NATIONAL WATER RESOURCES COMMISSION

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RECONNAISSANCE SOIL SURVEY AND LAND EVALUATION FOR IRRIGATION PURPOSES OF AN AREA NEAR RO'BIT (SHEWA)

S. Paris
FAO Consultant
Project FAO/ETH/82/008

December 1986

A COOPERATIVE PROJECT OF THE GOVERNMENT OF ETHIOPIA,
THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
AND THE UNITED NATIONS DEVELOPMENT PROGRAM

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ABSTRACT

A reconnaissance soil survey of approximately 2700 ha in the Robit valley was carried out by two FAO consultants during the last week of October 1986. The objective of this survey is to provide information on the soils of the Robit valley and to give recommendations on their suitability for irrigated agriculture.

A soil map at 1:55 000 scale was produced subdividing the area in ten mapping units. Each mapping unit is described in terms of a relatively large number of land and soil characteristics.

Land evaluation was carried out for fourteen selected irrigated crops. The main assumptions for this evaluation are, that:

- A drainage system will be constructed (major land improvement).
- Three minor land improvements will be carried out.
- The organizational form of the scheme will be either statefarm or producers cooperative.
- Cultivation will be partly mechanized, fertilizers will be applied and crop protection will be realized.

The main conclusions of the land evaluation are, that:

- A total area of 530 ha is highly suitable for irrigation development.
- A total area of 1060 ha is moderately suitable for irrigation development.

Other conclusions are, that double cropping can be practised, relying on irrigation supplementary to precipitation and that specifications for the irrigation and drainage design can not be given at this stage. At the end of the report recommendations are given for a high intensity soil survey of selected parts of the area.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 Objective of the study

Presently, the Medium Dam and Irrigation Design Unit of WRDA, in cooperation with a Yugoslavian irrigation design team, is in the process of planning an irrigation scheme in the Robit valley, which relies on a dam in the Robit river.

The objective of the present study is to provide, at reconnaissance level, information on the soils of the Robit valley with particular emphasis on their suitability for irrigated agriculture. The data presented in this report will serve as valuable information for the decision where to irrigate, for the choice of crops to be irrigated, for the design of the irrigation scheme etc..

1.2 Methodology

A reconnaissance soil survey of the Robit valley was carried out by two soil surveyors during a period of six days in late October 1986. In total 42 soil observations were made:

- 15 soil pits of approximately 150 cm depth were made. The soils exposed in these pits were described and sampled; pH and EC values of all mayor soil horizons were determined. In total 60 samples were taken to the laboratory for routine analysis.

- 27 augerings to a depth of approximately 120 cm were made. Soil characteristics were described in as much detail as is possible from the auger; pH and EC values were determined for all major soil horizons.

Additional observations of soil physics were made:

- Three infiltration tests in triplicate were carried out near three of the above soil pits. A double-cylinder infiltrometer was used. Each replicate site was prewetted with at least 100 l of water circa 18 hours before the test started.

- Core samples were taken in duplicate at three depths in each of the three pits, near to which infiltration tests were carried out. These core samples were taken to the National Soils Laboratory for analysis of bulk-density and pF-curves.

Good quality aerial photography at a scale of approximately 1:55 000, flown in 1957, are available for the area. Since topographic maps of the area at a suitable scale do not exist, the aerial photographs were used as basemap. They were used for orientation (which proved difficult in some areas due to a complete change in land use pattern) and for plotting of observation sites and soil boundaries. Naturally, the photographs were extremely helpful in providing a general overview of the area and in trying to understand the geology and geomorphology of the area.

A topographic survey of the area was under way during the soil survey. However, no additional topographic information became available in time for the present study.

1.3 Reliability of data and results

The average observation density is about 1/70 ha (42 observations in an area of circa 2775 ha). According to FAO (1979a, p.88-89) this density corresponds with a 'medium intensity' or 'reconnaissance' survey. 1:55 000 is a suitable mapping scale for a reconnaissance survey.

Two types of tests, as carried out during fieldwork, have severe limitations:

- Field measurements of pH were partly carried out with an electric pH meter, partly with a colorimetric kit; the last method proved to be fairly unreliable. Colorimetric pH figures are given in the text without digits after the stop.

- Two of the three infiltration tests show a high variation among the three replicates. In addition, the basic infiltration rates of several of these replicates are unlikely high. It seems probable that both the high variation and the high rates are explained by different quantities of water percolating along cracks. Hence, the true basic rates are not known.

It must be borne in mind by the user of this report, that a medium intensity soil survey provides information on the distribution of soils with differing potential for irrigation development. It is not an end-product in itself. It serves as a means for selection of areas, in which surveys of higher intensity for the assessment of irrigation feasibility seem to be justified.

The soil boundaries (see Figure 2) have a limited precision. Their location is not checked in the field, but inferred from geomorphological interpretation and the photo image.

CHAPTER 2

GENERAL DESCRIPTION OF THE AREA

2.1 Location, population and infrastructure

The survey area includes part of the Robit river valley. It is located 220 km to the north-east of Addis Ababa in the north-western part of Shewa administrative region, Yifat and Timuga Awraja, Mafud Woreda and Efrata and Gile Woreda. The survey area covers an area of approximately 2715 ha. (see Figure 1).

The tarmac main road, which connects Addis Ababa with Dessie, crosses the valley. The village of Robit lies on the southern survey area boundary and is located near the bridge of the main road over the Robit river.

A limited number of motorable tracks exists within the survey area (see Figure 2).

The boundaries of the survey area (see Figure 2) are selected along the following features:

- To the west and north the area boundary coincides with the lower limit of colluvial footslopes. These colluvial footslopes were excluded from the study area during the initial stage of the survey; see Chapter 2.2.2 .
- To the east the area boundary follows the Robit river (south of Robit village) and the tarmac main road (north of Robit village).
- To the south the survey area is bounded by an arbitrary strait line, to the south of which, during the initial stage of the survey, commandibility by gravity irrigation was thought to be impossible.

The people, that cultivate the land in the survey area, are members of the Amhara tribe. These people do not live on their land, but are located in four or five villages in or shortly outside the study area. Population density of the survey area is not known.

The major market, to which cash-crops grown in the survey area are being sold, is Addis Ababa. Other (potential future) markets are found in the major towns located along the Addis Ababa-Dessie main road; these towns include Debre

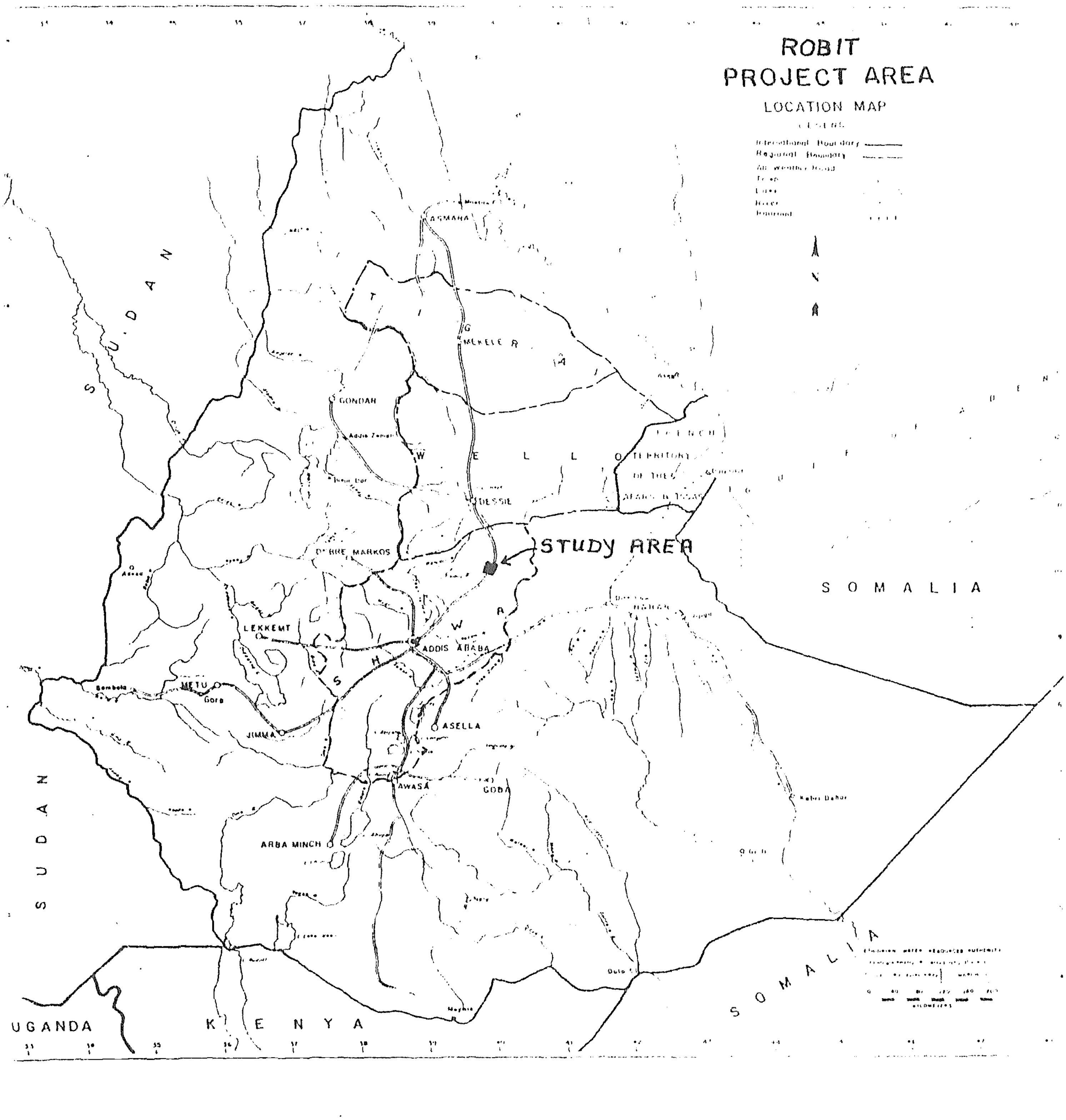


Figure 1. LOCATION MAP

Berhan, Debre Sina, Kombolcha and Dessie.

2.2 Physiography and geology

The survey area is located in the Robit river valley, which lies at the foot of the eastern escarpment of the Ethiopian highlands. Elevation within the survey area varies between approximately 1300 and 1500 m asl.

The present macro-relief of the Robit valley and surrounding areas is mainly the result of a sequence of tectonic events, which took place during the Cenozoic. In the Robit valley, abrupt transitions from mountainside to valleybottom coincide with faultlines.

The only rock types occurring in and around the Robit valley are basalt and related pyroclastics. These rocks are of Tertiary age (Kazmin, 1972). All alluvial and colluvial deposits occurring in the valley are derived from these rocks.

Two different physiographic units can be distinghuished in the valley:

2.2.1 Alluvial plain of the Robit river

The Robit river is a braided stream which slowly incises into the surrounding alluvial deposits. The river has formed several terraces, which' levels are a few meters above the present level of the river bed. Usually, a distinct break of one to three meters elevation difference exists between the riverbed and low terraces as well as between the low and higher terraces. The average slope of both the riverbed and terraces is 1-2 percent.

The alluvial plain of the Robit river is subdivided into three units (the riverbed is excluded from the survey area):

- The riverbed. The riverbed is 200-300 meters wide. It is strewn with boulders with diameters of upto one meter. This unit is excluded from the survey area.
- The low terraces. These terraces have formed in medium textured deposits. They are probably flooded by the river during exceptionally high peakflows.
- The higher terraces. These terraces have formed in

medium to fine deposits. They are not flooded.

2.2.2 Piedmont slopes

The piedmont slopes in the Robit valley are subdivided into four sub-units (the colluvial slopes are excluded from the survey area (see below)):

- Lower piedmont slopes. They have formed on medium to fine alluvial fan deposits and local colluvia. These deposits are probably mixed with Robit river alluvium. This unit has a slope of 1-3 percent.
- Upper piedmont slopes formed on medium textured deposits (alluvial fans). This unit has a slope of 1-4 percent. These fans overlay the upper piedmont slopes described below.
- Upper piedmont slopes formed on fine textured deposits (possibly pediments). Underlying bedrock has not been found within a depth of 2.5 meters. This unit has slopes of 1-6 percent.
- Colluvial slopes. They have formed directly at the foot of mountain slopes in stony, medium to fine textured deposits. Their slope is more than 6 percent. These slopes have been excluded from the survey area, since they are not directly commandable by gravity irrigation water directed from the planned dam site (see also Figure 2). In addition, they are not suitable for irrigated agriculture due to slope and stoniness.

2.3 Climate

Data on rainfall and temperature are available for a station, located at an altitude of 1300 m asl, near the village of Robit. Mean monthly rainfall (P), mean monthly temperature (T-mean) and mean monthly minimum and maximum temperature (T-min and T-max) data exist for 12 years (from 1963 to 1975; for 1974 and for the years after 1975 no reliable data were available). Monthly evapotranspiration (PE) has been calculated by means of the Penman-AGP formula (FAO, 1985a). See Table 1.

Table 1

MEAN MONTHLY RAINFALL (P)(in mm), EVAPORATION (PE)(in mm) AND TEMPERATURE (T)(in °C) FIGURES FOR ROBIT

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
P	50	65	62	126	68	31	171	280	110	24	25	36	1048
PE	105	106	137	133	150	160	137	126	121	129	110	103	1517
T-mean	20	21	23	24	25	26	25	24	24	23	21	20	23
T-min	12	14	15	17	17	17	17	17	17	15	13	12	15
T-max	28	29	31	31	33	34	32	30	30	31	29	28	30

Rainfall is bimodal. The main rainy season occurs from July to September (summer monsoon). A small rainy season occurs between February and May (easterly tradewinds). The temperature regime is warm tropical, with a considerable range between minimum and maximum temperatures.

2.4 Hydrology

The Robit river is a braided stream. It is a high-energy stream during peakflows; the huge boulders (diameters are up to one meter) that occur in the riverbed give evidence of this. The flow during the beginning of the dry season, as observed in October during the survey, is fairly low. The river water is non-saline (ECw < 0.5 dS/ m).

A dam is planned in the Robit river at the site where the river leaves the high relief area and enters the Robit valley (see Figure 2). It is recommended to make a careful study of the feasibility of this dam, in particular in relation to the large sediment load of the river.

Numerous small seasonal streams enter the valley from all directions. They contribute their waters to the Robit river or to groundwater.

During the survey, groundwater was found at several sites in the lower reaches of the survey area. In the low terraces of the Robit river (mapping unit A1) groundwater, probably raised due to irrigation, is found at a depth of 50-100 cm; the water is non-saline (ECw = 0.5 dS/ m). Sub-surface drainage will have to be effectuated if irrigated agriculture is to be continued. In part of the lower piedmont slopes (mapping unit P1) permanent groundwater was found close to the surface; this groundwater is saline (ECw = 6 dS/ m). In all other areas no groundwater was encountered within a depth of 250-300 cm below the surface.

2.5 Land use and vegetation

Rainfed agriculture is the dominant kind of land use in the survey area. Farming practices are mainly traditional: ploughing by ox-plough, use of local varieties of traditional crops, no or very limited use of fertilizers. On slopes steeper than three percent, commonly bunds at regular intervals have been constructed.

The dominant crops that are grown are sorghum (white and brown) and maize. Minor areas are under a mixture of teff and sesame. Chickpeas occur locally.

Irrigated agriculture is a well established form of agriculture in part of the survey area. Irrigation is practised in most of the almost flat to gently sloping alluvial land near the Robit river. Irrigation is probably only practised as supplementary irrigation at the end of the main rainy season. Irrigation water is diverted from the Robit river by means of handdug channels (run-of-river irrigation). Application of irrigation water on the cultivated field is done by temporary breaching of the banks of irrigation channels.

