F.N. MUCHENA

SOILS AND IRRIGATION OF THREE AREAS IN THE LOWER TANA REGION KENYA

A comparative study of soil conditions and irrigation suitability

Promotor: Professor dr.Ir. L.J. Pons
oud-hoogleraar in regionale bodemkunde

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A comparative study of soil conditions and irrigation suitability.

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
in het openbaar te verdedigen
op dinsdag 20 oktober 1987
des namiddags te vier uur in de aula
van de Landbouwuniversiteit te Wageningen.

To Gladys, Mwiti, Mwenda, Muthuuri, Mutai and Munene.

STATEMENTS

1. Irrigation development is expensive and usually requires investment and credit facilities and mistakes can be very costly. Therefore areas that are earmarked for irrigation development should be evaluated very carefully to ascertain their suitability for sustained use.

2. This study reveals that for on-going irrigation schemes regular monitoring of factors influencing salinization and sodication (alkalization) processes is indispensable if prevention of secondary formation of salt affected soils is to be tackled.

3. Soil survey reports should be user-friendly. Hence descriptive map legends, including aspects of practical interpretation, are preferred over taxonomic legends.

4. In soil surveys or soil investigations for irrigation-agriculture, exploratory observations should be made to at least a depth of three metres, the thickness of unconsolidated material permitting,to establish the occurrence of potentially limiting subsoil horizons. The depth of the subsequent survey observations should be determined by these observed soil conditions.

5. Text books require that land suitability evaluations should always be accompanied by specific criteria for the farming systems envisaged/examined and "conversion" tables. However, in many cases these criteria are not provided because researchers are not willing to specify criteria being used.

6. Although Dregne (1976) states that "reddish-brown or red subsoil horizons in arid-region soils are good indicators of argillic horizons" this is not always the case.
H.E. Dregne, 1976. p. 182. Soils of Arid Regions, Elsevier Scientific Publishing Co. Amsterdam.

7. It is often assumed that all land under a lush natural vegetation which is not presently under agriculture is potentially agricultural land. By and large this is a false assumption.

8. For successful irrigation schemes, particularly in developing countries, it is important that farmers should have at least some background knowledge of soil-water relationships. This can be attained through extension services including field excursions to various irrigated sites.

9. Poorly written terms of reference for development projects often lead to clients receiving poor or incomplete reports. It should be the moral obligation of the experts/consultants to advice the clients of any shortcomings in the terms of reference rather than exploit the opportunity.

10. In this computer age there is a great emphasis on quantitative land evaluation. Use of qualitative data in simulation models producing quantitative evaluations is however, basically incorrect.

11. Multidisciplinary problem-oriented research is crucial when developing irrigation schemes.

12. Direct transfer of technology/methodology from developed countries to developing countries should be discouraged, and instead developing countries should be encouraged and assisted in establishing methodologies/technologies compatible with their prevailing social, economic and environmental setting.

13. Financial and technical assistance to developing countries should be channelled through a Donor Coordinating Government Agent of the recipient country who should ensure that there is no duplication of efforts and that the assistance is directed to the appropriate development priorities.

14. Everything in the Netherlands seems to be well organised with an exception of the weather.

F.N. Muchena.
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ABSTRACT.

Muchena, F.N. (1987). Soils and Irrigation of Three Areas in the Lower Tana Region, Kenya. A comparative study of soil conditions and irrigation suitability. (XI)+ 194 pages, 43 tables, 91 figures, 172 references, 7 appendices (including three loose soil maps), 1 annex, English Summary.

The soils and soil conditions of three areas situated in different physiographic positions in the Lower Tana Region of Kenya were investigated in respect of their suitability for irrigated agriculture. The soils vary widely in both physical and chemical properties. Most of the soils have an alkaline soil reaction. Salinity and sodicity vary widely from soil to soil and within the same soil. The soils are characterised by low to moderate infiltration rates and slow hydraulic conductivity. Possibilities for deep subsurface drainage vary in the three study areas. The soils behave differently under the same irrigation practices and management. The bulk of the soils are marginally suitable to not suitable for irrigated agriculture. The most limiting factors are salinity, sodicity, drainability, effective rooting depth, availability of oxygen for root growth and workability of the soils.

Keywords: Kenya, soils, salinity, sodicity, irrigation suitability, productivity index, production potential, land quality, predictive models, soil monitoring.

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SUMMARY.

The objective of this study was to compare the soils and soil conditions of three areas, situated in different physiographic positions in the Lower Tana region of Kenya in respect of their suitability for irrigated agriculture.

The study areas comprises the proposed Bura East Irrigation Scheme, the Bura West Irrigation Scheme and the Hola Irrigation Scheme. They are situated between latitude 0°45' South and 1°30' South and longitudes 39°20' East and 40°30' East. In the Bura West and Hola areas about 2,500 ha and 872 ha, respectively are under irrigation.

The climatic of the region is semi-arid to arid, with an average annual rainfall of 300 to 400 mm, falling in two short rainy seasons. The temperatures are high throughout the year. Mean maximum temperatures do not fall below 31°C in any month and mean minimum monthly temperatures are above 21°C. On average potential evapotranspiration exceeds the rainfall by a factor of two or more throughout the year. Hence the chances of a successful rainfed crop production in the three areas is very small.

Tana river is the only year round source of surface water. It draws its supply of water from mount Kenya and the Aberdare and Nyambene ranges. The water flow is regulated through several reservoirs built for hydropower generation in its upper and middle reaches. The Tana river water is of excellent quality for irrigation purposes. The Bura West area is crossed by an intermittent river, Laga Hiraman, which has water only during the rainy season. The Bura East area forms part of a sedimentary plain which is characterised by a series of parallel-running low ridges oriented in a NW-SE direction. It lies at an altitude of between 80 and 112 metres above the mean sea level. The Bura West area forms part of a sedimentary plain comprising mainly old alluvial fans. It lies at an altitude of between 80 and 110 metres. The Hola Irrigation Scheme is situated on the upper terrace of Tana river at an altitude of approximately 70 metres.

The main physiognomic vegetation types found in the area are bushland. The vegetation generally reflects the semi-arid climate. The woody canopy is dominated by deciduous species which are in leaf only during the short rainy seasons. However, tall riverine trees in close proximity to the Tana river retain their leaves throughout the year.

The present land use in the Bura East area consists of grazing and browsing by domestic animals and wildlife. About 2,500 hectares of the Bura West area and 872 hectares of the Hola Irrigation Scheme are irrigated. Cotton is the main cash crop; other crops include maize, cowpeas, groundnuts, greengrams and vegetables. cotton yields are in the order of 2.5 to 3 tons seed cotton per hectare. The maize yields are generally low.

Chapter 3. gives an account of the soils found in the three study areas. For each area a separate soil map has been compiled. The legends of the soil maps are descriptive outlining the main soil morphological characteristics of both the topsoil and subsoil and at the same time giving the depth at which salinity, sodicity and calcareousness starts. At the end of each soil mapping unit description the soil classification according to the FAO/UNESCO (1974 Soil Map of the World Legend, the FAO Fourth Draft Revised Legend (FAO, 1987) and the USDA Soil Taxonomy (Soil Survey Staff, 1975) is given.

Twenty two (22), twelve (12) and nine (9) soil units have been identified for the Bura East, Bura West and Hola Irrigation Scheme respectively. The soils fall into six major soil groupings (FLUVISOLS, VERTISOLS, CALCISOLS, SOLONETZ and LUVISOLS) according to the FAO-Revised Legend or fall into six Great Groups (Torrifluvents, Torrerts, Camborthids, Natrargids, Haplargids and Paleargids) according to the USDA Soil Taxonomy.

