content | g |
| Texture | t |
| Surface outcrops or boulders | p |
| Flood hazard | f |
| Soil drainage | w |
| Gully erosion | e |

# IVORY COAST

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SOIL LEGEND

| SOIL SERIES | PHASE | DESCRIPTION |
|---|---|---|
| 1 | | Shallow soils (30 cm or less) over granite or gneiss. |
| 2 | | Shallow soils (30 cm or less) over cuirasse. |
| 3 | | Red gravelly fine textured soils of plateaux and upper connecting slopes. |
| | 3s | Red gravelly relatively shallow (30-60 cm) fine textured soils. |
| 4 | | Deep nongravelly fine textured soils. |
| | 4y | Deep nongravelly fine textured soils with yellow colours dominant. |
| 5 | | Deep nongravelly fine textured soils with significant amounts of quartz grit. |
| 6 | | Soils with distinct gravel layer, typical of connecting slopes. |
| | 6b | Soils with gravel layer below 40 cm. |
| | 6c | Gravelly soils, coarse textured to depths of 60 cm or more. |
| 7 | | Deep nongravelly soils with a coarse textured surface horizon thicker than 30 cm. |
| 8 | | Deep nongravelly coarse textured soils. |
| 9 | | Shallow soils over partially weathered rock, often with quartz stoneline. |
| 10 | | Deep pale coloured coarse textured soils of lower slopes. |
| 11 | | Hydromorphic soils of valley bottoms. |
| 12 | | Medium textured soils of Bandama teraces. |