Farmers seem to be mainly organized in producers cooperatives; no modern machines seem to be used. There is one exception: in one area to the north of Robit village tractor ploughing is practised on a prison farm.

The main crops grown under irrigation are sorghum, tobacco and cotton. Fruit crops are mainly grown to the east of Robit: orange, papaya, banana, pineapple and lemon. Minor crops grown are: onion, pepper, tomato and sesbenia. Sorghum seems to be mainly grown for subsistence. All other crops are grown as cash crops and sold to the AMC.

There are considerable livestock numbers in the survey area. Livestock is probably mostly fed with crop residues.

In addition livestock grazes on communal ground. The largest grazing area lies to the north-west of Robit on the left bank of the Robit river in an Acacia woodland area. Livestock consists of cattle and goats.

Very little original vegetation cover is left in the survey area. Probably the only notable area is the Acacia woodland area to the north-west of Robit.

Species, which could be recognized by the surveyors, are typical for the warm footslope areas of the eastern escarpment: Cordia africana, Croton macrostachys, Grewia sp., Calotropis sp. and Acacia sp..

CHAPTER 3

LAND AND SOILS OF THE ROBIT AREA

3.1 Introduction

The land and soils of the Robit area have been mapped at reconnaissance level. In the following text this map is referred to as soil map. See Figure 2.

Good quality aerial photographs at a scale of 1:55 000 exist for the Robit area. Since topographic maps at scales larger than 1:250 000 are not available of the Robit area, the photographs are used as topographic base for the soil map. The major disadvantage is, that scale is not constant throughout the soil map and that area measurements are approximations only. (Area measurements are based on the assumption that one cm.square on the photo equals 30 ha; this corresponds with an average photo-scale of 1:54.800).

Since no accurate topographic maps were available, the area commandable by gravity irrigation (i.e. the area with lower elevation than the contour of the planned dam site) was not known with acceptable accuracy when the survey started. After fieldwork, the location of the dam site contour was estimated on the aerial photographs with the aid of a parallax bar (see Figure 2).

The commandable area is smaller than the survey area: an estimated total of 2225 ha is commandable by gravity irrigation out of a total survey area measuring approximately 2715 ha. Hence, hectarages of mapping units as described in this chapter may differ from hectarages used in Chapters 4 and 5, since in those chapters reference is always made to the commandable part of land units.

In the following section all mapping units are described (see also Table 2 for a summary). For a statement on the reliability of the presented information, the reader is referred to Chapter 1.3. Representative profile descriptions with analytical results are presented in Appendix 1. Land and soil characteristics are as much as possible described according to guidelines as set out in FAO (1977) and NWRC (1985).

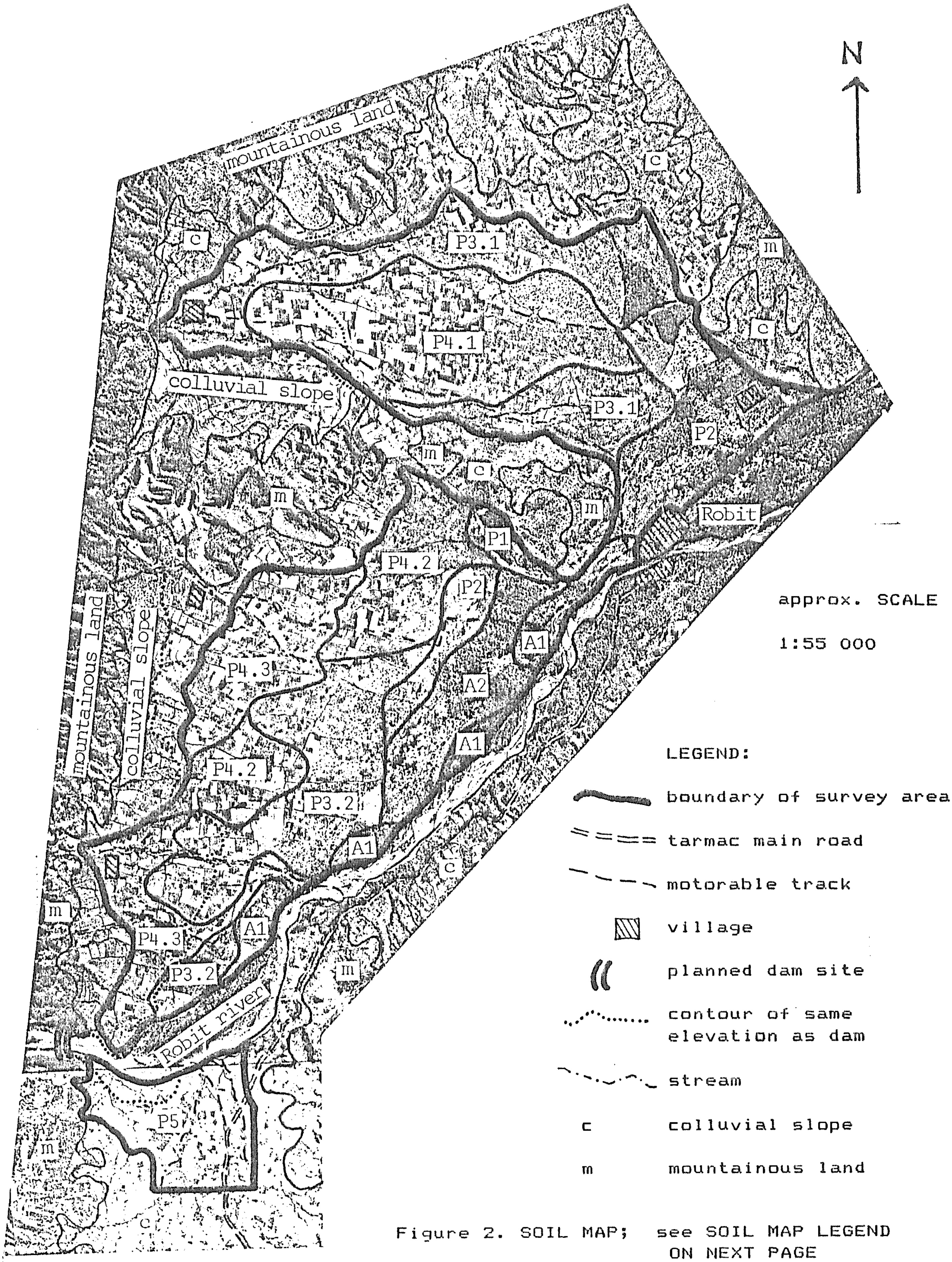


Figure 2. SOIL MAP; see SOIL MAP LEGEND ON NEXT PAGE

TABLE 2 SOIL MAP LEGEND

MAPPING UNIT SYMBOL	PHYSIOGRAPHY	SLOPE (%)	STONINESS (%)	WATER EROSION	SOIL DEPTH (cm)	SOIL TEXTURE	SOIL pH	SOIL COLOUR	SOIL DRAINAGE	SOIL PERMEABILITY	DEPTH TO GROUND-WATER (cm)	FLOODING	SOIL CLASSIFICATION (FAO)
A.	ALLUVIAL PLAIN OF ROBIT RIVER												
A1	Low terraces of Robit river	1-2	none; partly 3-15	none	50-100	L-SiCL	8	v.dark grayish brown	poor-mod.well	slow-mod.slow	variable: 50-100 cm (average)	exceptional flash-flooding	Calcaric Fluvisols, Gleyic Cambisols
A2	Higher terraces of Robit river	1-2	none	locally slight sheet	>150	SiCL	7-8	v.dark gray	mod.well	slow	n.o. >250 cm	none	Orthic Luvisols
P.	PIEDMONT SLOPES												
P1	Lower piedmont slopes	1	0.1-3	slight gully	<50	L	9	v.dark gray	poor	v.slow	variable: 50-100 cm (average)	frequent flash-flooding	Calcaric Gleysols
P2	Lower piedmont slopes	2-3	none	locally slight sheet	>150	SiL-SiC	8	v.dark grayish brown	mod.well	slow	>300 cm	none	Calcic Cambisols, Gleyic Cambisols
P3	Upper piedmont slopes (alluvial fans)	1-4		slight-moderate sheet	>100	sgr L-CL	7-8	dark brown -v.dark gr.brown	mod.well-well	mod.slow	n.o. very deep	locally flashfloods	Eutric Cambisols (with Gleyic Cambisols)
P3.1			none										
P3.2			3-15										
P4	Upper piedmont Slopes (pediments?)				60 - >150	sgr SiC-C	7-8	v.dark gray	imperfect -mod.well	slow	n.o. very deep	none	Pellic Vertisols (with Haplic Phaeozems or Eutric Cambisols)
P4.1		1-3	none	slight sheet									
P4.2		2-4	0.1-15	slight sheet									
P4.3	(dissected)	4-6	3-15	moderate sheet									
P5	Dissected piedmont slopes	2-4	3-15 ; locally 15-90	slight-moderate sheet	50-100	sgr SiCL-C	6-8	v.dark gray	imperfect -mod.well	slow	n.o. very deep	none	Vertic Cambisols

n.o. = not observ

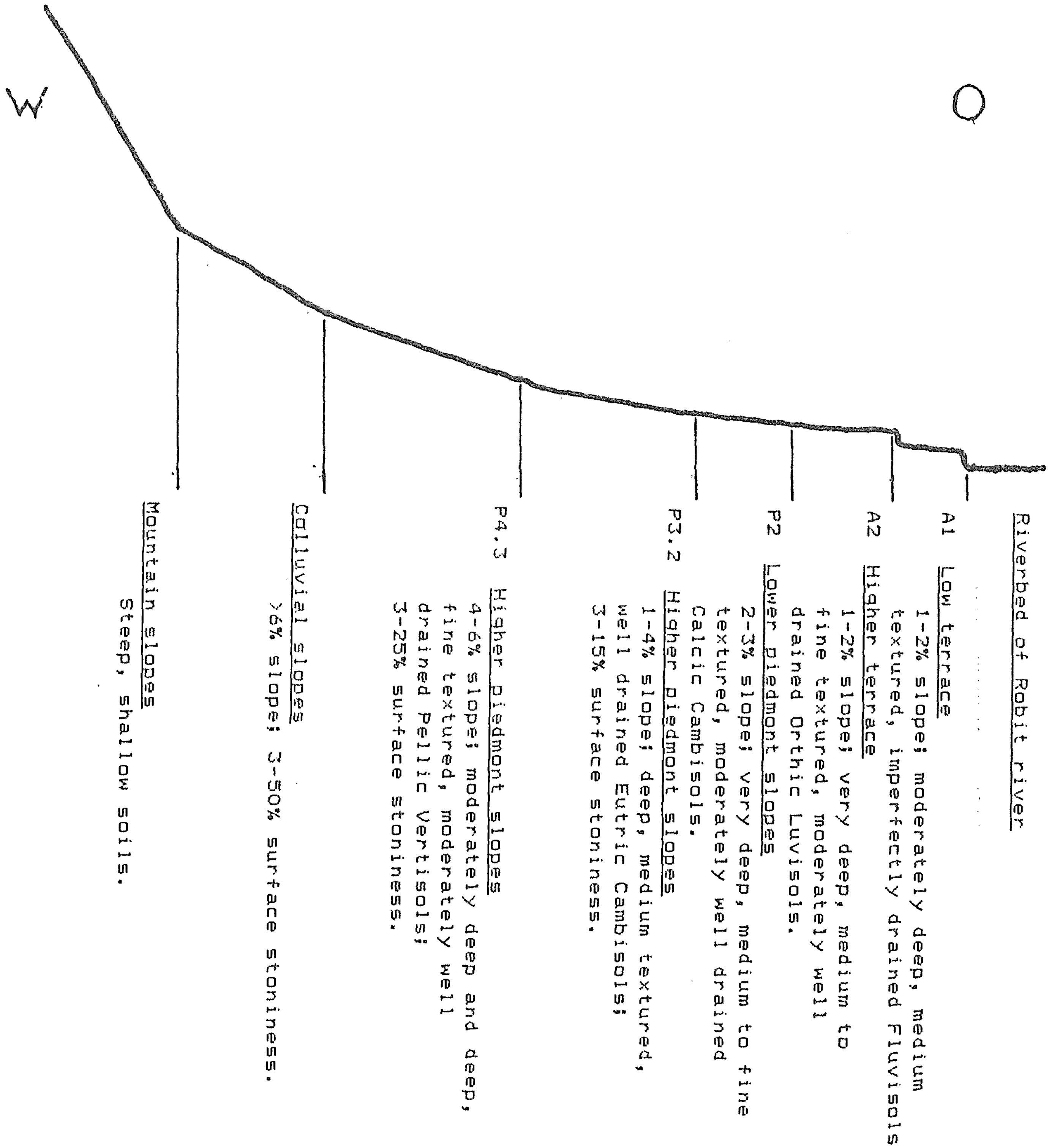


Figure 3. SCHEMATIC CROSS-SECTION THROUGH THE ROBIT VALLEY
horizontal scale is approx. 1:20 000

3.2 Description of the mapping units

3.2.1 Alluvial plain of Robit river

Mapping unit: A1 - Low terraces of Robit river

Location: Four relatively small areas along the west bank of the Robit river.

Total area: 125 ha.

Observation numbers: 47 (pit) and 8 (augering).

Land characteristics: This unit includes the low terraces of the Robit river. Parent material consists of medium textured flood-plain deposits of the Robit river; texture varies from loam in the upstream terraces to silty clay-loam in the downstream terraces. Average slope is 1-2 %. Flash-flooding probably occurs during exceptional peakflows of the Robit river (frequency is probably less than once a year). Within each terrace three subareas exist of approximately equal importance:

- Low lying marshy areas. They are covered with reed vegetation (Cyperus sp.). The fringes are used for cultivation of banana.
- Areas with 3-15 % stoniness. They are mainly covered with grassland and used for grazing; a minor part is used for irrigated agriculture.
- Remaining areas. They are mainly used for irrigated cultivation of tobacco, pepper and onion. Dry-land farming of sorghum, maize and teff also occurs.

Soils: Soils are variable. Not enough soil observations have been made to assess the true variability. Topsoils are high in organic matter and have granular structure. The ground water table is raised, probably due to irrigation and seepage. Effective soil depth varies according to the depth of the groundwater table: average depth probably 50-100 cm; texture is loam to silty clay-loam; very dark grayish brown colour; drainage is variable according to the depth of the groundwater table: probably varies form poor to moderately well. Permeability is slow to moderately slow. pH is around 8; EC is low. EC of groundwater is 0.5 dS/m. Base saturation is very high, with the exchange complex dominated by Ca followed by Mg; Na saturation is low. Free $CaCO_3$ percentage is high. Classification (according to FAO) is Calcaric Fluvisol and Gleyic Cambisol. See Appendix 1, Pedon 1.

Soil profile characteristics (typical for "remaining areas" - see above):

0-15 cm Ap horizon, very dark grayish brown, no mottles, silty clay-loam; soft and very friable, fine granular structure; strongly calcareous, pH=7.6 .

15-65 cm Bw horizon, very dark grayish brown, few faint mottles, silty clay-loam; firm, medium angular blocky structure; strongly calcareous, pH=7.8 .

65-85 cm Bg horizon, dark grayish brown, common distinct mottles, silty clay-loam; friable medium sub-angular blocky structure; strongly calcareous, pH=7.8 .

85-180+ cm Groundwater, Cg horizon, dark grayish brown, clay-loam. ECw=0.5 dS/m.