The soils vary widely in both physical and chemical properties. The soil reaction of most of the soils is mildly alkaline to strongly alkaline. The exchange complex is dominated by Ca, Mg and Na. The degree of salinity and sodicity vary widely from soil to soil and within the same soil depth wise. Calcium carbonate and gypsum contents are in general low.

The soils are adequately supplied with the major nutrients, Ca, Mg and K. However, phosphorus and Nitrogen contents are low. Nutrient induced deficiencies are possible due to occurrence of free carbonates and salts in these soils.

Micromorphological observations revealed the presence of densely packed relatively unporous aggregates which is an indication of crust formation in these soils.

The soil drainage classes vary from well drained to poorly drained. The bulk of the soils have clayey textures and have in general low to moderate infiltration rates and slow hydraulic conductivity, particularly in the subsoil. The possibilities for deep subsurface drainage vary in the three study areas. In chapter 4, the results of soil conditions monitoring and field observations on crop performance in irrigated soils are presented. Cotton crop was observed to be growing satisfactorily over most of the irrigated soils. However, some of the irrigation units had a patchy crop with some of the areas showing acute moisture stress and very little growth. The results of root observations indicated that the cotton plant roots were concentrated on the top 30 cm of the soil. This depth coincided with the bottom of the ridges on which the cotton was planted.

The results of the monitoring of soil conditions and changes under irrigation at Hola and Bura West Irrigation Schemes have revealed that the two soils monitored at Hola (Chromi-calcic VERTISOLS and Calcari-vertic CAMBISOLS) and the two soils monitored at Bura West (Chromi-calcic VERTISOLS and Chromi-calcaric

CAMBISOLS) behave differently under the same irrigation practices and management. The results have also shown that within the various irrigation subunits monitored the soils are not homogeneous with respect to salinity and alkalinity.

On the basis of the results of the soil conditions monitoring predictive models were constructed. These models have been used to predict the likely changes in salinity and alkalinity over a period of 10 years.

A land suitability evaluation has been carried out for six different land utilization types (LUTs) under irrigation. Eleven land qualities were considered. Each land quality was rated for all the land mapping units identified in the three study areas using the specifications outlined in appendix 4A. a land suitability evaluation criteria was set for each LUT separately taking into account its requirements. The land qualities of the land mapping units were compared ("matched") with the limits set for each LUT to arrive at the suitability classes. Five land suitability classes were distinguished; highly suitable, moderately suitable, marginally suitable, provisionally not suitable and permanently not suitable. Each suitability class was assigned a "productivity index". Potential production of the five crops considered were calculated.

The results of the land suitability evaluation revealed that the bulk of the soils in the three study areas are marginally suitable to not suitable for irrigated agriculture. The major limiting factors in order of severity are:

* salinity
* sodicity
* drainability
* effective rooting depth
* availability of oxygen for root growth
* workability of the soils
* capacity for water retention
* availability of nutrients
* conditions for germination
* ease of land clearing
* freedom for layout of field plans.

The first six factors are considered to be the most limiting in the study areas.

Chapter 6 gives a summary of the most salient conclusions. The methods of investigation are presented in appendix 1. while the detailed descriptions of the individual soil mapping units is given in appendix 2. Detailed descriptions of representative profile pits and analytical data are given in a separate annex II to this report.

The soil maps (appendices 5, 6 and 7) are given as loose attachments at the back of this report.

1. INTRODUCTION

1.1. GENERAL

The area being considered in the present study is part of the Lower Basin of Tana river, which is the largest perennial river in Kenya of which the water resources offer great potentials for irrigated agriculture. The Tana River Basin encompasses a total catchment area of some 102,400 square kilometres. The headwaters rise along the eastern slopes of the Aberdares and the Southern half of Mount Kenya/Nyambene massive, draining in a generally southerly direction. Below these mountain regions, the central portion of the basin is an upland which gradually descends to the eastern limit of the surfacing of the Basement System rocks. Between this rock system and the Indian Ocean, the river traverses a vast sedimentary plain.

The whole of the Tana Catchment can conveniently be grouped into three; the Upper, Middle and Lower reaches of the river. The Lower Tana area lies around 1°30'. South extending from sea level to about 200 metres above sea level. The area, with favourable topographical conditions and lying close to a good source of irrigation water appears to be a good region for agricultural development under irrigation. It thus may offer a good opportunity for settling people from densely populated areas elsewhere in Kenya.

Kenya already faces a severe constraint in the availability of good agricultural land vis à vis a very high rate of population growth (estimated at 4 per cent per annum) and a high demand for food. At the end of this century (2000 AD), Kenya is expected to have a population of about 35 million people, 78 percent more than lived in Kenya in 1984 (Government of Kenya Session Paper No. 1 of 1986). All Kenya's food grain production, except rice,is totally dependent on rainfall. To maintain a steady increase in production, there should be intensification of agricultural production per unit area of the already arable land through improved management and inputs. Also the currently cultivated lands could be expanded by reclamation of poorly drained land in the higher rainfall regions while at the same time production could be stabilized and increased through expansion of irrigation.

Kenya's irrigation potential is estimated at 500,000 hectares (Ministry of Agriculture, 1981 and Government of Kenya Session Paper No. 1 of 1986) and out of this only 26,000 hectares of land is currently under irrigation. The bulk of the land considered as having irrigation potential is within the Tana River Basin. In order to assess the potential of the land for irrigation-agriculture and to establish the actual hectarage of suitable soils, much attention should be paid to soil investigations. Considering that the present study areas have semi-arid to arid climatic conditions the soil investigations should in particular be focussed on those aspects of soil characteristics that may influence its suitability for irrigation, such as salinity, sodicity, permeability, soil texture and structure etc.

The present study aims at giving a good understanding of the soil conditions of three areas, situated in three different physiographic positions in the Lower Tana Basin, in respect of irrigation-agriculture. The study also aims at investigating the behaviour of the soils at the sites already under irrigation with a view of predicting what the short term and long term effects of irrigation would be.

The areas selected for the study include the Hola Irrigation Scheme which has been under irrigation since 1955. This provides 31 years of experience on which to base judgements on the development potentials under irrigation for the other study areas viz the Bura West Irrigation Scheme and the proposed Bura East Irrigation Scheme. The selected study areas have a diversity of soils which are representative of the soil conditions in the Lower Tana Basin.

1.2 LOCATION, POPULATION AND COMMUNICATIONS IN THE STUDY AREAS.

1.2.1. Location.

The area of study consists of three locations situated in three different physiographic positions in the Lower Tana River Basin. Figure 1. shows the setting of the study areas relative to the country. The three areas considered are: the proposed Bura East Irrigation Scheme, the Bura West Irrigation Scheme and the Hola Irrigation Scheme. The former is situated on the east bank of the Tana river in the Lower basin while the latter two areas are situated on the west bank.

The Bura East study area is about 81,600 hectares and forms part of Garissa District in North Eastern Province of Kenya. It is located approximately 26 kilometres east of the Bura Village. This area has not yet been developed for irrigation.

The Bura West study area covers about 15,000 hectares of which 3,900 are proposed for irrigation. Out of this proposed 3,900 hectares for irrigation, about 2,500 hectares were settled and cropped during the period of this study. The Bura West Irrigation Scheme falls within the administrative area of Tana River District in Kenya's Coast Province. It is located between Laga[1] Walesa in the north and Laga Dakaji in the south.

The Hola Irrigation Scheme study area comprises about 1,700 hectares of which 872 hectares are under irrigation. Like the Bura

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[1]Laga - refers to an intermittent watercourse, or wadi.

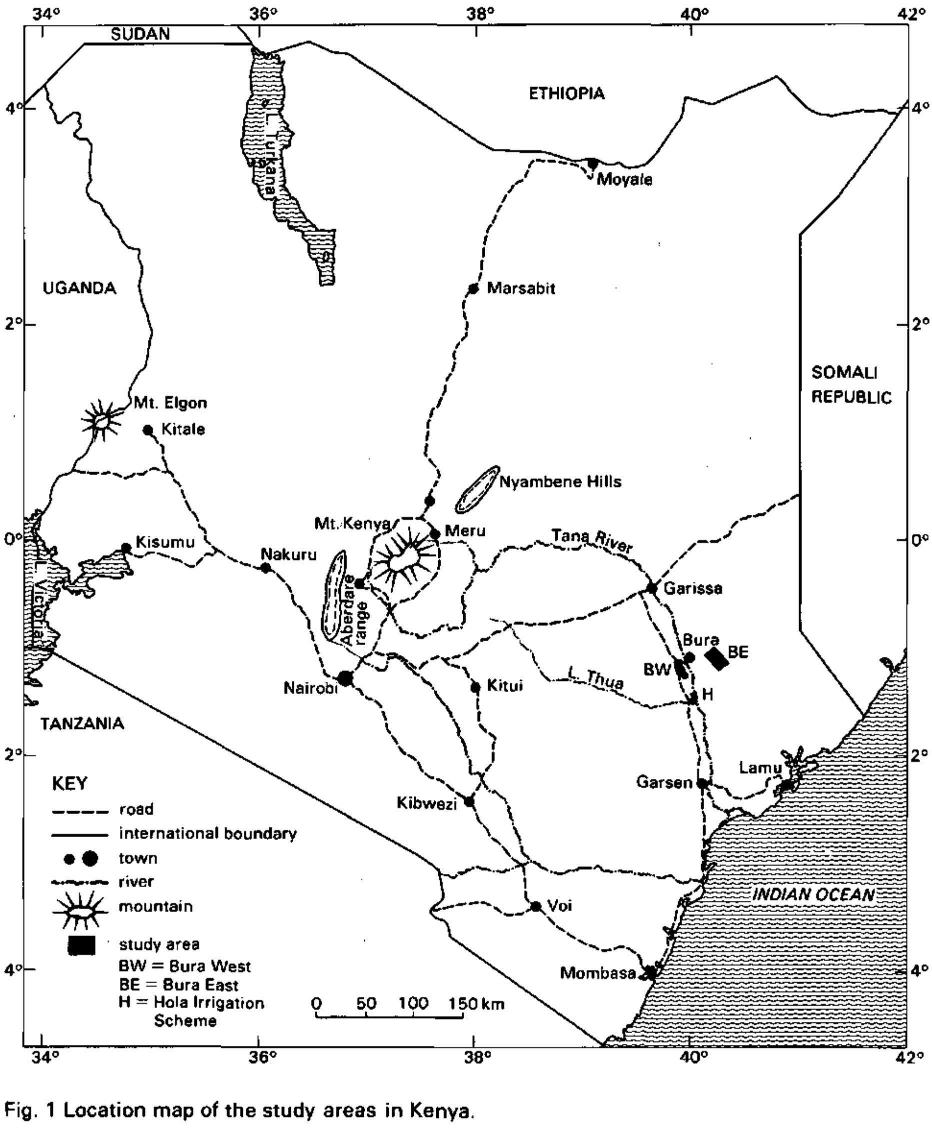

Fig. 1 Location map of the study areas in Kenya.

West Irrigation Scheme, it is located in Tana River District of Coast Province. It is located north of Laga Thua or Galole and south of Laga Dakaji. The scheme is some 120 km north of the Tana river estuary into the Indian Ocean.

The three parts of the study area are situated between latitudes 0°45' South and 1°30' South and longitude 39°20' East and 40°30' East. The altitude ranges between 50 and 200 metres above the mean sea level. Figure 2 shows the location of the three sites within the Lower Tana area.

1.2.2. Population.

It is not possible to give precise figures on the population in the three study areas. However, the population density varies from 1 person per square kilometre in the Bura East area to about 2 and 5 persons per square kilometre in the Bura West and Hola Irrigation Schemes respectively.

In the Bura East area the main ethnic group is the Somalis who are nomadic pastoralists. In the Bura West and Hola areas the main ethnic groups are the Orma, who are nomadic pastoralists and the Pokomo/Malakote who are agriculturalists. The Orma frequent the area mainly during and after the rainy seasons, living in temporary huts. The Pokomo/Malakote live in permanent villages along the Tana river. They cultivate along the riverine margins. Within the Bura West and Hola Irrigation Schemes there are also people from other ethnic groups from upcountry who have been allocated plots within the irrigation schemes. Besides these there are government and other workers.

The population of the Tana River District, where Bura West and Hola Irrigation Schemes are located, is increasing rapidly. Between 1969 and 1979 it rose from 50,696 to 92,401 (Central Bureau of Statistics, 1969, 1981). At the 1979 census the composition of the population was 35 per cent Pokomo/Malakote, 37 per cent Orma, 9.5 per cent Somali, 2.7 per cent Mijikenda, 1.2 per cent Boran and 14.6 per cent other ethnic groups.

1.2.3. Communications.

The Bura East part of the study areas is traversed by a road from Bura Village to Kolbio near the Somali border in the east via Galma Galla. The Bura Village is connected with Garissa in the north by two roads, one passing over a relatively high-lying plain and a lower one right alongside the Tana floodplain. It is also connected via Masabubu and Ijara with Lamu on the ocean coast. All the roads in this area are without any surfacing and do not permit car traffic during the rainy seasons. On the topographical maps of the area several "cutlines" are indicated, that were prepared for a Shell-BP oil exploration programme around 1960. At the period of the study these cutlines were overgrown and were hardly motorable.