Mapping unit: A2 - Higher terraces of Robit river

Location: One area on the west bank of the Robit river to the south-west of Robit village.

Total area: 165 ha.

Observation numbers: 6 (pit), 7 (pit), 9 and 10 (augerings).

Land characteristics: This unit includes the higher terraces of the Robit river. Parent material consists of medium to fine textured flood-plain deposits of the Robit river. The average slope is 1-2 %. Locally slight sheet erosion occurs. In the northern part of the unit a small hot spring is located; whitish salt crusts were observed directly around the spring. The dominant land use is irrigated cultivation of sorghum, tobacco, pepper (onion and sesbenia locally). About one third of the unit is covered with Acacia woodland with dense grass ground-cover and is used as communal grazing land.

Soils: Groundwater has not been observed within a depth of 250 cm. Topsoils, where cultivated, have deteriorated to a massive structure (extremely hard when dry). Soil depth is very deep (>150 cm); texture is silty clay-loam; very dark gray colour; drainage is moderately well; permeability is slow. pH = 7 - 8; EC is low. Soils are high in exchangeable bases, dominated by Ca and followed by Mg; saturation with Na is low. (Base Saturation = 100%). CEC is around 40 me/100 g. Org.C in the topsoil is 2%. Classification (according to FAO) is Orthic Luvisol. See Appendix 1, Pedon 2.

Soil profile characteristics:

0-12 cm A(h) horizon, very dark grayish brown, mottles, silty clay-loam; very hard, medium sub-angular blocky structure; non calcareous, pH=7.4.

12-70 cm Bw horizon, very dark gray, no mottles, silty clay-loam, friable, medium sub-angular blocky; non calcareous, pH= 7.2.

70-150 cm Bt horizon, very dark gray, few faint mottles, silty clay; friable, medium sub-angular blocky structure, broken clay cutans; strongly calcareous, pH=7.2.

150-190+ cm Bg horizon, very dark grayish brown, common distinct mottles, silty clay-loam; calcareous, pH=7.4.

Moisture characteristics:

One infiltration test (three replicates) was carried out around pit no.6 . The basic infiltration rates of the three replicates are highly variable (see Appendix 1, Pedon 2); replicate a, with a basic rate of 2 cm/h is probably most reliable (the rates of replicates b and c are probably influenced by infiltration along soil cracks). A basic rate of 2 cm/h is suitable for irrigation development.

At field capacity (pF=2.5), water holding capacity is 44-54 %; at wilting point (pF=4.2) it is 30-37%. Available water holding capacity is 140-170 mm/m. These figures are partly based on an estimated bulk density of 1.2 g/cm3 (see Appendix 1, Pedon 2).

3.2.2 Piedmont slopes

Mapping unit: P1 - Lower piedmont slopes

Location: One area to the west of Robit village.

Total area: 35 ha.

Observation numbers: 48 (pit).

Land characteristics: This unit includes part of the lower piedmont slopes. Parent material consists of layered piedmont alluvium of variable texture; it has probably admixtures of Robit river alluvium. The average slope is 1 %. Flash-flooding seems to occur frequently (probably every year). Two sub-areas are distinguished:

- Low lying marshy area covered with reed vegetation (Cyperus sp.), which covers the largest part of the unit. This area is permanently flooded.
- Area transitional to higher ground. Slight gully erosion; stoniness is 0.1-3 %. This area is under grassland and used for grazing.

Soils: The soils of the permanently flooded marshy area were not examined. The soils of the transitional area are as follows: soil depth is limited due to a relatively high water table: 100-150 cm; soils are stratified: texture varies from sandy loam to silty clay-loam; very dark gray colour; drainage is poor; permeability is very slow. pH is 8.2-8.8. These soils are saline: EC is 1.5-2.5 dS/m. Locally white salt efflorescence is found on the surface. EC of groundwater is 6 dS/m. The exchange complex is dominated by Ca and Na, followed by Mg. These soils are highly sodic: ESP is 40-50. Free $CaCo_3$ percentage is high. Classification (according to FAO) is Calcaric Gleysol, sodic phase. See Appendix 1, Pedon 3.

Soil profile characteristics (typical for "transitional area" - see above):

0-10 cm Ah(g) horizon, dark grayish brown, common faint mottles, silty clay-loam; firm, medium sub-angular blocky structure; calcareous, pH=8.6; EC=2.5 dS/m.

10-50 cm BCg horizon, dark gray, few distinct mottles, sandy loam; non sticky and non plastic, weak structure; calcareous, pH=8.8; EC=1.5 dS/m.

50-130+ cm Cg horizon, very dark gray, no mottles, layered texture loam - silty clay; slightly sticky and slightly plastic, very weak structure; calcareous, pH=8.2-8.8; EC=1.1-1.5 dS/m. ECw=6 dS/m. Groundwater at 90 cm.

Mapping unit: P2 - Lower piedmont slopes

Location: Two separate areas: on to the north of Robit village and one to the west.

Total area: 325 ha.

Observation numbers: 2 (pit), 11 (pit), 16 (pit), 33 (pit), 1 (augering).

Land characteristics: This unit includes the larger part of the lower piedmont slopes. Parent material consists of medium to fine textured piedmont alluvium and local colluvia, probably with admixtures of Robit river alluvium. The average slope is 2-3 %. In part of the area slight sheet erosion occurs. This unit is partly dry-farmed (sorghum and maize) and partly irrigated (cotton, citrus and other fruits, tobacco and tomato).

Soils: The groundwater table is not observed within 300 cm below the surface, except at one site (pit 33), where groundwater is raised to 140 cm due to irrigation. Topsoil usually has a good granular or sub-angular blocky structure. Soil depth is very deep (>150 cm; except where raised groundwater occurs); texture is usually silty clay-loam, silty clay also occurs; very dark grayish brown colour; drainage is moderately well (to imperfect); permeability is slow. pH = 7.3-8.2; EC is low. The soils are high in exchangeable bases, dominated by Ca. $CaCO_3$ percentage is moderately high. Classification (according to FAO) is Calcic Cambisol and Gleyic Cambisol. See Appendix 1, Pedon 4.

Soil profile characteristics:

0-26 cm Ap and Ah horizon, very dark grayish brown, no mottles, loam; hard and friable, medium sub-angular blocky structure; slightly calcareous, pH=7.6 .

26-80 cm Bw horizon, very dark gray, no mottles, silty clay-loam with few basalt gravel; friable, fine angular blocky structure; slightly calcareous, pH=7.6 .

80-165 cm Bk horizon, very dark gray, few distinct mottles, silty clay-loam; friable, fine angular blocky structure; strongly calcareous with many lime mycelia, pH=7.8 .

165-250+ cm Ck horizon, very dark brown, silt loam to silty clay-loam; very friable, medium sub-angular blocky structure; strongly calcareous with few lime mycelia, pH=7.8 .

Moisture characteristics:

One infiltration test (three replicates) was carried out around pit no.2 . Average basic infiltration rate = 5.6 cm/h. (See Appendix 1, Pedon 4). This rate is suitable for irrigation development.

At field capacity (pF-2.5), water holding capacity is 58-64 %; at wilting point (pF=4.2) it is 35-44 %. Available water holding capacity is 200-230 mm/m. These figures are partly based on an estimated bulk density of 1.3 g/cm3 (see Appendix 1, Pedon 4).

P3 - Upper piedmont slopes (alluvial fans). This unit has been subdivided into two phases, differentiated on the basis of stoniness: see below.

Observation numbers: 12 (pit), 40 (pit), 41 (pit), 5, 14, 17, 19, 22, 24, 28 and 42 (augerings).

Land characteristics: This unit comprises alluvial fans. Parent material consists of medium textured piedmont alluvium derived from basic volcanic rocks. The average slope is 1-4 %. Slight or moderate sheet erosion occurs. The land is bunded. Flashfloods occur locally along or at the end of stream channels. Land use is dry-farmed cultivation in bunded fields of sorghum with minor areas of teff mixed with sesame; shrubland also occurs.

Soils: Topsoils have largely deteriorated to massive structure. Soil depth is mainly 100-150 cm due to the occurrence of stone layers, which cannot be penetrated by roots; locally soils are deeper than 150 cm. Texture is slightly gravelly loam to clay-loam; dark brown to very dark grayish brown colour; drainage is moderately well to well; permeability is moderately slow. pH = 7.0-7.5; EC is very low. Base saturation is high, mainly consisting of Ca ions. Classification (according to FAO) is Eutric Cambisol with locally Gleyic Cambisol. Inclusions of Pellic Vertisols, as described in unit P4, occur. See Appendix 1, Pedon 5.

Soil profile characteristics:

0-17 cm Ap horizon, very dark grayish brown, no mottles, slightly gravelly loam; hard, partly massive partly coarse rumb structure; non calcareous, pH=7.1 .

17-80 cm Bw horizon, very dark grayish brown, no mottles, slightly gravelly clay-loam; friable, coarse sub-angular blocky structure; non calcareous, pH=7.1.

80-150+ cm 2C horizon, very gravelly loamy sand - gravel.

<u>Mapping unit: P3.1</u>

Phase: Stoniness: none.

Location: Two areas to the north of Robit village.

Total area: 480 ha.

<u>Mapping unit: P3.2</u>

Phase: Stoniness: 3-15 %.

Location: Two areas to the south-west of Robit village.

Total area: 370 ha.

<u>P4 - Upper piedmont slopes (pediments ?)</u>. This unit has been subdivided into three phases on the basis of slope, stoniness and erosion: see below.

Observation numbers: 3 (pit), 4 (pit), 13, 15, 18, 20, 21, 23, 25, 26, 27, 29 and 30 (augerings).

Land characteristics: This unit includes upper piedmont slopes. Parent material consists of fine textured alluvium derived from volcanic rocks. Land use consists of dry-farmed cultivation of sorghum with minor areas of teff mixed with sesame. Fields are frequently bunded.

Soils: Topsoil quality varies: it has partly deteriorated to massive structure, partly granular structure prevails. Soil depth is variable due to the occurrence at variable depth of stone layers, which cannot be penetrated by roots. Texture is slightly gravelly silty clay or clay; very dark gray (and very dark grayish brown) colour; drainage is imperfect to moderately well. pH = 7-8; EC is very low. These soils are very high in exchangeable bases, mainly Ca and Mg. Classification (according to FAO) is Pellic Vertisol with minor areas of Haplic Phaeozem or Eutric Cambisol. See Appendix 1, Pedon 6.

Soil profile characteristics:

0-18 cm Ap horizon, very dark gray, no mottles, slightly gravelly clay; extremely hard and extremely firm, medium angular blocky structure; non calcareous, pH=7.0 .

18-65 cm AC1 horizon, black, no mottles, slightly gravelly clay; extremely firm, coarse angular blocky structure; common non-intersecting slickensides; non calcareous, pH=7.0 .

65-110 cm AC2 horizon, very dark gray, no mottles, slightly gravelly clay; firm, medium angular blocky structure; many intersecting slickensides; slightly calcareous, pH=7.4 .

110-140+ cm C horizon, very dark grayish brown, no mottles, slightly gravelly silty clay; friable, medium angular blocky structure; few slickensides; calcareous, pH=8.0 .

Moisture characteristics:

One infiltration test (three replicates) was carried out around pit no.4 . The measured basic infiltration rate is highly variable (see Appendix 1, Pedon 6). Replicate a, with a basic infiltration rate of 2.5 cm/h is probably most reliable (the rates of replicates b and c are heavily influenced by infiltration along soil cracks).

At field capacity (pF=2.5), water holding capacity is 63-68 %; at wilting point (pF=4.2) it is 44-46 %. Available water holding capacity is 180-230 mm/m. These figures are partly based on an estimated bulk density of 1.5 g/cm3 (see Appendix 1, Pedon 6).

Mapping unit: P4.1

Phase: Slope: 1-3 %.
Stoniness: none.
Erosion: slight sheet.

Location: One area to the north-west of Robit village.

Total area: 420 ha.

Mapping unit: P4.2

Phase: Slope: 2-4 %.
Stoniness: 0.1-15 %.
Erosion: slight sheet.

Location: Two separate areas to the west of Robit village.

Total area: 275 ha.

Mapping unit: P4.3

Phase: Slope: 4-6 %, dissected.
Stoniness: 3-15 %.
Erosion: moderate sheet.

Location: Two separate areas to the west and south-west of Robit village.

Total area: 350 ha.

Mapping unit: P5 - Dissected piedmont slopes.

Location: One area to the south of Robit village on the east bank of the Robit river.

Total area: 170 ha (boundaries are arbitrary - see Chapter 2.1).

Observation numbers: 45 (pit), 46 (pit), 43 and 44 (augerings).

Land characteristics: This unit comprises dissected piedmont slopes. Parent material consists of slightly gravelly usually fine textured piedmont alluvium derived from basic volcanic rocks; stone layers frequently occur. The average slope is 2-4 %. Surface stoniness is 3-15

%; locally near streams or on eroded sites stoniness is 15-90 %. There is slight to moderate sheet erosion. Land use is dry-farmed cultivation of sorghum with minor areas of teff.

Soils: Average soil depth is 50-100 cm due to the presence of stone layers, which cannot be penetrated by roots. Texture is slightly gravelly silty clay-loam to clay; very dark gray to very dark grayish brown colour; drainage is imperfect to moderately well; permeability is slow. pH=7.1-7.3; EC is very low. These soils are high exchangeable bases, dominated by Ca and Mg. Classification (according to FAO) is Vertic Cambisol, stony phase. See Appendix 1, Pedon 7.

Soil profile characteristics:

0-17 cm Ap horizon, black, no mottles, slightly gravelly clay; extremely hard and extremely firm, massive structure; slightly calcareous, pH=7.1 .

17-35 cm AC horizon, black, no mottles, slightly gravelly clay; very firm, coarse angular blocky structure; common non-intersecting slickensides; slightly calcareous, pH=7.1 .

35-60 cm 2C horizon, black, no mottles, very gravelly and very stony clay ("semi-permeable" to roots); slightly calcareous, pH=7.2 .

60-140 cm 3Bt horizon, very dark brown, common distinct mottles, slightly gravelly silty clay-loam; friable, coarse angular blocky structure; broken clay cutans; calcareous, pH=7.3 .

140+ cm 4C horizon, very dark brown, gravelly silty clay-loam.

CHAPTER 4

LAND EVALUATION FOR IRRIGATED AGRICULTURE

In this Chapter a qualitative land suitability evaluation for irrigation purposes is attempted. It is qualitative, since only a limited amount of data has been collected during the present reconnaissance survey.

4.1 Envisaged farming systems

At present, it is not known who will be the beneficiaries of the Robit irrigation scheme. No political decision seems to have been taken on the future land use under irrigated conditions. At the present stage, for general land evaluation purposes, some assumptions on future land use have been made. It is hoped, that this will provide sufficient basis for land use planning, whichever type of land use will be effectuated in the future in the Robit valley.

The future land use, which is assumed to be established in the survey area, is based on three activities:

- Cultivation of gravity irrigated cash crops. Crops to be considered are: pulses, citrus and other fruit crops, pepper, tomato, tobacco, sugarcane, sunflower, and cotton. Labour intensive; tillage operations are partly mechanized. Management practices nclude application of fertilizers, weeding, crop protection.

- Cultivation of foodcrops for subsistence , which are partly gravity irrigated and partly rainfed. Crops to be considered are: sorghum, maize, teff and pulses. Labour intensive; limited mechanization or ox-ploughed. Improvement of present management practices must be sought in the application of fertilizers, introduction of improved seeds, weeding and crop protection.

- Livestock grazing. Livestock consists of cattle and goats. Grazing on (improved?) pasture land and additional feeding on crop residues either in harvested fields or in the barn. Essential is the return of manure to the field.