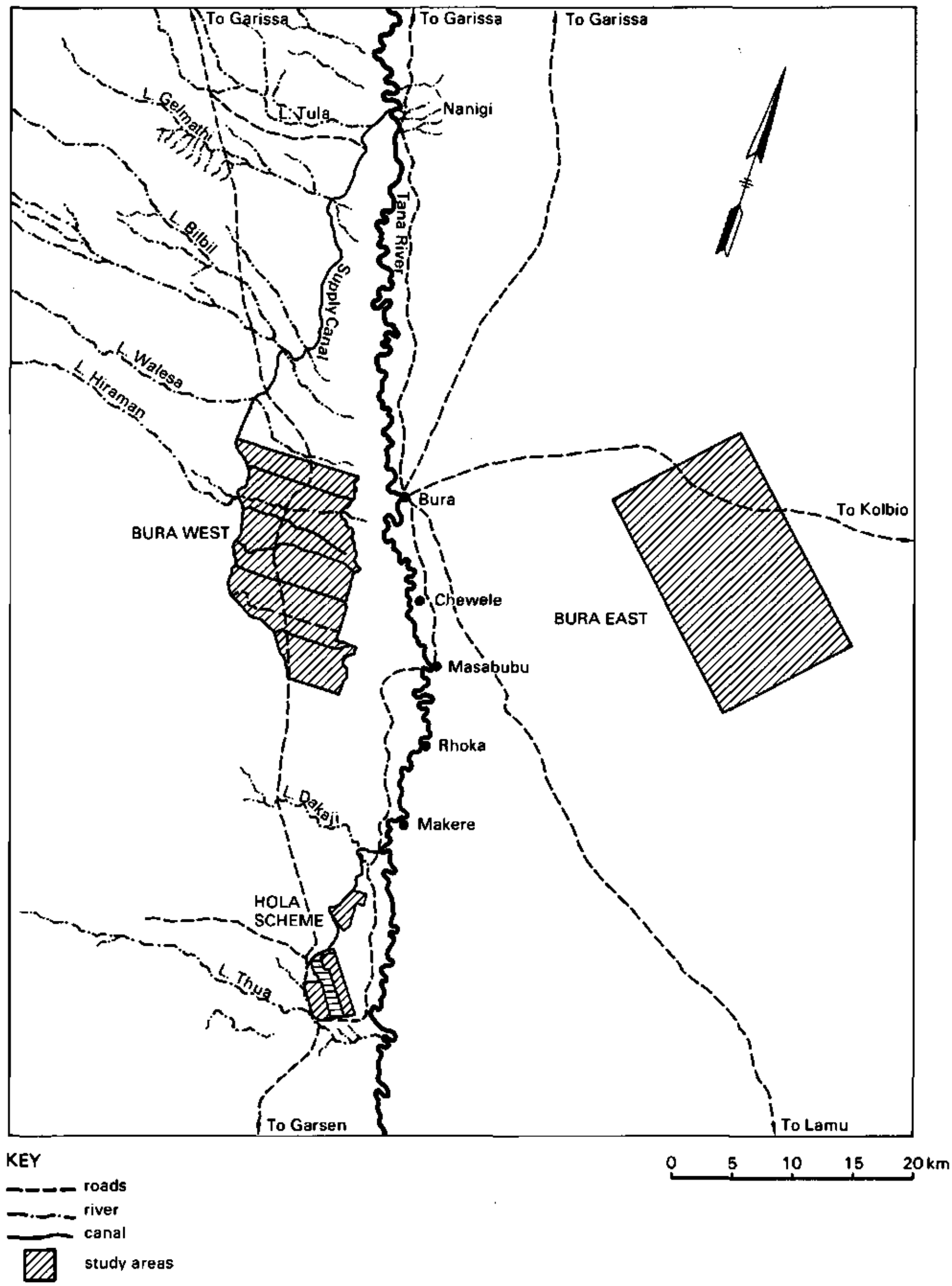

Fig. 2 Location of the study areas within the Lower Tana area

The Bura West and Hola areas are traversed by a road which on the northern side joins the Nairobi-Garissa road and proceeds southwards to Garsen and eventually to Malindi and Mombasa. At Garsen this road joins the road to Lamu. By 1985 no connection between the Bura East and Bura West existed except for a canoe crossing at Bura Village. The only overland connection which existed then between the three study areas was only via Garissa or Lamu through Garsen. However, at present a bridge is being constructed to connect the Bura West Irrigation Scheme with the Bura Village on the east bank. The road Garissa-Garsen is frequently impassable to motor vehicles during the rainy seasons. However, at present this road is being surfaced. The nearest railhead is at Mombasa.

The study areas can be reached by air through landing strips at Bura Village on the east bank, Bura West Irrigation Scheme and at Hola. Bura West and Hola are well provided with other infrastructural facilities such as shops, police posts and schools.

1.3 PREVIOUS INVESTIGATIONS AND OBJECTIVES OF THIS STUDY.

The need to develop the irrigation potential of the Lower Tana area has long been recognised by the Government of the Republic of Kenya. In 1955 a small experimental station was established near Hola. Initially it consisted of two six-acre (2.43 hectares) units, one on a reddish brown soil (now classified as Calcari-vertic CAMBISOLS) and the other, on a yellowish-grey soil (now classified as Chromi-calcic VERTISOLS). It soon became evident that the "reddish brown" soil was more suitable for irrigation-agriculture and early in 1957 it was decided to develop 200 hectares of "reddish brown" soils. The scheme was extended and it covered an area of approximately 400 hectares when the soils investigations in the Lower Tana River Basin were carried out between 1963 and 1965 by consultants (Acres/ILACO, 1967). These soil investigations consisted of a soil survey covering over 240,000 hectares which included the Bura West Irrigation Scheme. This soil survey was termed "semi-detailed" but it should be more properly called "reconnaissance" survey since soil profile observations were made at one per square mile (approximately 1 observation per 2.59 square kilometres). The soil map was prepared on scale 1:50,000 and the soils found in the area were classified in accordance with the Seventh Approximation System of the U.S. Department of Agriculture (Soil Survey Staff, 1960). Table 1. shows the soil classification of the soil units identified during the Lower Tana Survey (1963-1965).

Table 1.: Soil classification Units of Lower Tana Survey (1963-1965).

Parent material	Order	Suborder	Great Group	Subgroup	Mapping symbol
Old Alluvium	Entisol	Ustent	Psammustent	Typic Psammustent	PR
	Aridisol	Argid	Natrargid	Typic Natrargid Mazic Natrargid	N3
		Orthid	Camborthid	Typic Camborthid	C
			Halorthid	Typic Halorthid	S
	Vertisol	Usent	Grumustert	Natric Grumustert	GU
		Aquert	Grumaquert	Natric Grumaquert	GA
Young Alluvium	Entisol	Udent	Hapludent	Typic Hapludent	PL
				Vertic Hapludent	US
				Vertic Hapludent Regularly flooded	U
				Soils of the meander plain	P

Source: Lower Tana Survey 1963-1965 (Acres/ILACO, 1967)

Following these investigations, it was proposed to set up a permanent Research and Training Centre, which was to carry out continuous agronomic research into new crops, fertilizers etc. In addition, agricultural staff and farmers were to be trained. The site for the Research and Training Centre was selected immediately South of Laga Hiraman where soil conditions were thought to be reasonably representative of the major soil types found in the overall study area. An intensified soil survey of this area was carried out to broaden the insight into the soil units and their distribution over the centre. A. 1:10,000 soil map was made (Acres/ILACO, 1967) and the following soil units were identified:

- Typic Natrargids (Units N1 and N2) - soils with a capped natric horizon. They were subdived according to occurrence of hardpans.
- Mazic Natrargids (Unit N3) - these are Natrargids which are truncated
- Vertic Natrargids (Unit N4) - these are Natrargids that have vertic characteristics i.e. high clay content, cracks, absence of a cap etc.

Typic Halorthids[2] (Unit S)	-	these are saline soils with non-saline and non-sodic topsoil.
Typic Camborthids (Unit C)	-	these are non-saline and non-sodic soils
Natric[3] Grumusterts (Unit GU)	-	these are cracking clay soils. they were subdivided on the basis of the depth of non-saline / non-sodic topsoil
Vertic Hapludents (Unit US)	-	these are low-lying young alluvial soils of the Tana River Basin as well as of the streambed of Laga Hiraman.

The Hola Irrigation Scheme was not included in the 1963-1965 survey of the Lower Tana Basin. It was not until 1967, some 12 years after the start of the Scheme, that a detailed Soil Survey on a 1:10,000 scale was carried out (ILACO, 1968).
The survey distinguished the following soil units:

A Soils	-	Intergrade between Typic Halorthids (Unit S of Lower Tana Survey) and Natric Grumusterts (Unit GU of Lower Tana Survey)
A/B Soils	-	Natric Grumusterts (Unit GU1 or GU2 of Lower Tana Survey)
B Soils	-	Natric Grumaquerts (Unit GA1 or GA2 of Lower Tana Survey)
C Soils	-	Typic Natrargids (Unit N23 of Lower Tana Survey)

A soil map of the Extension area, which was brought under cultivation in 1972, was prepared in 1976 (ILACO, 1976). The dominant soils in this area were classified as Typic Halorthids (soil unit S of the Lower Tana Survey - see table 1).

During 1972 and 1973 a feasibility study of the Bura West area, covering a gross area of some 7,000 hectares, was carried out (ILACO, 1973), For this study a soil suitability map, scale 1:20,000, was prepared by reducing and enlarging the existing Lower Tana survey maps (Acres/ILACO, 1967) of the area under consideration. No additional field mapping was carried out but additional soil samples were taken and analysed.

Towards the end of 1974 additional survey work was undertaken as part of the Bura West Feasibility studies. A detailed soil survey of 8,500 hectares north of Laga Hiraman was carried out. Also a detailed soil survey of four sample areas of 500 hectares each south of Laga Hiraman was done (ILACO, 1975). As the result of

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[2]The Great Group "Halorthirds" does not exist in the Seventh Approximation (Soil Survey Staff, 1960). It was introduced by Acres-ILACO (1967) to cater for soils which were saline (ECe>4 mmhos/cm), but did not contain at least 2 percent salt to qualify them as having a salic horizon and hence classified as salorthids.

[3]The Subgroup "Natric" was also introduced by Acres/ILACO (1967) to cater for those soils which had non-saline but sodic horizons.

these soil investigations the Bura West Irrigation Scheme was established.

In 1975, Sombroek et.al. carried out a site evaluation to determine the irrigation potential of the east bank of the Lower Tana. The results of this site evaluation revealed that about 30 kilometres east of Bura Village there were two sizeable blocks of level land where the soils appeared moderately suitable for irrigation of commercial crops. In view of this a proposal to start a major irrigation scheme in the area as a complementary to the Bura West Irrigation Scheme, got underway. This area, comprising about 81,600 hectares was investigated in 1981 by the author and other staff members of the Kenya Soil Survey (Muchena and Van der Pouw, 1981a), to determine its suitability for irrigation. It is during this survey, that the author, as the teamleader of the soil survey investigations, developed an interest in carrying out a comparative study of the soil conditions in the Bura East, Bura West and Hola Irrigation Scheme. During the soil survey in the Bura East area, the following questions were often asked: "Are the soils in the Bura East area similar to those of the Bura West or the Hola Irrigation Scheme?; Can the experiences gained at Hola be extrapolated to the Bura East area as was the case for the Bura West area?. Are the possibilities for surface and deep drainage to ensure long-term success of irrigation comparable?" A search for the answers to the above questions motivated the author to undertake this study.

The soil studies conducted in the Lower Tana River Basin have revealed that the area comprises soils that differ considerably in characteristics over short distances both in horizontal and vertical direction. These soils too have developed in different types of landscapes with possibly different types of parent materials and substrata properties. In view of this, it is apparent that there is a need to have a good understanding of the soil conditions in the area before one makes judgements on the potential of the area for irrigation. From this point of view, the objective of this study is therefore to carry out a comparative study of the soil conditions in the Bura West Irrigation Scheme, the proposed Bura East Irrigation Scheme and the Hola Irrigation Scheme in order to get an insight of their genesis and behaviour under irrigation with a view of predicting what the short term and long term effects of irrigation on them would be.

1.4 WORKING METHODS AND PROCEDURES.

This study mainly concerns an investigation of the soils and soil conditions of three areas. At two of them the soil conditions before and after irrigation were investigated. At the other site only the soil conditions before irrigation were investigated. The object of the investigation is to arrive at the suitability of these soils for irrigation and to predict their likely behaviour under irrigation. An attempt was also made to investigate the possibilities of extrapolation of the experience gained from an irrigated area to another area earmarked for irrigation development.

To enable a comparative study to be made it was necessary as a first step to have a detailed description and characterisation of the various soils occurring in the study areas. For the Hola and Bura West Irrigation Schemes, the soils data gathered by Acres-ILACO (1967) and ILACO (1968 and 1975) was used. This was however, supplemented with additional profile pits and augerings in both the irrigated and non-irrigated areas for more detailed soil characterisation. A total of 23 additional profile pits were made; 17 in the Hola Irrigation Scheme and 6 in the Bura West area. In the case of the proposed Bura East Irrigation Scheme, the soils data obtained from a recent soil survey by the author (Muchena and Van der Pouw, 1981a) was utilised. Soil descriptions were based on the FAO Guidelines for Soil Profile Description (FAO, 1977) and the Soil Survey Manual (USDA, Soil Survey Staff, 1951). Munsell Colour charts were used for the colour identification. The soils were classified according to the FAO legend for the Soil Map of the World (FAO, 1974), the Revised FAO legend (FAO, 1987) and U.S. Department of Agriculture Soil Taxonomy (Soil Survey Staff, 1975).

In order to get an insight of the water movements in the soils and the substrata of the study areas, infiltration and hydraulic conductivity measurements were carried out at selected sites representative of the major soil types. For the Bura West and Hola Irrigation Schemes infiltration measurements were carried out using the double ring infiltrometer method (see figure 3) while in the Bura East area the single ring method was used. Hydraulic conductivity measurements were carried out on those layers that are likely to limit vertical drainage using the augerhole pour-in method (ILRI, 1980). At the sites where infiltration and hydraulic conductivity measurements were carried out undisturbed ring samples and disturbed samples were taken to determine bulk density, porosity and moisture retention characteristics. A detailed account of the various office, field and laboratory methods is given in Appendix I.

The data on the crops and crop performance under irrigation at Hola and Bura West Irrigation Schemes was acquired by studying the annual reports of the National Irrigation Board. This was supplemented by published data such as that contained in the feasibility studies (ILACO, 1975 and 1976). Actual ground observations on the crop performance under irrigation were made at Bura and Hola Irrigation Schemes. Root observations for cotton crop were made at 4 selected sites in the Hola area and at 4 sites in the Bura West area. Figure 4 shows an example of a profile pit where root observations were made.

In order to assess the changes in soil conditions that might occur after irrigation, the monitoring of chemical and physical

Fig. 3. Infiltration measurements in Hola Irrigation Scheme (uncultivated site) using the double ring method.

Fig. 4. A profile pit dug in an irrigated cotton field at Hola for root observations. Note the area between the hammer and the knife (about 40 cm wide) where the roots were counted.

properties of the soils were carried out. This monitoring was confined to Bura West and Hola areas since they are the only ones which are at present under irrigation-agriculture. The monitored irrigation subunits were selected in such a way that they would be representative of the major soils under irrigation. The subunits were located in different irrigation units. In each subunit there were at least two sampling sites. The location of the irrigation subunits sampled for soil conditions monitoring are shown in figures 5 and 6 for Bura West and Hola respectively. In each subunit there were at least two sampling sites (see figure 61 chapter 4.2.2.). At each sampling site six subsamples were taken and mixed for each depth. In case of the Bura area, the samples were collected at depth intervals of 30 cm down to a depth of 150 cm. However, for the Hola area the samples were collected at depth intervals of 15 cm down to 60 cm and thereafter at depth intervals of 30 cm down to 150 cm. The different sampling depth at Hola was used to enable utilisation of soils data which had been collected prior to this study. A maximum depth of sampling of 150 cm was selected taking into account the root zone depth of cotton crop as observed at Hola. The soil samples collected were analysed for pH-H_2O, Electrical Conductivity (EC), Exchangeable Sodium Percentage (ESP), P-Olsen, percent organic carbon (%C). Exchangeable Cations and Cation Exchange Capacity (CEC). The methods used for the analysis are those used at the National Agricultural Laboratories (N.A.L.) as described by Hinga et al (1980). A summary of the methods used is given in Appendix I.