Two different management situations or farming systems are considered:

- All farmers who will participate in agricultural activities within the future irrigation scheme will be organized within producer cooperatives. This will make possible a rational use of different types of lands and a proper management of irrigation activities. Irrigated cash crops are sold to the Agricultural Marketing Corporation. Subsistence farming and grazing activities can be practised on lands which are not or less suitable for irrigation development.

- The irrigation scheme will be run as a statefarm. Farmers can possibly work as employees on the statefarm and practice subsistence farming and grazing activities on lands which are not or less suitable for irrigation development.

For both farming systems the following assumptions are made:

- Appropriate sub-surface drainage will be effectuated. This is a major land improvement which requires considerable investment. Under irrigated conditions the salinization hazard is serious in several of the land units.

- Minor land improvements (bunding, minor flood protection works and topsoil amelioration) will be carried out wherever necessary.

- Supply of irrigation water is adequate and never a limiting factor.

- (Supplementary) irrigation enables two separate growing periods per annum (December-May and June-November).

4.2 Land utilization types and land improvements

Land utilization types (LUT's) that are considered for land evaluation are irrigated single crops. Rainfed crops and livestock grazing are not evaluated. The fourteen selected irrigated LUT's are:

- sorghum
- maize
- beans
- soybean
- groundnut
- sunflower
- tomato
- pepper
- cotton
- tobacco
- sugarcane
- citrus
- banana
- pineapple

Only one management level is considered: it is labour intensive; tillage operations are at least partly mechanized (in particular tractor-ploughing). Improvements in management, as compared with present activities, are mainly in more rigorously organized management, in the introduction of improved seeds, application of fertilizers and crop protection.

One major land improvement, i.e. the construction of a sub-surface drainage system, is assumed to be effectuated. Without such a system the irrigation scheme is thought to be not feasible. A drainage system is envisaged for land units A1, A2, P2 and possibly P4.1 . Specifications of such a system are left to further detailed studies.

Three minor land improvements are assumed to be effectuated wherever necessary:

- Amelioration of topsoils by application of manure. Some topsoils have deteriorated to massive structures. If manure is returned to the field instead of being used as fuel, topsoils may improve. This has a positive influence on the land quality workability.

- Bunding. Presently, no bunding has been effectuated on land with slopes below 2-3 %. Bunding will reduce overland-flow and sheet erosion. This has a positive influence on the land quality erosion hazard.

- Localized flood protection. Several little streams need some form of flood protection along their courses.

4.3 Relevant land characteristics and land qualities for evaluation of irrigated agriculture

Temperature regime:

Temperature data for Robit station (see Chapter 2.3) are considered to be representative for the whole survey area. (Temperature differences within the total range in elevation of circa 200 meters are considered to be irrelevant). The temperature regimes for the two growing seasons are 21-26 °C and 20-25 °C; for land evaluation purposes one temperature regime of 20-26 °C has been used for both seasons (see Table 4).

Moisture availability and length of growing period:

Moisture availability is a resultant of many factors; no attempt will be made to make a fair estimate. Since all soils in the survey area have available moisture capacities above 100 mm (see Appendix), it may be assumed that all soils have sufficient buffer capacity against short term drought. Since irrigation water is assumed to be not limiting (see Chapter 4.1), also moisture availability is assumed to be not limiting.

The data presented in Table 1 (Chapter 2.3) and estimates of windspeed and radiation have been used for the calculation of the Length of Growing Period (LGP) (FAO, 1985a). The growing period is defined as the period during the year that P/PE > 0.5, plus a period required to evapotranspire 100 mm of stored available soil moisture. The LGP indicates the number of days during which both temperature and soil moisture permit crop growth. (For more information on LGP's, see FAO, 1978).

Table 3

LENGTH OF GROWING PERIODS (LGP) FOR ROBIT

NUMBER OF YEARS	NUMBER OF LGP'S	DURATION OF LGP1	DURATION OF LGP2	DURATION OF LGP3	TOTAL LGP
5	2	84 days	134 days		218 days
7	3	59 days	86 days	70 days	215 days

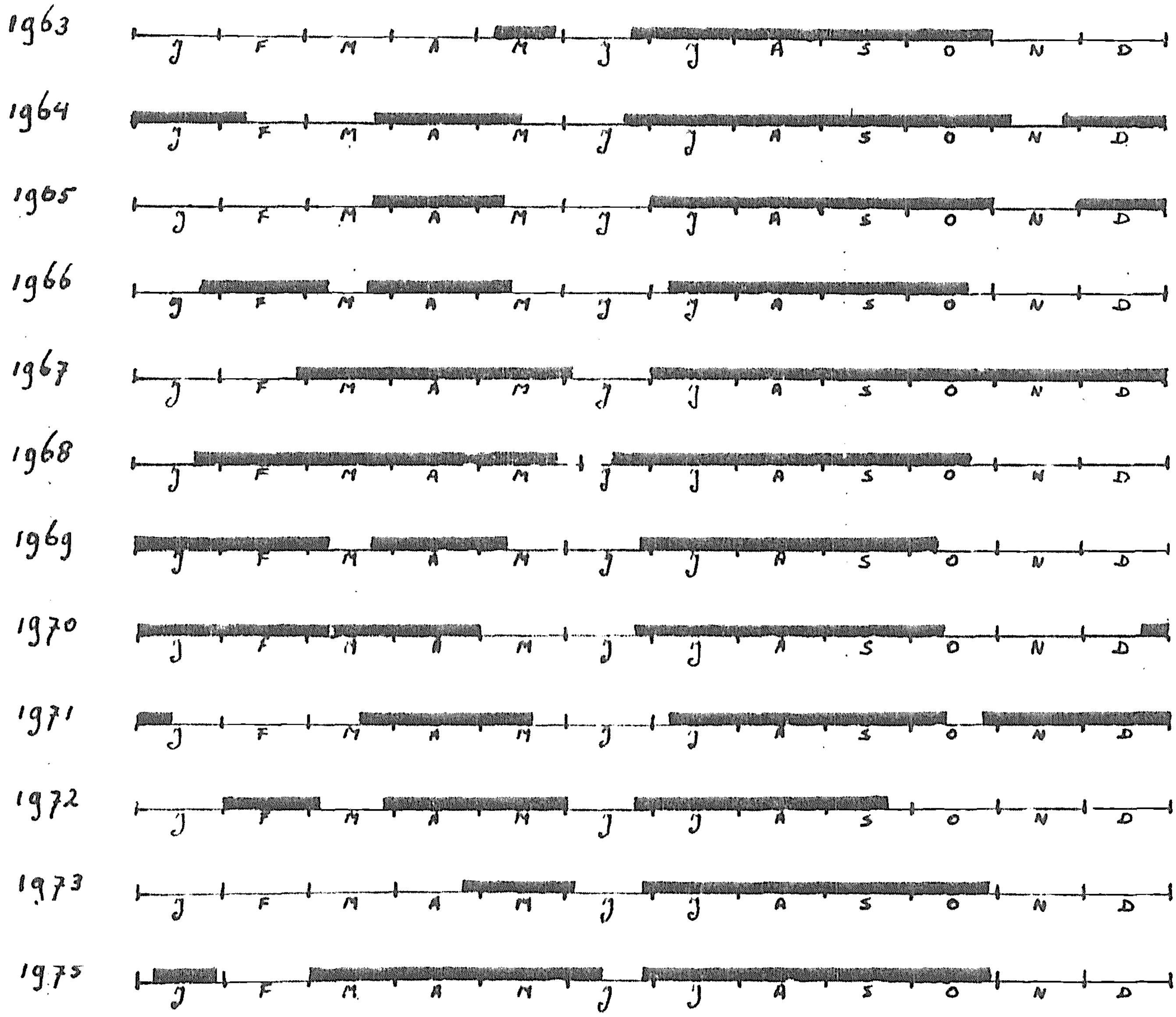


Figure 4 LENGTH OF GROWING PERIODS FOR ROBIT

Analysis of the climatic data of 12 years for Robit station result in estimates of LGP's and of gaps between LGP's (FAO, 1985a) presented in Table 3 and Figure 4. Two or three LGP's occur during a year. Standard deviations for individual LGP's are in the order of 30-40. Hence, these data must be used as indications only and not for quantative analysis. The results presented in Table 3 indicate, that individual growing periods are fairly short and must be classified as marginally suitable for most crops under rainfed conditions. (Both normal and intermediate growing periods occur; the main period from July-October is always normal; it varies for the other periods.) In contrast to this, the average total LGP is long (216 days).

The duration of individual growing periods may not be sufficient for crop growth under rainfed conditions. Supplementary irrigation can provide the additional moisture needed.

It is concluded, that with the aid of supplementary irrigation two growing seasons per year (for most annual crops) can be created; these growing seasons include a dry period both at the beginning and end of each growing period to allow seedbed preparation respectively ripening and harvesting. The two growing seasons cover the periods:

1) From June till November
2) From December till May

Figure 4 shows, that during the June-November growing season many (short duration) crops can be grown under rainfed conditions; supplementary irrigation may be needed at the end of the rainy season (October), in particular for crops with longer growth cycles. During the December-May growing season supplementary irrigation is needed for growing any crop. Since natural rainfall is highly erratic during this period, supplementary irrigation may be needed at any time during the course of this period.

Nutrient availability:

Present levels of N and P are not known (no analytical data). K levels are around 1-2 me/100g, which is adequate for growing any crop. Present levels of Ca and Mg are very high. Micronutrients have not been analysed. pH for all soils is between 7 and 8.2 (with the exception of unit P1, which has higher pH). Present levels of N,P and K are likely to reduce under future intensive irrigated cultivation. This possible situation is considered as non limiting, since shortages (which will certainly occur in a double cropping situation) can be overcome by application of fertilizer.

Oxygen availability:

Oxygen availability is considered to be mainly a function of drainage class, with one modification. It is assumed that a sub-surface drainage system will be constructed in order to keep groundwater levels at adequate depth (major land improvement); this makes oxygen availability mainly dependent of inherent soil characteristics such as texture and porosity.

Rooting space:

Rooting space is a fuction of effective rooting depth (depth to an impermeable layer, hardrock or permanent groundwater). In addition, rooting depth is slightly reduced in soils with swelling and shrinking clays (destruction of roots). Rooting depth of land unit A1 will be increased by lowering of groundwater by the sub-surface drainage system. See Table 4.

Workability:

Workability is a function of stoniness, soil texture and structure. It is considered for tractor-ploughing. Topsoil amelioration by manuring (minor land improvement) is assumed to be carried out wherever necessary. See Table 4.

Present salinity and sodicity:

Actual salinity and sodicity are high in land unit P1 and low in all other land units. It makes unit P1 unsuitable for crop cultivation.

Erosion hazard:

Erosion hazard is a function of slope angle and infiltration rate. Although many more soil characteristics play a role (texture, structure, organic matter content), they are left out of consideration, since they are components of the rate of infiltration. Slope lenght is taken as a constant (> 200 m). Erosion hazard may be reduced by construction of bunds in some mapping units (minor land improvement). Land levelling is not considered to be an economically feasible option at present .

Salinization hazard:

Salinization is considered to be an important land quality, which however is difficult to estimate. It is mainly a function of actual salinity, the quality of irrigation water, the level of the present groundwater table, the permeability of the subsoil and the quantity of percolating water originating from inefficient irrigation practices in upslope areas. Salinity levels are likely to build up in the future, in particular in the lower reaches of the survey area. Quantification of this hazard has not been attempted at the present stage.

In the present study, it is assumed, that the construction of a sub-surface drainage system (major land improvement) will keep the groundwater and salinity at levels which do not interfere with crop performance (with the exception of land unit P1).

Flooding hazard:

Flooding risk refers to the destructive action of running water. Ponding is not included, since it is covered by the drainage component in oxygen availability. It is assumed that flood protection will be effectuated along small streams wherever necessary (minor land improvement), with the exception of land unit P1.

Climatic hazard:

Hail is known to occur in the survey area. The degree of incurred damage to crops is not known.

4.4 Class determining land qualities and crop requirements: matching

All relevant land qualities for physical land evaluation are described in Chapter 4.3 . Some of these land qualities can be considered, for different reasons, as being constant for the whole survey area or as not differentiating. Only those land qualities, that contribute to a differentiation in land suitability for irrigated agriculture, are used in the matching process.

The land qualities, which are differentiating in terms of land suitability and which therefore are selected as class determining land qualities, are:

- Temperature regime
- Oxygen availability
- Rooting space
- Workability
- Erosion hazard

In Table 4 each of these land qualities has been rated in a qualitative manner for each mapping unit. The land qualities have been presented in the form of limitations.

Not-differentiating land qualities are:

- Moisture availability (irrigation ensures adequacy).
- Nutrient availability (use of fertilizer rules out shortages).
- Hail (no data).
- Flooding hazard (only for land unit P1).
- Present salinity (only for land unit P1).

The crop requirements which are used in the present study are presented in Table 5. Crop requirements are mainly derived from FAO (1986), FAO (1985b), FAO (1979b) and Acland (1971). Sensitivity or resistance to erosion and flooding have been omitted from the table since these requirements have been assumed to be equal for all crops. Workability requirements of individual crops are not considered, since it is assumed that topsoil quality can be raised to the required standard by adequate inputs. Tolerance to salinity is included as a matter of interest.

The land suitability tables for individual crops, which are the result of matching land qualities with crop requirements, are included in the Appendix.

4.5 Land suitability classification

The land suitability classes are defined as follows (see also FAO, 1976):

- S1 - Highly suitable. Land having no significant limitations to the sustained application of a given use.
- S2 - Moderately suitable. Land having limitations which in aggregate are moderately severe to the sustained application of a given use; production levels will be reduced and/or costs will be increased when compared with S1.
- S3 - Marginally suitable. Land having limitations which in aggregate are severe to the sustained application of a given use; production levels will be reduced and/or costs will be increased such that it is economically marginal for the defined use.
- N - Not suitable. Land having limitations so severe as to preclude any possibility of successful sustained use in the given manner.

Land suitability subclasses are indicated with a suffix (e.g. S2o). Suffixes used are:

- t - limitation due to temperature regime
- o - limitation in oxygen availability
- r - limitation in rooting depth
- w - limitation in workability
- e - limitation due to erosion hazard

In Table 6 the land suitability of the fourteen crops under consideration is presented for each of the ten mapping units. This table is a summary of the land suitability tables for individual crops included in the Appendix. Generalized land suitability for irrigated agriculture is presented in Table 7 and presented in the form of a map in Figure 5.

TABLE 4 DIFFERENTIATING LAND QUALITIES FOR IRRIGATED AGRICULTURE (qualitative)

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	20-26 °C , equal for all mapping units									
LIMITATIONS IN OXYGEN AVAILABILITY	slt	slt	mod	slt	none	none	slt	slt	slt	slt
ROOTING DEPTH (see footnote)	4	5	2	5	4	4	3+4	3+4	3+4	3
LIMITATIONS IN WORKABILITY	none	none	mod	none	none	mod	none	mod	sev	sev
EROSION HAZARD with bunding	none	none	slt	none	mod	mod	mod	mod	sev	mod

Explanation of abbreviations: slt = slight, mod = moderate, sev = severe

2 = 25-50 cm
3 = 50-100 cm
4 = 100-150 cm
5 = >150 cm

TABLE 5 CROP REQUIREMENTS
(land qualities equal for all crops are not included in this table - see text).