Soil samples for micromorphological analysis were collected in selected sites at both Bura West and Hola Irrigation Schemes. The micromorphological analysis was carried out to verify some of the observations made during the soil studies in the field. These include features such as surface crusting, occurrence of clay cutans, soil compaction etc.

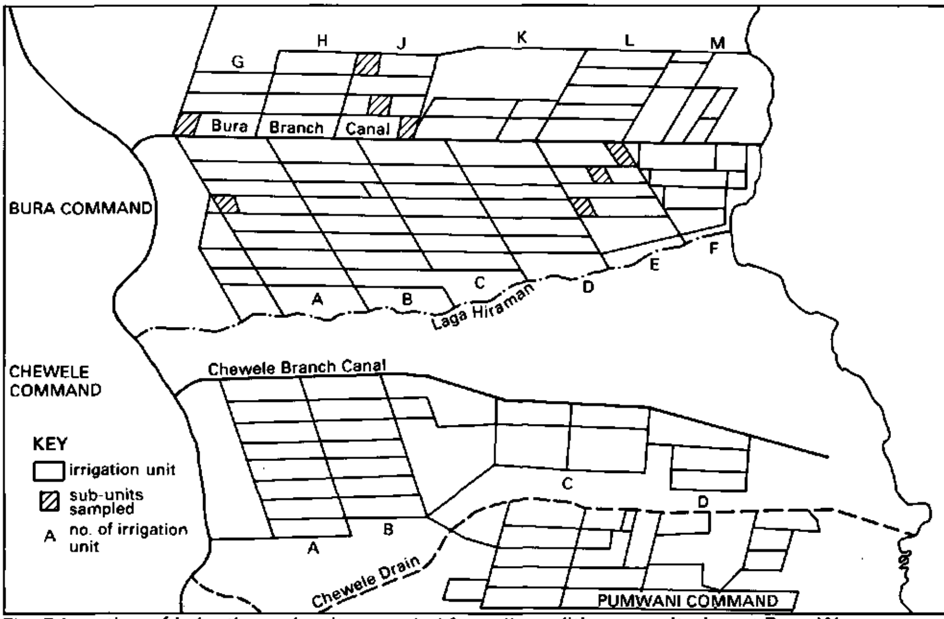


Fig. 5 Location of irrigation subunits sampled for soil conditions monitoring at Bura West Irrigation Scheme.

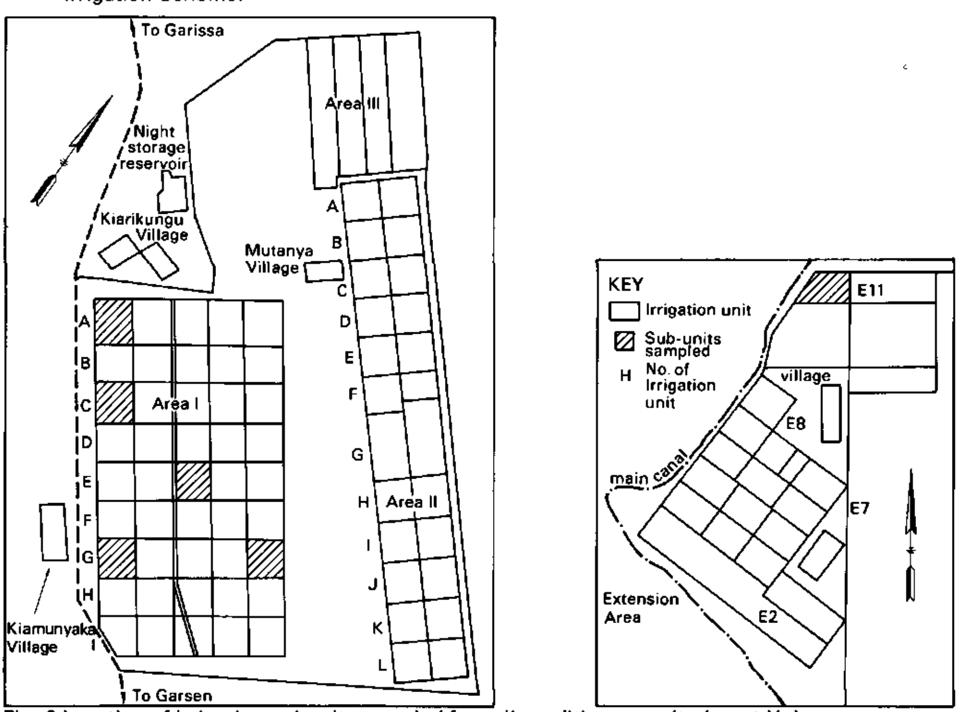


Fig. 6 Location of irrigation subunits sampled for soil conditions monitoring at Hola Irrigation Scheme.

2. GENERAL ENVIRONMENTAL DATA.

2.1. GEOLOGY, LANDFORMS AND GEOMORPHOLOGY.

2.1.1. Geology.

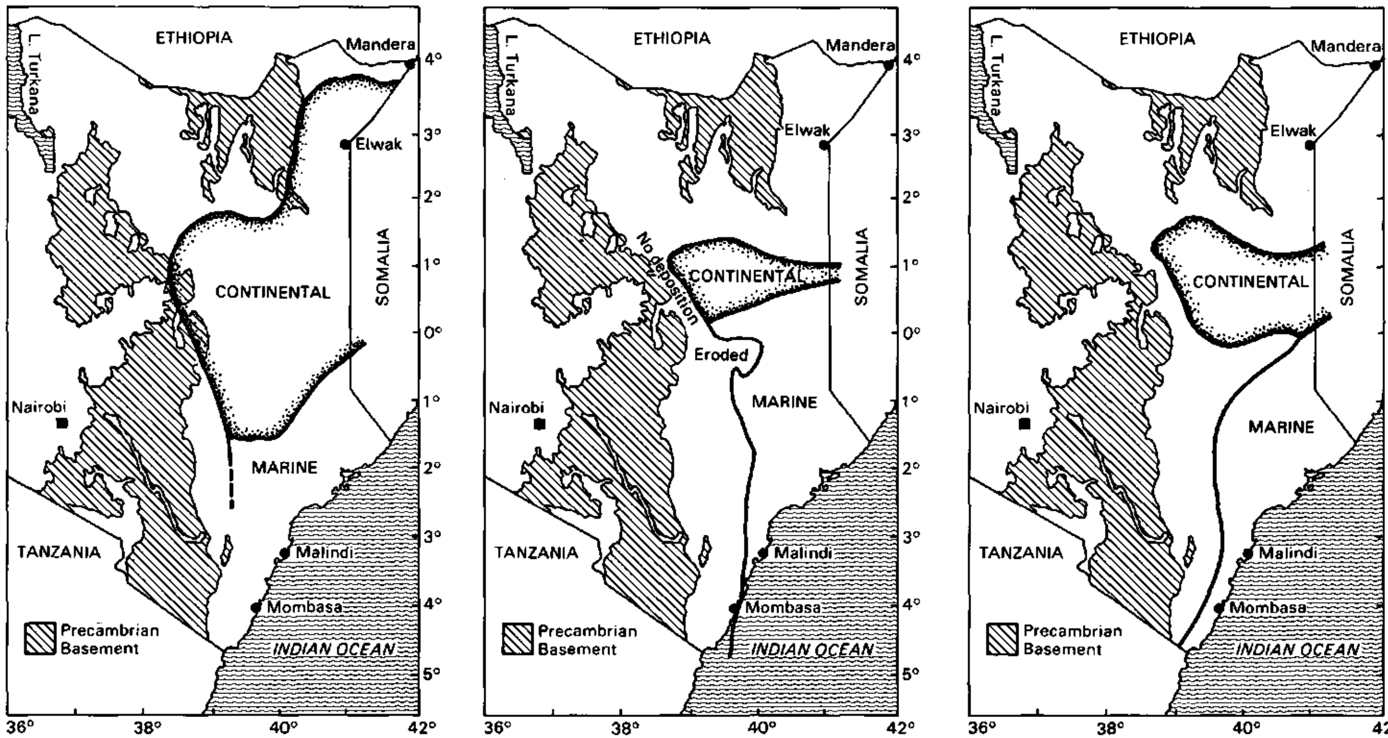
To understand the geology of the study areas it is important to look into the stratigraphical and geological history of the region in which they are situated. The study areas form part of the sedimentary basins of the East Kenya. Walters and Linton (1972) divided the coastal part of this sedimentary basin into two; the Lamu Embayment and the Mombasa-Malindi sedimentary belt. Karanja (1983) subdivided the Lamu Embayment into three: the Lamu Basin, the Garissa and Walmerer High and the Anza Basin (cf. figure 8). The three study areas fall within the Lamu Basin. The whole of the sedimentary basin of East Kenya is underlain by Precambrian Basement System rocks at an approximate depth of 10,000 metres. These are overlain unconformably by Paleozoic/Mesozoic age Karroo continental sediments up to a depth of approximately 6,400 metres (Cole, 1950 and Russel, 1962). The deposition of the Karroo age continental sediments came to an end after a major Jurassic phase of faulting which was succeeded by a widespread marine invasion during which shallow marine epicontinental sediments were deposited over the Karroo (Joubert, 1963; Walters and Linton, 1972 and Karanja, 1983). Figures 7a to 7e give the sequence of deposition of the continental and marine sediments in Eastern Kenya from the period Lower Cretaceous to Miocene.

During the early Cretaceous, deltaic conditions prevailed over most of the northwestern part of the Lamu Basin resulting in the deposition of continental sediments (cf. figure 7a) by a system of fluvial deltas. In the middle-Cretaceous continental sediments may have been deposited on the Garissa-Walmerer High of the Lamu Basin but these were subsequently removed by erosion. In the Anza Basin continental sedimentation continued (cf figure 7b).

The end-Cretaceous uplift was widespread in the Lamu and Anza Basins and correlates with Cretaceous igneous activities in East Kenya (Karanja, 1983). The uplift was particularly pronounced in the area of the Garissa-Walmerer Paleo High, shutting off the sea from the Anza Basin. Continental sediments were deposited in the basin under fluvial deltaic conditions (cf figure 7c).

Throughout Tertiary times, the greater part of East Africa was above sea level (Russel, 1962). This period of quiescence enabled the mid-Tertiary (Sub-Miocene) peneplain to develop (Dixie, 1948; Puffrey, 1960; Saggerson and Baker, 1965).

The Tertiary sediments of the Lamu and Anza Basins overlie the older sediments with an unconformity and represent a distinct

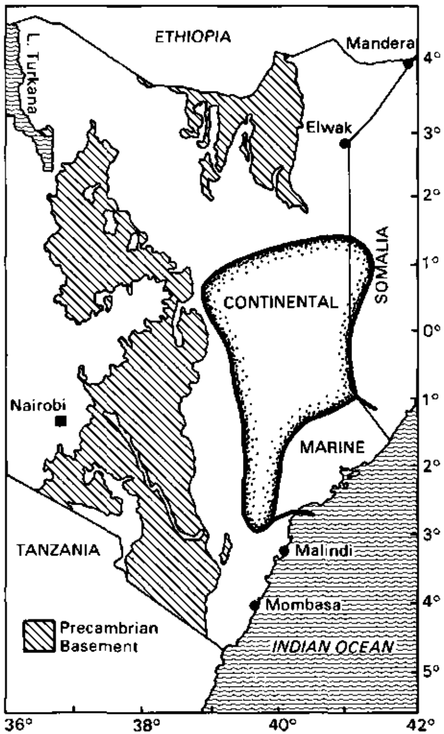


7 (a) Lower Cretaceous

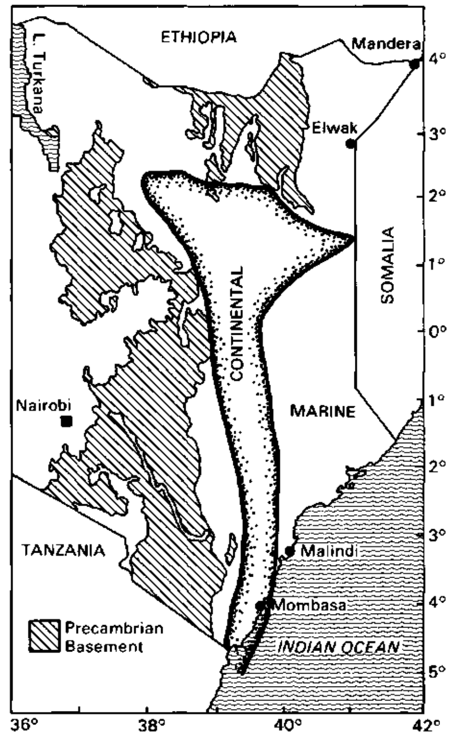
7 (b) Middle Cretaceous

7 (c) Upper Cretaceous

Fig. 7 Deposition of continental and marine sediments in Eastern Kenya during the period Lower Cretaceous to Miocene (After Karanja, 1983).



7 (d) Middle Eocene-oligocene



7 (e) Miocene

Fig. 7 Cont.d

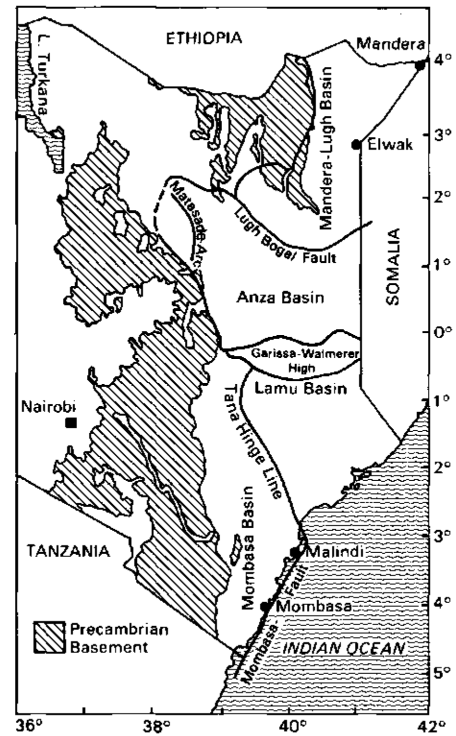


Fig. 8 Distribution of sedimentary basins in East Kenya.

cycle of deposition. There is a facies change from marine in the southeastern part of the Lamu Basin to continental in the northwestern part of the basin and in the entire Anza Basin.