	TEMPERATURE REGIME (T-mean) (°C)			SENSITIVITY TO LIMITATIONS IN OXYGEN AVAILABILITY	ROOTING DEPTH REQUIREMENT(cm)			TOLERANCE TO SALINITY
	s1	s2	s3		s1	s2	s3	
BANANA	23-28	20-32		mod. tolerant	>50	>25		sensitive
BEANS	15-25			mod.sensitive	>75	>50	>25	sensitive
CITRUS	22-29	20-33		sensitive	>150	>100	>75	sensitive
COTTON	22-30	20-32		mod.tolerant	>150	>100	>75	tolerant
GROUNDNUT	22-28	18-33		sensitive	>100	>75	>50	mod.sensitive
MAIZE	16-26			sensitive	>100	>75	>50	mod.sensitive
PEPPER	18-27			mod.sensitive	>75	>50	>25	mod.sensitive
PINEAPPLE	22-26	20-30		sensitive	>50	>25		mod.tolerant
SORGHUM	17-30			mod.tolerant	>100	>75	>50	mod.tolerant
SOYBEAN	22-29	20-35		sensitive	>100	>75	>50	mod.tolerant
SUGARCANE	22-30	20-32		mod.tolerant	>150	>100	>75	mod.sensitive
SUNFLOWER	18-25			mod.sensitive	>100	>75	>50	sensitive
TOBACCO	20-30			sensitive	>75	>50	>25	sensitive
TOMATO	18-25			mod.sensitive	>75	>50	>25	mod.sensitive

TABLE 6: IRRIGATED CROPS,
LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
commandable area (in ha)	40	165	35	325	380	320	360	270	225	20
BANANA	S2t	S2t	N	S2t	S2t	S2tw	S2t	S3w	N	N
BEANS	S1	S1	N	S1	S2e	S2we	S2oe	S3w	N	N
CITRUS	S2tr	S2t	N	S2t	S2tr	S2tr	N	N	N	N
COTTON	S2t	S2t	N	S2t	S2tr	S2tr	S3r	S3rw	N	N
GROUNDNUT	S2t	S2t	N	S2t	S2t	S2tw	S2to	S3w	N	N
MAIZE	S2o	S2o	N	S2o	S2e	s2e	S3o	S3ow	N	N
PEPPER	S1	S1	N	S1	S2e	S2e	S2e	S3w	N	N
PINEAPPLE	S2t	S2t	N	S2t	S2t	S2tw	S3o	S3o	N	N
SORGHUM	S1	S1	N	S1	S2e	S2e	S2e	S3w	N	N
SOYBEAN	S2t	S2t	N	S2t	S2t	S2tw	S2to	S3w	N	N
SUGARCANE	S2t	S2t	N	S2t	S2tr	S2tr	S3r	S3rw	N	N
SUNFLOWER	S1	S1	N	S1	S2e	S2w	S2oe	S3w	N	N
TOBACCO	S2o	S2o	N	S2o	S2e	S2e	S3o	S3ow	N	N
TOMATO	S1	S1	N	S1	S2e	S2e	S2o	S3w	N	N

Explanation of symbols:

t - limitation due to temperature regime
o - limitation in oxygen availability
r - limitation in rooting depth
w - limitation in workability
e - limitation due to erosion hazard

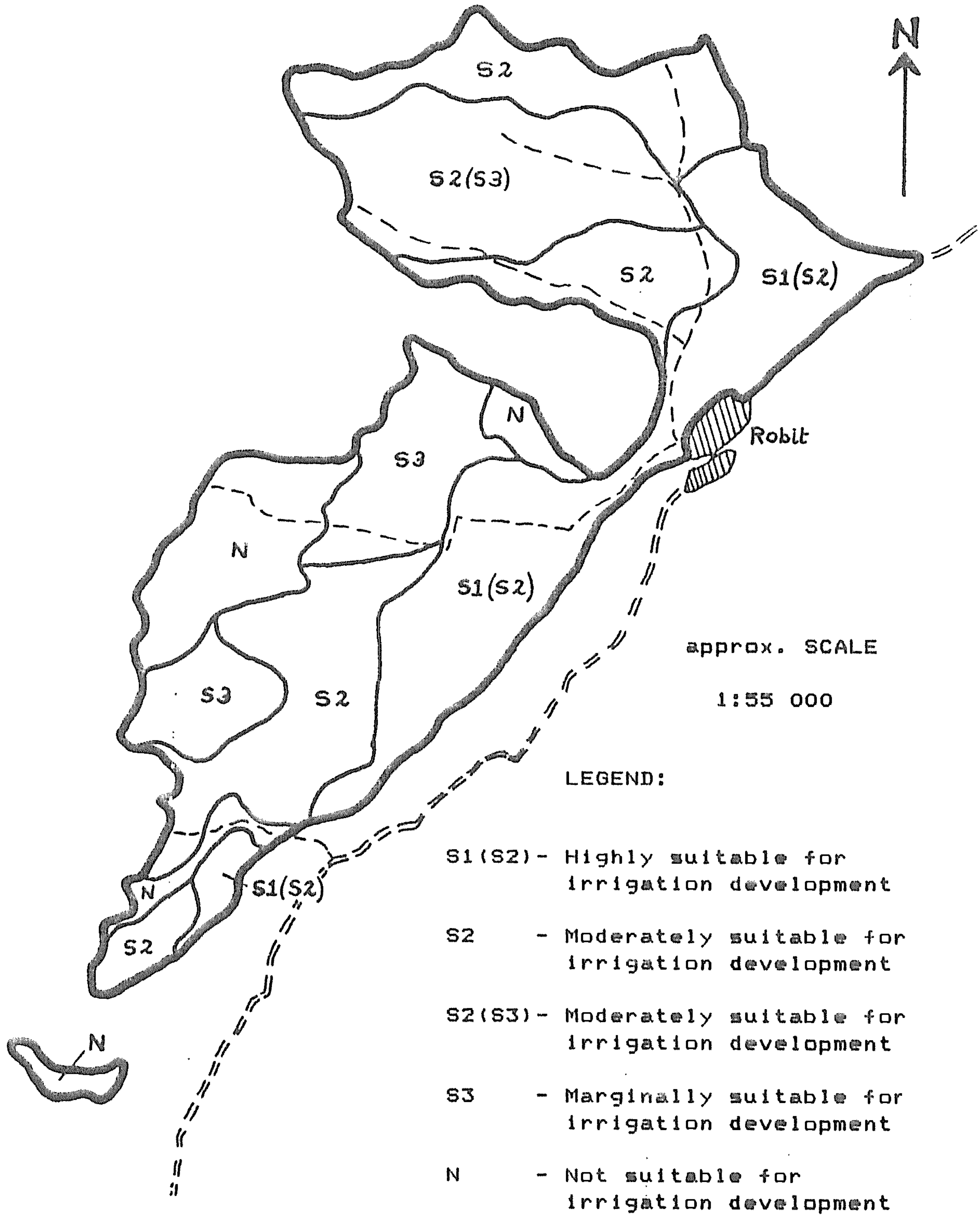
NOTE: The commandable area of 40 ha of unit A1 refers to that part of the unit which is neither stony nor swampy (see Chapter 3).

Table 7

GENERALIZED LAND SUITABILITY
FOR IRRIGATED AGRICULTURE
(based on the land suitability of 14 selected crops)

		LAND UNITS	TOTAL AREA
S1(S2)	- Highly suitable for irrigation development (= highly suitable for *five* of the irrigated crops considered; moderately suitable for *eight* other crops).	A1, A2, P2	530 ha
S2	- Moderately suitable for irrigation development (= moderately suitable for thirteen of the irrigated crops considered).	P3.1, P3.2	700 ha
S2(S3)	- Moderately suitable for irrigation development (= moderately suitable for seven of the irrigated crops considered; marginally suitable for six other crops).	P4.1	360 ha
S3	- Marginally suitable for irrigation development (= marginally suitable for thirteen of the irrigated crops considered)	P4.2	270 ha
N	- Not suitable for irrigation development (= not suitable for any irrigated crop under consideration).	P1, P4.3, P5	280 ha

NOTE: The commandable area of unit A1 is taken here as 40 ha only; it refers to the part of this unit which is neither stony nor swampy (see Chapter 3).



approx. SCALE

1:55 000

LEGEND:

S1(S2) - Highly suitable for irrigation development

S2 - Moderately suitable for irrigation development

S2(S3) - Moderately suitable for irrigation development

S3 - Marginally suitable for irrigation development

N - Not suitable for irrigation development

Note: See Table 7 for more detailed explanation of symbols.

Figure 5 GENERALIZED LAND SUITABILITY FOR IRRIGATED AGRICULTURE

CHAPTER 5

POTENTIAL AND CONSTRAINTS FOR IRRIGATION DEVELOPMENT
(findings and recommendations)

1) A total area of 2225 ha is commandable by gravity irrigation within the study area, assuming that a dam will be built at the planned dam site. Out of these 2225 ha, a total area of 530 ha is classified as highly suitable for irrigation development and an area of 1060 ha is classified as moderately suitable for irrigation development. In total 270 ha are classified as marginally suitable. (Table 7 and Figure 5).

2) A total area of 530 ha is classified as highly suitable for irrigation development. This area includes the low lying alluvial lands along the Robit river (land units A1, A2 and P2). These lands are higly suitable for irrigation development under the assumption that investments will be carried out:

   - The construction of a sub-surface drainage system, which will keep groundwater levels and salinity at levels which do not interfere with crop performance.
   - Topsoil amelioration and bunding will be carried out wherever necessary.

   Crops which rate as highly suitable under irrigated conditions are: pepper, sorghum, sunflower, beans, tomato. The nine other crops considered rate as moderately suitable.

   The land and soils of this unit pose almost no limitations to irrigated agriculture, if the above mentioned land improvements are carried out. Only crops which are sensitive to oxygen deficiences may suffer limited yield decline. The main limitation for the ten moderately suitable crops is climatic (temperature regime) and not related to the land.

   Presently, an area of about 50 ha to the south west of Robit is covered with Acacia woodland and is used as communal grazing area. This is judged to be under-utilization of the land. It is recommended to investigate opportunities to move the grazing activities to land with a lower suitability for irrigation development.

It must be noted, that only 40 ha out of the 125 ha of unit A1 are included in this assessment of high suitability for irrigation development. The rest of unit A1 is either too stony or swampy.

3) A total area of 1060 ha is classified as moderately suitable for irrigation development. This area includes part of the higher piedmont slopes (land units P3.1, P3.2 and P4.1). These lands are moderately suitable for irrigation development under the assumption, that wherever necessary topsoil amelioration will be effectuated and (minor) flood protection works will be constructed.

   Limitations to crop performance are of several types depending on the crop type or the land unit. Climatic limitation (temperature regime) and erosion hazard are the dominant limitations. Erosion hazard can not be controlled much better than is effectuated by present bunds. Limited rooting depth and workability problems (P3.2) are other limitations.

4) A total area of 270 ha is classified as marginally suitable for irrigation development. This area includes part of the higher piedmont slopes (land unit P4.2).

   Limitations to crop performance are severe and of several types: limited rooting depth, workability problems and oxygen deficiences for certain crops. Continuation of rainfed agriculture may prove to be a more feasible option than irrigated agriculture.

5) A total area of 280 ha is classified as not suitable for irrigation development. Erosion hazard, workability problems, limited rooting depth (land units P4.3 and P5) and salinity, flooding hazard and limited rooting depth (land unit P1) form in aggregate limitations which are too severe for irrigation development. These lands can be used for rainfed agriculture (P4.3 and P5) or as grazing lands (part of P1).

6) There is one, possibly overruling, constraint to irrigation development which must be considered carefully. The Robit river is a river which carries a large sediment load during peakflows. The rate at which a dam would lose efficiency by filling up with sediments is high. Careful

study of the feasibility of this dam is strongly recommended. In the present study the simple (and in the light of the above argumentation possibly unrealistic) assumption is made, that irrigation water can be commanded from the dam without limitation.

7) In the present study it is assumed that irrigation water is not a limiting factor, both in a quantitative and a qualitative sense. No barriers seem to exist for the construction of primary irrigation channels. Basic soil infiltration rates, estimated soil permeabilities and available soil water holding capacities are suitable for irrigation development. Furrow irrigation is recommended as irrigation application technique. Specifications for the irrigation design cannot be given at the present stage and must await further detailed studies.

8) It is recommended that double cropping under irrigation will be practised and that adequate crop rotations will be adopted. Fertilizers, pesticides etc. are assumed to be available.

   The two growing seasons cover the following periods of the year:

   - From June till November
   - From December till May

   The rainfall distribution is such, that in many years supplementary irrigation at the end of growing periods or between two short growing periods will be sufficient to create two growing seasons per year of adequate length.

9) One major land improvement, i.e. the construction of a sub-surface drainage system in land units A1, A2 and P2, is assumed to be part of the irrigation and drainage package. Without a drainage system, the land suitability of the best land will be reduced due to the build up of salinity in the soil profile, caused by a rise of saline groundwater. Quantification of this problem is not possible at this stage. Specifications for this drainage system are left to future detailed studies. Sensitivy to salinity of the 14 crops under consideration is presented in Table 5 as a matter of interest.

10) Three minor land improvements are to be effectuated. These include:

- bunding (land units A2 and P2) to reduce erosion.
- topsoil amelioration wherever necessary to improve soil structure.
- limited flood protection along streams.

11) It is recommended that lands will be rationally distributed according to their suitability for different uses, independant of the management situation (whether it is statefarm or cooperative). It is recommended:

- That units S1(S2), S2 and S2(S3) (see Figure 5 and Table 7) be developed for irrigated agriculture. This is subject to revision according to the outcome of detailed soil investigations as recommended below (see paragraph 12) and subject to economic evaluation of the rather long irrigation channel, which must be build to supply the area to the north of Robit with irrigation water.
- That units S3 and N (and possibly part of S2(S3))(see Figure 5 and Table 7) not be developed for irrigation but be used for rainfed production of subsistence crops and for livestock grazing.

12) It is recommended, that a high intensity soil survey be carried out as part of a feasibility study of the Robit valley irrigation project. The area to be surveyed comprises an estimated total of 1675 ha. It covers the areas classified as "highly suitable for irrigation development" and "moderately suitable for irrigation development" (land units A1, A2, P2, P3.1, P3.2 and P4.1).

In this recommended soil survey activities must be concentrated on the following items:

- To map the textural variation in all units.
- To map the depth of stone layers, which act as a barrier to root penetration, in units P3.1, P3.2 and P4.1.
- To quantify the future rise in groundwater level and the salinization hazard. Deep augerings to assess the depth of groundwater will have to be made, subsoil hydraulic conductivity will have to be measured and losses of irrigation water to deep percolation must be estimated. Estimations of the urgency to drain and of drain spacings will be part of the recommendations.
- To measure basic soil infiltration rates for different land units in a higher density than for the present survey in order to estimate irrigation efficiencies.

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APPENDIX 1

PROFILE DESCRIPTIONS AND ANALYTICAL RESULTS

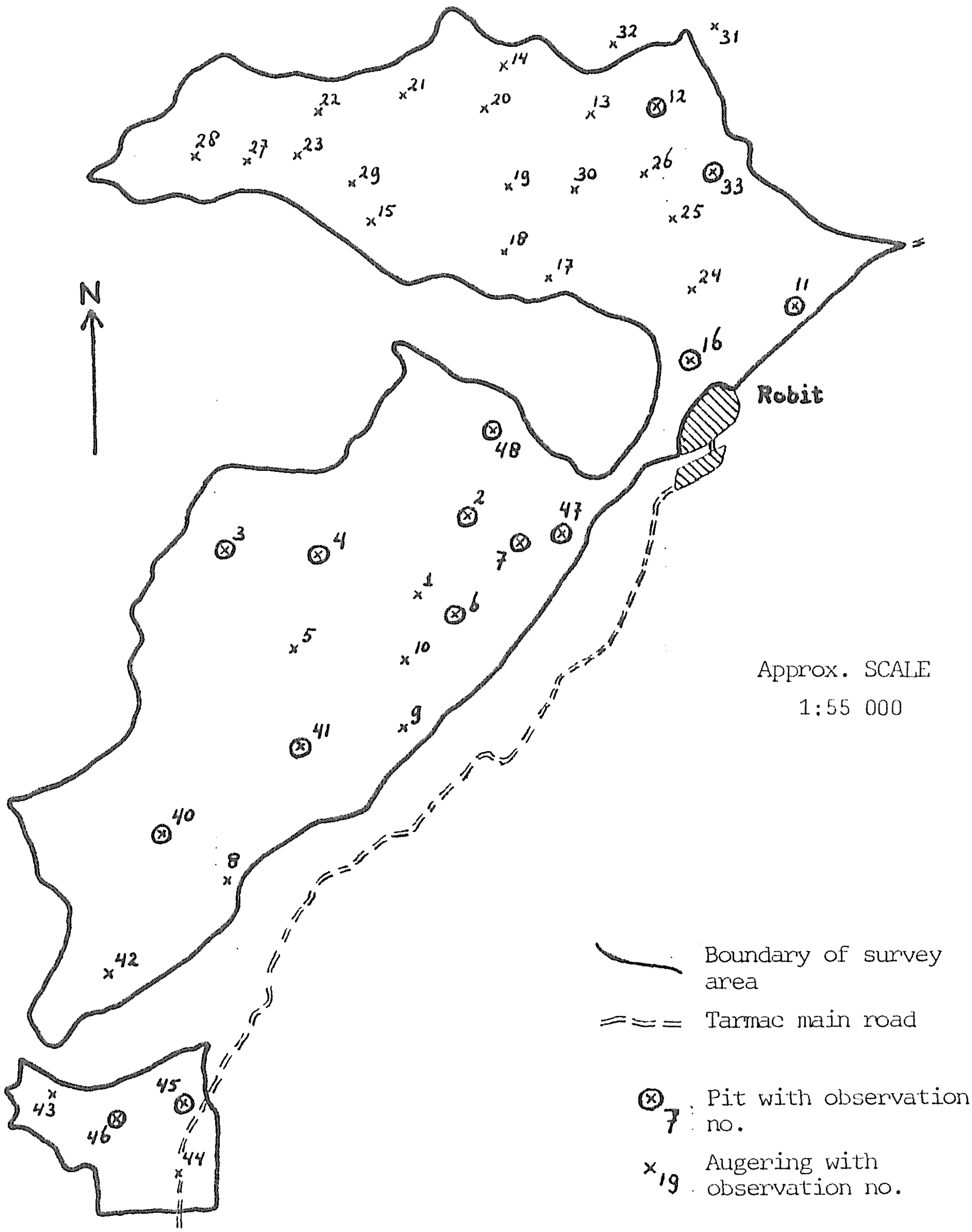

FIGURE 6. OBSERVATIONS MAP.

PEDON: 1 DATE OF DESCRIPTION: 31/10/86
PROFILE NO: Rob/47 MAPPING UNIT: A1 PHOTO NO: 1445
AUTHOR(S): J. Mirza
LOCATION: distance from Robit bridge = 1400 m
direction: WSW (240°)

SOIL CLASSIFICATION (FAO): GLEYIC CAMBISOL

PARENT MATERIAL: recent fluvial deposits of Robit river
PHYSIOGRAPHY: low terrace
MICRORELIEF: none
ELEVATION: ca. 1300 m asl SLOPE: 1-2%
LAND USE/VEGETATION: dry-farmed teff, maize, sorghum.
irrigated tobacco
CLIMATE: subhumid warm tropical

MOISTURE CONDITION: 0-75 cm moist; wet below.
GROUNDWATER LEVEL: at 85 cm RUNOFF: mod.slow
DRAINAGE CLASS: imperfect PERMEABILITY: slow
FLOODING: none INTERNAL DRAINAGE: v.slow

ROCKINESS: none STONINESS: none
EROSION: slight sheet SURFACE CRACKING: none

PROFILE DESCRIPTION:

Ap 0-15 cm; Very dark grayish brown (10YR3/2)(moist) and dark grayish brown (10YR4/2)(dry) silty clay-loam; soft (dry), very friable (moist), slightly sticky and plastic (wet); weak fine granular structure; common fine vesicular and many very fine interstitial pores; common very fine and fine roots; strongly calcareous; pH=8 and EC=0.2 dS/ m; clear and smooth on:
(Rob/47-1)

Bw 15-65 cm; Very dark grayish brown (10YR3/2)(moist) silty clay to silty clay-loam; few fine faint diffuse brown mottles; very hard (dry), firm (moist), very sticky and very plastic (wet); fine and medium moderate angular blocky structure; few very fine tubular pores; 1-2% rounded basalt gravel; few fine and very fine roots; strongly calcareous; pH=8.2 and EC=0.01 dS/ m; clear and smooth on:
(Rob/47-2)

Bg 65-85 cm; Dark grayish brown (10YR3.5/2)(moist) silty clay loam; common medium distinct clear yellowish brown mottles; friable (moist), sticky and plastic (wet); weak medium and coarse subangular blocky structure; common very fine tubular pores; 3-5% angular basalt gravel; strongly calcareous; pH=8.1 and EC=0.01 dS/ m; clear and smooth on:
(Rob/47-3)

Cg 85-180+ cm; Dark grayish brown (10YR4/2)(wet) clay-loam; strongly calcareous; ECw=0.5 dS/ m.

LABORATORY AND FIELD TEST DATA

Field Nº.	Rob7 47-1	Rob7 47-2	Rob7 47-3		
COARSE FRAG(%)					
TEXTURE					
Coarse sand %					
medium sand %					
fine sand %					
total sand %	16.4	–	–		
silt %	48.3	–	–		
clay %	35.3	–	–		
silt / clay					
texture class	SiCL	–	–		
BULK DENSITY					
MOISTURE % W/V					
pF 0					
pF 1.					
pF 2.					
pF 2.					
pF 2.					
pF 3.					
pF 3.					
pF 4.2					
AWC (FIELD)					
FC rep. 1					
FC rep. 2					
FC rep. 3					
AWC (mm/m)					
AWC(Lab)					
AWC(corrected for coarse fragm)					

INFILTRATION (rate in cm h-1)

Average :
equation
max. infiltration rate:
average infiltration rate
instantaneous infiltration rate after 4h :

Replicate	Accumulated intake (cm) after 1h	2h	3h	4h
1				
2				
3				

HYDRAULIC CONDUCTIVITY (AUGER HOLE)

K(cm.h-1)	Depth of test (cm) 0-100	100-200
Rep. 1		
2		
3		

OTHER FIELD TEST DATA

PH-H_2O (1:2.5 v/v)	7.6	7.8	7.8		
PH-$CaCl_2$	7.0	7.2	7.4		
EC (mS/cm) (1:2.5)	0.2	0.2	0.2		
$CaCO_3$ (%)	17.5	6.5	7.7		
$CaSO_4$ (%)					
OC (%)	2.1	1.2	1.1		
N (%)					
C/N					
P (ppm)					
CEC (meq/100g soil)					
$CaCl_2$ - extr.	59.6	47.4	59.3		
KNO_3 - extr.					
EXCHANGEABLE CATIONS (meq/100g soil)					
exch. Ca	48.8	40.0	45.2		
exch Mg	10.0	2.8	12.8		
exch K	2.0	2.4	2.0		
exch. Na	0.8	1.6	1.2		
Sum Cations	61.6	46.8	61.2		
% Base Sat (sum cat)					
% Base Sat (CEC)	100	98.7	100		
ESP (sum Cat.)					
ESP (CEC)					
CEC (clay frac.)					
SATURATION EXTRACT					
pH -paste					
ECe (mS/cm)					
Soluble salts (meq/l)					
Na^+					
K^+					
Ca^{2+}					
Mg^{2+}					
Sum cations					
CO_3^{2-}					
HCO_3^-					
Cl^-					
SO_4^{2-}					
Sum anions					
Adj. SAR					
OTHER					
Boron (ppm)					

PEDON: 2 DATE OF DESCRIPTION: 27/10/86
PROFILE NO: Rob/6 MAPPING UNIT: A2 PHOTO NO: 1445
AUTHOR(S): S. Paris
LOCATION: distance from Robit bridge = 2600 m
direction: WSW (240°)

SOIL CLASSIFICATION (FAO): ORTHIC LUVISOL

PARENT MATERIAL: subrecent fluvial deposits of Robit river
PHYSIOGRAPHY: higher terrace
MICRORELIEF: none
ELEVATION: ca. 1300 m asl SLOPE: 2%
LAND USE/VEGETATION: Communal grazing in Acacia woodland with dense grass cover and scattered Acacia shrubs.
CLIMATE: subhumid warm tropical

MOISTURE CONDITION: moist throughout
GROUNDWATER LEVEL: none RUNOFF: slow
DRAINAGE CLASS: mod.well PERMEABILITY: slow
FLOODING: none INTERNAL DRAINAGE: medium

ROCKINESS: none STONINESS: none
EROSION: none SURFACE CRACKING: none

PROFILE DESCRIPTION:

Ah (Rob/6-1) 0-12 cm; Very dark grayish brown (10YR3/1-2)(moist) silty clay-loam; very hard (dry), slightly sticky and slightly plastic (wet); moderate medium and coarse subangular blocky structure; many fine and very fine tubular pores; many fine and medium roots; non calcareous; pH=7 and EC=0.1 dS/ m; abrupt and smooth on:

Bw1 (Rob/6-2) 12-45 cm; Very dark gray (10YR3/1)(moist) silty clay-loam; friable (moist); moderate fine subangular blocky structure; many very fine tubular pores; common very fine to medium roots; non calcareous; pH=7 and EC=0.1 dS/ m; gradual and smooth on:

Bw2 (Rob/6-3) 45-70 cm; Very dark gray (10YR3/1)(moist) loam; friable (moist); weak coarse subangular blocky structure; many very fine and fine tubular pores; non calcareous; pH= 7 - 8 and EC=0.1 dS/ m; gradual and smooth on:

Bt (Rob/6-4) 70-150 cm; Very dark gray (10YR3/1)(moist) silty clay-loam to silty clay; few fine faint mottles; friable (moist); moderate medium subangular blocky structure; many very fine tubular pores; broken moderately thick clay cutans; few very fine roots; strongly calcareous; pH=8 and EC=0.1 dS/ m; gradual and smooth on:

Bg 150-190 cm; Very dark gray (10YR3/1)(moist) silty clay-loam to silty clay; common medium distinct diffuse mottles; friable (moist); slightly calcareous; EC=0.1 dS/ m; on:

BCg 190+ cm; loam containing 70% rounded basalt gravel.

LABORATORY AND FIELD TEST DATA

Field Nº	Rob/6-1	Rob/6-2	Rob/6-3	Rob/6-4	
COARSE FRAG(%)					
TEXTURE					
Coarse sand %					
medium sand %					
fine sand %					
total sand %	12.2	10.2	24.7	6.9	
silt %	56.5	53.7	27.2	45.7	
clay %	31.3	36.1	48.1	47.5	
silt / clay					
texture class	SiCL	SiCL	C	SiC	
BULK DENSITY	1.2	1.2	1.2	1.2	(estimate)
MOISTURE % W/V					
at pF 0					
pF 1.					
pF 2.					
pF 2.5	44.3	48.2	54.1		
pF 3.0	45.2	47.3	51.9		
pF 3.5	42.8	45.2	50.3		
pF 3.9	34.1	38.5	41.8		
pF 4.2	30.1	33.0	37.0		
AWC (FIELD)					
FC rep. 1					
FC rep. 2					
FC rep. 3					
AWC (mm/m)					
AWC(Lab) (mm/m)	142	152	171		
AWC(corrected for coarse fragm)					

INFILTRATION (rate in cm. h-1)

Average:

equation

max. infiltration rate:

average infiltration rate:

instantaneous infiltration rate after 4h:

Replicate	Accumulated intake (cm) after 1h	2h	3h	4h
1	2.7	5.0	7.1	9.1
2	15.0	26.3	37.3	48.6
3	8.8	16.0	22.5	29.0

HYDRAULIC CONDUCTIVITY (AUGER HOLE)

K (cm. h-1)	Depth of test (cm) 0-100	100-200
Rep. 1		
2		
3		

OTHER FIELD TEST DATA

PH-H_2O (1:2.5 v/v)	7.4	7.4	7.2	7.4	
PH-$CaCl_2$	6.4	6.3	6.3	6.7	
EC (mS/cm) (1:2.5)	0.2	0.1	0.3	0.3	
$CaCO_3$ (%)	3.3	3.6	3.7	4.5	
$CaSO_4$ (%)					
OC (%)	2.2	1.5	0.8		
N (%)					
C/N					
P (ppm)					
CEC (meq/100g soil)					
$CaCl_2$ - extr.	45.3	36.3	39.2	47.2	
KNO_3 - extr.					
EXCHANGEABLE CATIONS (meq/100g soil)					
exch. Ca	41.2	39.6	41.6	58.0	
exch. Mg	8.0	7.6	6.8	10.8	
exch. K	3.8	1.8	2.9	2.1	
exch. Na	0.3	0.4	0.8	0.5	
Sum Cations	53.3	49.4	52.1	71.4	
% Base Sat. (sum cat)					
% Base Sat (CEC)	100	100	100	100	
ESP (sum-Cat.)					
ESP (CEC)					
CEC (clay frac.)					
SATURATION EXTRACT					
pH-paste					
ECe (mS/cm)					
Soluble salts (meq/l)					
Na^+					
K^+					
Ca^{2+}					
Mg^{2+}					
Sum cations					
CO_3^{2-}					
HCO_3^-					
Cl^-					
SO_4^{2-}					
Sum anions					
Adj. SAR					
OTHER					
Boron (ppm)					

PEDON: 3 DATE OF DESCRIPTION: 31/10/86
PROFILE NO: Rob/48 MAPPING UNIT: P1 PHOTO NO: 1445
AUTHOR(S): S. Paris
LOCATION: distance from Robit bridge = 2000 m
direction: W (280°)

SOIL CLASSIFICATION (FAO): CALCARIC GLEYSOL, saline and sodic phase

PARENT MATERIAL: piedmont alluvium
PHYSIOGRAPHY: lower piedmont slope
MICRORELIEF: few gullies
ELEVATION: ca. 1300 m asl SLOPE: 1%
LAND USE/VEGETATION: livestock grazing on grassland
nearby marsh with reed vegetation (Cyperus sp.)
CLIMATE: subhumid warm tropical

MOISTURE CONDITION: 0-20 cm moist; wet below.
GROUNDWATER LEVEL: at 130 cm RUNOFF: slow
DRAINAGE CLASS: poor PERMEABILITY: slow
FLOODING: flashflooding each year INTERNAL DRAINAGE: v.slow

ROCKINESS: none STONINESS: 0.1-3%
EROSION: slight gully SURFACE CRACKING: none
SURFACE CRUSTING: whitish salt crust of 1 cm thickness.

PROFILE DESCRIPTION:

Ahg 0-10 cm; Dark grayish brown (10YR4/2)(moist) silty clay-loam; common medium faint clear mottles; firm (moist), slightly sticky and slightly plastic (wet); weak medium and coarse subangular blocky structure; many fine and medium interstitial and tubular pores; common fine to coarse roots; calcareous; pH=9.4 and EC=1.1 dS/ m; clear and smooth on:
(Rob/48-1)

BCg 10-53 cm; Dark gray (2.5Y4-3/0)(wet) sandy loam; few faint distinct clear brown mottles along root channels; non-slightly sticky and non-slightly plastic (wet); no to weak subangular blocky structure; few very fine and fine tubular pores; many fine and very fine roots; calcareous; pH=9.1 and EC=1.2 dS/ m; clear and smooth on:
(Rob/48-2)

Cg1 53-90 cm; Very dark gray (2.5Y3/0)(wet) stratified loam to silty clay-loam; slightly sticky and slightly plastic (wet); no to weak subangular blocky structure; common very fine and fine tubular pores; calcareous; pH=8.6 and EC=1.0 dS/ m; clear and smooth on:
(Rob/48-3)

Cg2 90-150 cm; Very dark gray (2.5Y3-2/0)(wet) silty clay to silty clay-loam; slightly sticky and slightly plastic (wet); weak fine angular blocky structure; few fine tubular pores; common very fine roots; calcareous; pH=9.2 and EC=0.6 dS/cm. Groundwater table is at 130 cm; ECw=6 dS/ m.
(Rob/48-4)

LABORATORY AND FIELD TEST DATA

Field Nº	Rob/48-1	Rob/48-2	Rob/48-3	Rob/48-4	
COARSE FRAG(%)					
TEXTURE					
Coarse sand %					
medium sand %					
fine sand %					
total sand %	27.9	54.2	–	18.6	
silt %	38.9	25.2	–	37.0	
clay %	33.2	20.6	–	44.4	
silt / clay					
texture class	CL	S L	–	C	
BULK DENSITY					
MOISTURE % W/V					
pF 0					
pF 1.					
pF 2.					
pF 2.					
pF 2.					
pF 3.					
pF 3					
pF 4.2					
AWC (FIELD)					
FC rep. 1					
FC rep. 2					
FC rep. 3					
AWC (mm/m)					
AWC (Lab)					
AWC (corrected for coarse fragm)					

INFILTRATION (rate in cm h-1)

Average:
equation
max. infiltration rate:
average infiltration rate
instantaneous infiltration rate after 4h:

Replicate	Accumulated intake (cm) after 1h	2h	3h	4h
1				
2				
3				

HYDRAULIC CONDUCTIVITY (AUGER HOLE)

K (cm. h-1)	Depth of test (cm) 0–100	100–200
Rep. 1		
2		
3		

OTHER FIELD TEST DATA

Field Nº	Rob/48-1	Rob/48-2	Rob/48-3	Rob/48-4	
$PH-H_2O$ (1:2.5 v/v)	8.6	8.8	8.2	8.8	
$PH-CaCl_2$	8.0	8.0	7.6	8.0	
EC (mS/cm) (1:2.5)	2.5	1.5	1.1	1.5	
$CaCO_3$ (%)	7.5	7.5	8.5	11.5	
$CaSO_4$ (%)					
OC (%)	2.0	1.0	0.6		
N (%)					
C/N					
P (ppm)					
CEC (meq/100g soil)					
$CaCl_2$ - extr.	56.1	41.0	41.2	52.8	
KNO_3 – extr.					
EXCHANGEABLE CATIONS (meq/100g soil)					
exch. Ca	22.8	16.4	21.2	17.6	
exch. Mg	11.2	4.8	13.2	5.2	
exch. K	2.6	1.3	4.3	6.6	
exch. Na	28.4	18.5	0.2	20.2	
Sum Cations	65.0	41.0	38.9	49.6	
% Base Sat. (sum cat.)					
% Base Sat (CEC)	100	100	94.4	93.9	
ESP (sum-Cat.)	44	45	<1	41	
ESP (CEC)	51	45	<1	38	
CEC (clay frac.)					
SATURATION EXTRACT					
pH-paste					
ECe (mS/cm)					
Soluble salts (meq/l)					
Na^+					
K^+					
Ca^{2+}					
Mg^{2+}					
Sum cations					
CO_3^{2-}					
HCO_3^-					
Cl^-					
SO_4^{2-}					
Sum anions					
Adj. SAR					
OTHER					
Boron (ppm)					

PEDON: 4 DATE OF DESCRIPTION: 26/10/86
PROFILE NO: Rob/2 MAPPING UNIT: P2 PHOTO NO: 1445
AUTHOR(S): J. Mirza and S. Paris
LOCATION: distance from Robit bridge = 2100 m
direction: W (260°)

SOIL CLASSIFICATION (FAO): CALCIC CAMBISOL

PARENT MATERIAL: piedmont alluvium derived from basic volcanic rocks possibly with admixtures of Robit river alluvium.
PHYSIOGRAPHY: lower piedmont slope
MICRORELIEF: none
ELEVATION: ca. 1350 m asl SLOPE: 2-3%
LAND USE/VEGETATION: Fallow. Nearby dry-farmed sorghum and maize.
CLIMATE: subhumid warm tropical

MOISTURE CONDITION: 0-25 cm dry; moist below.
GROUNDWATER LEVEL: none RUNOFF: slow
DRAINAGE CLASS: mod.well PERMEABILITY: slow
FLOODING: none INTERNAL DRAINAGE: medium

ROCKINESS: none STONINESS: none
EROSION: slight sheet SURFACE CRACKING: none

PROFILE DESCRIPTION:

A (Rob/2-1) 0-26 cm; Very dark grayish brown (10YR3/2)(moist) and dark grayish brown (10YR4/2)(dry) loam; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); moderate medium subangular blocky structure; common very fine interstitial pores; many fine roots; slightly calcareous; pH=7.8 and EC=0.5 dS/ m; abrupt and smooth on:

Bw (Rob/2-2) 26-75/85 cm; Very dark gray (10YR3/1)(moist) silty clay-loam to silty clay; friable (moist), sticky and plastic (wet); moderate fine angular blocky and granular structure; common very fine tubular pores; patchy thin clay cutans; 1-2% slightly rounded basalt gravel; few very fine and fine roots; slightly calcareous; pH=7.7 and EC=0.5 dS/ m; gradual and wavy on:

Bca (Rob/2-3) 75/85-165 cm; Very dark gray (10YR3/1)(moist) silty clay-loam; friable (moist) sticky and plastic (wet); moderate fine angular blocky structure; few very fine tubular pores; few very fine roots; strongly calcareous and many lime mycelia; pH= 7.7 and EC=0.6 dS/ m; clear and smooth on:

C1 (Rob/2-4) 165-190 cm; Dark brown (10YR4/3)(moist) silt-loam; few fine distinct clear dark gray mottles; very friable (moist); weak medium subangular blocky structure; common very fine tubular pores; strongly calcareous and few lime mycelia; pH=8.0 and EC=0.3 dS/ m; on:

C2 190-250+ cm; Very dark grayish brown (10YR3/2) silty clay-loam; strongly calcareous with few lime mycelia.

LABORATORY AND FIELD TEST DATA

Field Nº.	Rob/2-1	Rob/2-2	Rob/2-3	Rob/2-4	
COARSE FRAG(%)					
TEXTURE					
Coarse sand %					
medium sand %					
fine sand %					
total sand %	27.7	12.4	20.8	14.5	
silt %	32.5	35.8	29.2	52.9	
clay %	39.7	55.7	50.1	32.6	
silt / clay					
texture class	CL	C	C	SiCL	
BULK DENSITY	1.3	1.3	1.3	1.3	(estimate)
MOISTURE % W/V					
pF 0					
pF 1.					
pF 2.					
pF 2.5	58.5	64.5	62.4		
pF 3.0	53.1	60.6	59.6		
pF 3.5	51.2	58.0	57.5		
pF 3.9	43.3	53.3	50.6		
pF 4.2	35.4	44.3	42.1		
AWC (FIELD)					
FC rep. 1					
FC rep. 2					
FC rep. 3					
AWC (mm/m)					
AWC(Lab) (mm/m)	231	202	203		
AWC(corrected for coarse fragm)					

INFILTRATION (rate in cm. h-1)

Average :

equation

max. infiltration rate:

basic infiltration rate: 5.6 cm/hr

instantaneous infiltration rate after 4h

Replicate	Accumulated intake (cm) after 1h	2h	3h	4h
1	7.4	13.6	19.9	
2	7.0	13.3	19.4	
3	4.8	9.5	14.0	

HYDRAULIC CONDUCTIVITY (AUGER HOLE)

K(cm.h-1)	Depth of test (cm) 0-100	100-200
Rep. 1		
2		
3		

OTHER FIELD TEST DATA

PH-H_2O (1:2.5 v/v)	7.6	7.6	7.8	7.8	
PH-$CaCl_2$	7.0	6.6	6.8	7.0	
EC (mS/cm) (H_2O 1:2.5)	0.4	0.2	0.2	0.2	
$CaCO_3$ (%)	3.8	3.9	8.5	46.5	
$CaSO_4$ (%)					
OC(%)	1.9	1.7	0.8		
N(%)					
C/N					
P (ppm)					
CEC (meq/100g soil)					
$CaCl_2$ - extr.	49.1	47.7	54.1	59.6	
KNO_3 - extr.					
EXCHANGEABLE CATIONS (meq/100g soil)					
exch. Ca	46.0	45.2	67.2	62.4	
exch. Mg	3.6	3.6	10.2	6.6	
exch. K	1.9	1.8	1.2	1.0	
exch. Na	0.4	0.4	0.3	0.2	
Sum Cations	51.9	51.0	78.9	70.2	
% Base Sat.(sum cat.)					
% Base Sat (CEC)	100	100	100	100	
ESP (sum-Cat.)					
ESP (CEC)					
CEC (clay frac.)					
SATURATION EXTRACT					
pH-paste					
ECe (mS/cm)					
Soluble salts (meq/l)					
Na^+					
K^+					
Ca^{2+}					
Mg^{2+}					
Sum cations					
CO_3^{2-}					
HCO_3^-					
Cl^-					
SO_4^{2-}					
Sum anions					
Adj. SAR					
OTHER					
Boron (ppm)					

PEDON: 5 DATE OF DESCRIPTION: 28/10/86
PROFILE NO: Rob/41 MAPPING UNIT: P3 PHOTO NO: 1445
AUTHOR(S): S. Paris
LOCATION: distance from Robit bridge = 4400 m
direction: SW (230°)

SOIL CLASSIFICATION (FAO): EUTRIC CAMBISOL

PARENT MATERIAL: piedmont alluvium derived from basic volcanic rocks.
PHYSIOGRAPHY: alluvial fan on higher piedmont slope
MICRORELIEF: none
ELEVATION: ca. 1400 m asl SLOPE: 4%
LAND USE/VEGETATION: dry-farmed sorghum
CLIMATE: subhumid warm tropical

MOISTURE CONDITION: slightly moist throughout
GROUNDWATER LEVEL: none RUNOFF: medium
DRAINAGE CLASS: well PERMEABILITY: mod.slow
FLOODING: none INTERNAL DRAINAGE: medium

ROCKINESS: none STONINESS: 3-15%
EROSION: moderate sheet SURFACE CRACKING: none

PROFILE DESCRIPTION:

Ap 0-17 cm; Very dark grayish brown (10YR3/2)(moist) and dark grayish brown (10YR4/2)(dry) loam; hard (dry), non sticky and non plastic (wet); moderate coarse subangular blocky and crumb structure, partly massive; many very fine to medium tubular pores; 2-5% slightly rounded basalt gravel ; many very fine to medium roots; non calcareous; pH= 6 - 7 and EC=0.1 dS/ m; ; abrupt and smooth on:
(Rob/41-1)

Bw1 17-50 cm; Very dark grayish brown (10YR3/2)(moist) silty clay-loam to loam; friable (moist); moderate coarse subangular blocky structure; many very fine and fine tubular pores; 2-5% slightly rounded basalt gravel; many very fine roots; non calcareous; pH= 6 - 7 and EC=0.1 dS/ m; diffuse and smooth on:
(Rob/41-2)

Bw2 50-77 cm; Very dark grayish brown (10YR3/2)(moist) loam; friable (moist); moderate medium and coarse subangular blocky structure; many very fine and fine tubular pores; 2-5% slightly rounded basalt gravel; few very fine roots; non calcareous; pH=7 and EC=0.2 dS/ m; clear and smooth on:
(Rob/41-3)

2C 77-150+ cm; loamy sand containing 80% slightly rounded basalt gravel and stones.

LABORATORY AND FIELD TEST DATA

Field Nº.	Rob7/41-1	Rob7/41-2	Rob7/41-3		
COARSE FRAG(%)					
TEXTURE					
Coarse sand %					
medium sand %					
fine sand %					
total sand %	28.2	30.2	46.1		
silt %	45.9	32.4	28.6		
clay %	25.9	37.4	25.3		
silt / clay					
texture class	L	CL	L		
BULK DENSITY					
MOISTURE % W/V					
pF 0					
pF 1.					
pF 2.					
pF 2.					
pF 2.					
pF 3.					
pF 3					
pF 4.2					
AWC (FIELD)					
FC rep. 1					
FC rep. 2					
FC rep. 3					
AWC (mm/m)					
AWC(Lab)					
AWC(corrected for coarse fragm)					

INFILTRATION (rate in cm h-1)

Average :
equation
max. infiltration rate:
average infiltration rate
instantaneous infiltration rate after 4h :

Replicate	Accumulated intake (cm) after 1h	2h	3h	4h
1				
2				
3				

HYDRAULIC CONDUCTIVITY (AUGER HOLE)

K(cm h-1)	Depth of test (cm) 0-100	100-200
Rep. 1		
2		
3		

OTHER FIELD TEST DATA

PH-H_2O (1:2.5 v/v)	7.1	7.2	7.0		
PH-$CaCl_2$	6.5	6.6	6.8		
EC (mS/cm) (1:2.5)	0.1	0.1	0.2		
$CaCO_3$ (%)	3.1	3.3	2.2		
$CaSO_4$ (%)					
OC (%)	1.2	1.3	1.0		
N (%)					
C/N					
P (ppm)					
CEC (meq/100g soil)					
$CaCl_2$ - extr.	41.3	46.8	35.9		
KNO_3 - extr.					
EXCHANGEABLE CATIONS (meq/100g soil)					
exch. Ca	29.2	34.0	28.4		
exch. Mg	6.4	7.6	4.8		
exch. K	3.3	1.5	1.5		
exch. Na	0.9	0.4	0.4		
Sum Cations	39.8	43.5	35.1		
% Base Sat. (sum cat.)					
% Base Sat (CEC)	96.4	92.9	97.8		
ESP (sum-Cat.)					
ESP (CEC)					
CEC (clay frac.)					
SATURATION EXTRACT					
pH-paste					
ECe (mS/cm)					
Soluble salts (meq/l)					
Na^+					
K^+					
Ca^{2+}					
Mg^{2+}					
Sum cations					
CO_3^{2-}					
HCO_3^-					
Cl^-					
SO_4^{2-}					
Sum anions					
Adj. SAR					
OTHER					
Boron (ppm)					

PEDON: 6 DATE OF DESCRIPTION: 27/10/86
PROFILE NO: Rob/4 MAPPING UNIT: P4 PHOTO NO: 1445
AUTHOR(S): S. Paris
LOCATION: distance from Robit bridge = 3300 m
direction: W (255°)

SOIL CLASSIFICATION (FAO): PELLIC VERTISOL

PARENT MATERIAL: piedmont alluvium derived from basic volcanic rocks.
PHYSIOGRAPHY: higher piedmont slope
MICRORELIEF: none
ELEVATION: ca. 1400 m asl SLOPE: 3%
LAND USE/VEGETATION: Fallow. Nearby dry-farmed sorghum.
CLIMATE: subhumid warm tropical

MOISTURE CONDITION: moist throughout
GROUNDWATER LEVEL: none RUNOFF: slow-medium
DRAINAGE CLASS: imperfect PERMEABILITY: v.slow
FLOODING: none INTERNAL DRAINAGE: v.slow

ROCKINESS: none STONINESS: 0.1-3%
EROSION: slight sheet SURFACE CRACKING: 80 cm deep

PROFILE DESCRIPTION:

Ap 0-18 cm; Very dark gray(10YR3/1)(moist) clay; extremely hard (dry), extremely firm (moist), sticky and plastic (wet); strong medium and coarse angular blocky structure; many fine tubular pores; 2-5% slightly rounded basalt gravel and stones; many medium and coarse roots; non calcareous; pH= 6 - 7 ; clear and smooth on:
(Rob/4-1)

AC1 18-65 cm; Black (2.5Y2/0)(moist) clay; extremely firm (moist), sticky and plastic (wet); strong coarse and very coarse angular blocky structure; few very fine tubular pores; 2-5% slightly rounded basalt gravel and stones; few very fine and fine roots; common moderately developed non intersecting slickensides; non calcareous; pH=7; gradual and wavy on:
(Rob/4-2)

AC2 65-110 cm; Very dark gray (10YR3/1)(moist) clay; firm (moist) ; moderate to strong medium angular blocky structure; few fine tubular pores; 2-5% slightly rounded basalt gravel; no roots; many moderately developed intersecting slickensides; slightly calcareous and few lime mycelia; pH= 7-8 and EC=0.2 dS/ m; diffuse and irregular on:
(Rob/4-3)

C 110-140+ cm; Very dark grayish brown (10YR3/2-3)(moist) silty clay; friable (moist); moderate medium angular blocky structure; very few tubular pores; 2-5% slightly rounded basalt gravel; calcareous and few lime mycelia; pH= 7 - 8 and EC=0.1 dS/ m.
(Rob/4-4)

LABORATORY AND FIELD TEST DATA

Field Nº.	Rob/4-1	Rob/4-2	Rob/4-3	Rob/4-4	
COARSE FRAG(%)					
TEXTURE					
Coarse sand %					
medium sand %					
fine sand %					
total sand %	16.6	17.5	20.3	10.7	
silt %	23.4	19.8	22.4	47.4	
clay %	60.0	63.0	57.3	41.9	
silt / clay					
texture class	C	C	C	SiC	
BULK DENSITY	1.5	1.5	1.5	1.5	(estimate)
MOISTURE % W/V					
pF 0					
pF 1.					
pF 2.					
pF 2.5	66.7	63.3	68.1		
pF 3.0	61.8	62.6	64.8		
pF 3.5	56.6	60.6	61.6		
pF 3.9	47.6	46.8	53.2		
pF 4.2	44.6	45.8	45.0		
AWC (FIELD)					
FC rep. 1					
FC rep. 2					
FC rep. 3					
AWC (mm/m)					
AWC(Lab) (mm/m)	221	175	231		
AWC(corrected for coarse fragm)					

INFILTRATION (rate in cm. h-1)

Average :

equation

max. infiltration rate:

basic infiltration rate: 2.5 cm/h

instantaneous infiltration rate after 4h :

Replicate	Accumulated intake (cm) after 1h	2h	3h	4h
1	4.0	7.2	9.8	12.3
2	15.0	26.0	37.0	47.0
3	47.0	76.0	97.0	114.0

HYDRAULIC CONDUCTIVITY (AUGER HOLE)

K (cm.h-1)	Depth of test (cm) 0-100	100-200
Rep 1		
2		
3		

OTHER FIELD TEST DATA

PH-H_2O (1:2.5 v/v)	7.0	7.0	7.4	8.0	
PH-$CaCl_2$	6.2	6.4	6.4	6.6	
EC (mS/cm) (1:2.5)	0.1	0.1	0.2	0.2	
$CaCO_3$ (%)	3.5	4.2	4.4	4.4	
$CaSO_4$ (%)					
OC (%)	2.0	1.6	1.2		
N (%)					
C/N					
P (ppm)					
CEC (meq/100g soil)					
$CaCl_2$ - extr.	40.3	51.1	54.1	55.9	
KNO_3 - extr.					
EXCHANGEABLE CATIONS (meq/100g soil)					
exch. Ca	42.4	34.8	56.8	40.8	
exch. Mg	20.4	12.0	12.8	11.4	
exch. K	1.2	2.5	0.6	1.2	
exch. Na	0.5	0.2	0.8	1.9	
Sum Cations	64.5	49.5	71.0	55.3	
% Base Sat. (sum cat)					
% Base Sat (CEC)	100	96.9	100	98.9	
ESP (sum-Cat)					
ESP (CEC)					
CEC (clay frac.)					
SATURATION EXTRACT					
pH - paste					
EC (mS/cm)					
Soluble salts (meq/l)					
Na^+					
K^+					
Ca^{2+}					
Mg^{2+}					
Sum cations					
CO_3^{2-}					
HCO_3^-					
Cl^-					
SO_4^{2-}					
Sum anions					
Adj. SAR					
OTHER					
Boron (ppm)					

PEDON: 7 DATE OF DESCRIPTION: 29/10/86
PROFILE NO: Rob/45 MAPPING UNIT: P5 PHOTO NO: 1445
AUTHOR(S): S. Paris
LOCATION: distance from Robit bridge = 7500 m
direction: SW (220°)

SOIL CLASSIFICATION (FAO): VERTIC CAMBISOL

PARENT MATERIAL: piedmont alluvium derived from basic volcanic rocks.
PHYSIOGRAPHY: dissected piedmont slope
MICRORELIEF: none
ELEVATION: ca. 1400 m asl SLOPE: 3-4%
LAND USE/VEGETATION: dry-farmed sorghum
CLIMATE: subhumid warm tropical

MOISTURE CONDITION: moist throughout
GROUNDWATER LEVEL: none RUNOFF: medium
DRAINAGE CLASS: mod.well PERMEABILITY: v.slow
FLOODING: none INTERNAL DRAINAGE: v.slow

ROCKINESS: none STONINESS: 3-15%
EROSION: moderate sheet SURFACE CRACKING: 50 cm deep

PROFILE DESCRIPTION:

Ap (Rob/45-1) 0-17 cm; Black (10YR2/0)(moist) clay; extremely hard (dry), extremely firm (moist), sticky and plastic (wet); massive structure; common medium interstitial pores; 10% slightly rounded basalt gravel and stones; many medium and coarse roots; slightly calcareous; pH=7 ; abrupt and smooth on:

AC (Rob/45-2) 17-25/45 cm; Black (10YR2/0)(moist) clay; very firm (moist), sticky and plastic (wet); strong coarse angular blocky structure; common very fine tubular pores; 2-3% slightly rounded basalt gravel; many very fine roots; common moderately developed non intersecting slickensides; slightly calcareous; pH=7; abrupt and wavy on:

2C 25/45-60 cm; Black (10YR2/0)(moist) clay; few very fine tubular pores; 60-70% slightly rounded basalt gravel and stones; few very roots; slightly calcareous; abrupt and smooth on:

3Bt (Rob/45-3) 60-90 cm; Very dark grayish brown (10YR3/2-2)(moist) silty clay to silty clay-loam; friable (moist), slightll sticky and slightly plastic (wet); moderate coarse angular blocky structure; few very fine tubular pores; continuous moderately thick clay cutans; slightly calcareous; pH= 7 - 8; gradual and smooth on:

3B (Rob/45-4) 90-140 cm; Very dark grayish brown (10YR3/2-2)(moist) silty clay-loam; common fine distinct clear mottling; friable (moist); moderate coarse angular blocky structure; very few pores; broken thin clay cutans; 5% slightly rounded basalt gravel; calcareous; pH= 7 - 8 .

LABORATORY AND FIELD TEST DATA

Field Nº.	Rob/45-1	Rob/45-2	Rob/45-3	Rob/45-4	
COARSE FRAG(%)					
TEXTURE					
Coarse sand %					
medium sand %					
fine sand %					
total sand %	16.1	14.8	26.9	21.2	
silt %	26.8	20.0	23.3	22.8	
clay %	57.1	65.2	49.8	56.0	
silt / clay					
texture class	C	C	C	C	
BULK DENSITY					
MOISTURE % W/V					
pF 0					
pF 1.					
pF 2.					
pF 2.					
pF 2.					
pF 3.					
pF 3.					
pF 4.2					
AWC (FIELD)					
FC rep. 1					
FC rep. 2					
FC rep. 3					
AWC (mm/in)					
AWC(Lab)					
AWC(corrected for coarse fragm)					

INFILTRATION (rate in cm h-1)

Average :
equation
max. infiltration rate:
average infiltration rate
instantaneous infiltration rate after 4h :

Replicate	Accumulated intake (cm) after 1h	2h	3h	4h
1				
2				
3				

HYDRAULIC CONDUCTIVITY (AUGER HOLE)

K(cm.h-1)	Depth of test (cm) 0-100	100-200
Rep. 1		
2		
3		

OTHER FIELD TEST DATA

PH-H_2O (1:2.5 v/v)	7.1	7.1	7.2	7.3	
PH-$CaCl_2$	6.6	6.6	7.4	7.2	
EC (mS/cm) (1:2.5)	0.1	0.1	0.3	0.2	
$CaCO_3$ (%)	3.4	4.0	4.3	4.2	
$CaSO_4$ (%)					
OC(%)	2.0	1.7	0.7		
N(%)					
C/N					
P (ppm)					
CEC (meq/100g soil)					
$CaCl_2$ - extr.	49.8	58.1	59.2	59.4	
KNO_3 - extr.					
EXCHANGEABLE CATIONS (meq/100g soil)					
exch. Ca	37.2	45.2	46.4	44.4	
exch. Mg	8.8	10.0	12.0	12.0	
exch. K	2.1	1.1	1.0	0.9	
exch. Na	0.2	0.4	0.6	0.6	
Sum Cations	48.3	56.7	60.0	57.9	
% Base Sat.(sum cat.)					
% Base Sat (CEC)	97.0	97.6	100	97.0	
ESP (sum-Cat.)					
ESP (CEC)					
CEC (clay frac.)					
SATURATION EXTRACT					
pH-paste					
EC (mS/cm)					
Soluble salts (meq/l)					
Na^+					
K^+					
Ca^{2+}					
Mg^{2+}					
Sum cations					
CO_3^{2-}					
HCO_3^-					
Cl^-					
SO_4^{2-}					
Sum anions					
Adj. SAR					
OTHER					
Boron (ppm)					

APPENDIX 2

LAND SUITABILITY TABLES OF 14 SELECTED CROPS

TABLE B1 IRRIGATED BANANA, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s1	s1	s2	s1	s1	s1	s1	s1	s1	s1
ROOTING DEPTH	s1	s1	s2	s1	s1	s1	s1	s1	s1	s1
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL CURRENT SUITABILITY	S2t	S2t	N *	S2t	S2t	S2tw	S2t	S3w	N	N

TABLE B2 IRRIGATED BEANS, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
OXYGEN AVAILABILITY	s1	s1	s3	s1	s1	s1	s2	s2	s2	s2
ROOTING DEPTH	s1	s1	s3	s1	s1	s1	s1	s1	s1	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S1	S1	N *	S1	S2e	S2we	S2oe	S3 w	N	N

TABLE B3 IRRIGATED CITRUS, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s2	s2	n	s2	s1	s1	n	n	n	n
ROOTING DEPTH	s2	s1	n	s1	s2	s2	s3	s3	s3	n
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY	S2tr	S2t	N	S2t	S2tr	S2tr	N	N	N	N

TABLE B4 IRRIGATED COTTON,
LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s1	s1	n	s1	s1	s1	s1	s1	s1	s1
ROOTING DEPTH	s2	s1	n	s1	s2	s2	s3	s3	s3	s3
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S2t	S2t	N	S2t	S2tr	S2tr	S3r	S3rw	N	N

TABLE B5 IRRIGATED GROUNDNUT,
LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s2	s2	n	s2	s1	s1	s2	s2	s2	s2
ROOTING DEPTH	s1	s1	n	s1	s1	s1	s2	s2	s2	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S2t	S2t	N	S2t	S2t	S2tw	S2to	S3w	N	N

TABLE B6 IRRIGATED MAIZE,
LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
OXYGEN AVAILABILITY	s2	s2	n	s2	s1	s1	s2	s2	s2	s2
ROOTING DEPTH	s1	s1	n	s1	s1	s1	s2	s2	s2	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S2o	S2o	N	S2o	S2e	S2e	S2eo	S3w	N	N

TABLE B7 IRRIGATED PEPPER, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s1	s1	s3	s1	s1	s1	s2	s2	s2	s2
ROOTING DEPTH	s1	s1	s3	s1	s1	s1	s1	s1	s1	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S2t	S2t	N *	S2t	S2t	S2tw	S2to	S3w	N	N

TABLE B8 IRRIGATED PINEAPPLE, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s2	s2	n	s2	s1	s1	s3	s3	s3	s3
ROOTING DEPTH	s1	s1	s2	s1	s1	s1	s1	s1	s1	s1
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY	S2t	S2t	N	S2t	S2t	S2tw	S3o	S3o	N	N

TABLE B9 IRRIGATED SORGHUM, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
OXYGEN AVAILABILITY	s1	s1	s2	s1	s1	s1	s1	s1	s1	s1
ROOTING DEPTH	s1	s1	n	s1	s1	s1	s2	s2	s2	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S1	S1	N	S1	S2e	S2e	S2e	S3w	N	N

TABLE B10 IRRIGATED SOYBEAN, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s2	s2	n	s2	s1	s1	s2	s2	s2	s2
ROOTING DEPTH	s1	s1	n	s1	s1	s1	s2	s2	s2	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S2t	S2t	N	S2t	S2t	S2tw	S2to	S3w	N	N

TABLE B11 IRRIGATED SUGARCANE, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s2	s2	s2	s2	s2	s2	s2	s2	s2	s2
OXYGEN AVAILABILITY	s1	s1	n	s1	s1	s1	s1	s1	s1	s1
ROOTING DEPTH	s2	s1	n	s1	s2	s2	s3	s3	s3	s3
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY	S2t	S2t	N	S2t	S2tr	S2tr	S3r	S3rw	N	N

TABLE B12 IRRIGATED SUNFLOWER, LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
OXYGEN AVAILABILITY	s1	s1	n	s1	s1	s1	s2	s2	s2	s2
ROOTING DEPTH	s1	s1	n	s1	s1	s1	s2	s2	s2	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S1	S1	N	S1	S2e	S2w	S2oe	S3w	N	N

TABLE B13 IRRIGATED TOBACCO,
LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
OXYGEN AVAILABILITY	s2	s2	n	s2	s1	s1	s3	s3	s3	s3
ROOTING DEPTH	s1	s1	s3	s1	s1	s1	s1	s1	s1	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S2o	S2o	N	S2o	S2e	S2e	S3o	S3ow	N	N

TABLE B14 IRRIGATED TOMATO,
LAND SUITABILITY

MAPPING UNIT	A1	A2	P1	P2	P3.1	P3.2	P4.1	P4.2	P4.3	P5
TEMPERATURE REGIME	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1
OXYGEN AVAILABILITY	s1	s1	s3	s1	s1	s1	s2	s2	s2	s2
ROOTING DEPTH	s1	s1	s3	s1	s1	s1	s1	s1	s1	s2
WORKABILITY	s1	s1	s2	s1	s1	s2	s1	s3	n	n
EROSION HAZARD	s1	s1	s2	s1	s2	s2	s2	s2	n	s2
OVERALL LAND SUITABILITY (equal for both growing seasons)	S1	S1	N *	S1	S2e	S2e	S2o	S3w	N	N

NOTE: The land qualities FLOODING HAZARD and SALINITY are not included in the tables of this Appendix. Both rate as "n" for land unit P1 and as "s1" for all other land units