The middle-Eocene-Oligocene sediments of the Anza and Lamu Basins are mainly continental (cf. figure 7d). They consist of grey, red and purple variegated carbonaceous mudstones, poorly sorted argillaceous sands and soft sandstones. Gravel and conglomerates occur occasionally and clay and marly horizons are locally found interbedded.

The lithological characteristics (eg amount of feldspars) of the middle-Eocene-Oligocene continental sediments of the Lamu and Anza Basins strongly point to, reworking of the Basement and the Karroo deposits of the basins peripheries (Walters and Linton, 1972 and Karanja, 1983).

During the Miocene-Pliocene times, the sediments of the Anza Basin were deposited under mainly continental deltaic conditions. However, in the southeastern part of the Lamu Basin sedimentation was under marine conditions whereas in the northern and western parts of the basin sedimentation was under deltaic conditions (cf. figure 7e).

In the mid-Pliocene times the deformation of the end-Tertiary surface started. This led to a downflexing of the whole of the Lamu Basin, permitting the incursion of a shallow sea over the end-Tertiary surface and the deposition of marine sediments near the coast, with extensive continental and probably lagoonal deposits farther inland. Subsequently, however, renewed uplift of the Rift Valley Zone led to the Pliocene seaward tilting of Eastern Kenya. This raised the Pliocene sediments from their former position at near sea level to over 300 m above sea level west of Garissa (Saggerson and Baker, 1965).

During the mid-Pliocene, too, mature rivers developed over the end-Tertiary peneplain. The Tana river is of Pleistocene age and it is thought that its origin can be linked with the late Pliocene titling (Williams, 1962). During the Pleistocene times, variations in sea level and climatic conditions occurred frequently. These, together with the late Pleistocene tilting and local uplifts, caused the initiation and continuation of the incision and aggradation by these rivers (Puffrey, 1960 and Rix, 1964). During the upper-Pleistocene and Recent times, many of the Plio-Pleistocene sediments deposited on the end-Tertiary surface were reworked and redeposited under different conditions. These remodelled sediments represent the surfacial mantle from which the soils in the study areas have been developed.

Sombroek et.al. (1982) identified and mapped six different forms of sedimentary plains which are associated with the Plio-Pleistocene saline-alkali (sodic) bay sediments. The external boundary of these plains more or less coincides with that of the

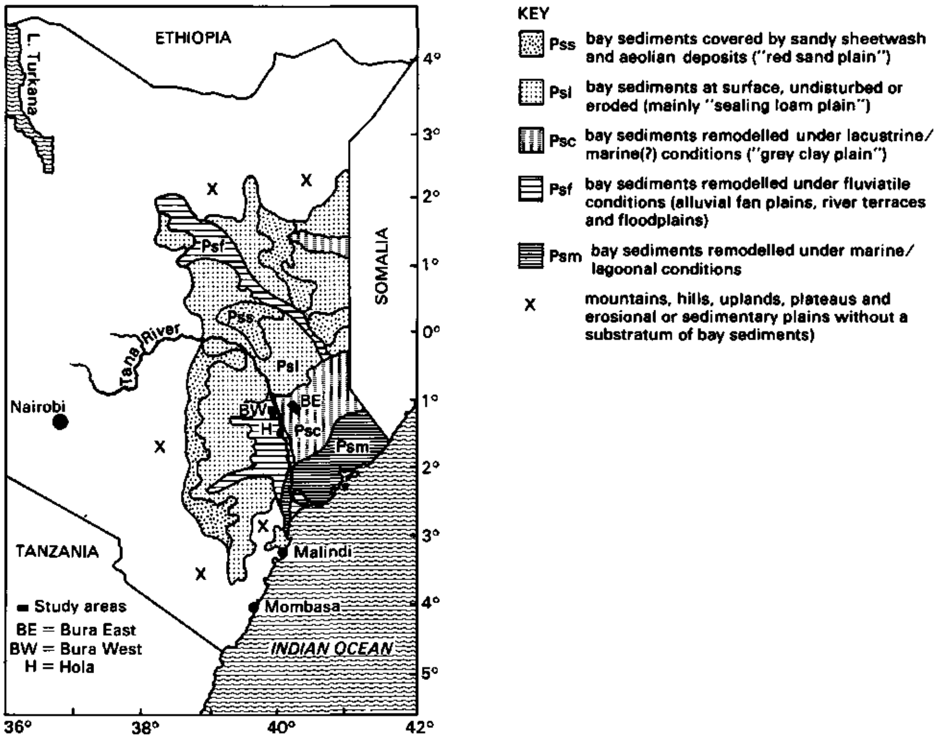


Fig. 9 Extent of the Plio- Pleistocene saline-sodic bay sediments in East Kenya. (after Sombroek et al, 1982)

Lamu Embayment of Walters and Linton (1972) and that of Karanja's (1983) Lamu Basin, Anza Basin and Garissa-Walmerer High. The probable extent of the Plio-Pleistocene saline-sodic sediments is given in figure 9.

The Bura East study area falls under the "grey clay Plain" of Sombroek et.al. (1982) where the Plio-Pleistocene sediments were probably remodelled under lacustrine and/or marine conditions. The Bura West and Hola study areas fall under alluvial fan plains and river terraces respectively, where the bay sediments were remodelled under fluviatile conditions.

2.1.2. Landforms and Geomorphology.

A. Bura East area.
Geomorphologically the Bura East study area can be considered as a sedimentary plain (map symbol Ps of appendix 5). The bulk of the area lies at an altitude between 80 metres and 112 metres. The terrain has a very gentle gradient. On a micro-scale the area can be divided into three units: slightly high-lying land (map symbol Ps 1), slightly low-lying land (map symbol Ps 2) and low-lying land (map symbol Ps 3). The slightly high-lying land consists of parallel-running, low ridges with the low-lying land occurring as narrow depressional strips alongside these ridges. A close relationship exists between the soils and topography. The slightly high-lying land has soils with hardpans while the low-lying areas are characterised by imperfectly drained "cracking clay" soils. Figure 10 is a block diagram showing the landform of the part of the Lower Tana area within which the Bura East, Bura West and Hola areas are situated. From this figure it can be observed that the Bura East area has a "peculiar" parallel low ridge pattern which runs in a northwest to southeast direction. The land slopes gently in the same direction towards the coast. Figure 11. gives a schematic crossection of the area showing the relationship between topography and soil mapping units.

B. Bura West area.
The Bura West study area can be divided physically into two land types: (a) a floodplain (map symbol A of appendix 6) consisting of young alluvial soils along Laga Hiraman and bordering the lower terrace of the Tana river and (b) a plain (map symbol Pf) consisting of old alluvial soils. The bulk of the area studied lies at an altitude between 80 metres and 110 metres above the mean sea level. The plain has very gentle slopes. The dominant slope is from West to East towards the river. Its gradient varies from 1 to 3 percent. The gradient of the overall north-south slope is less than 1 percent. The west-east slopes are long and regular. However, occasionally slight ridges and depressions, running in a west-east direction are encountered. In view of the importance of the slight differences in relief in relation to irrigation and soil formation, the plain has been divided into three units; slightly high-lying land (map symbol Pf 1), slightly low-lying land (map symbol Pf 2) and low-lying land (map symbol

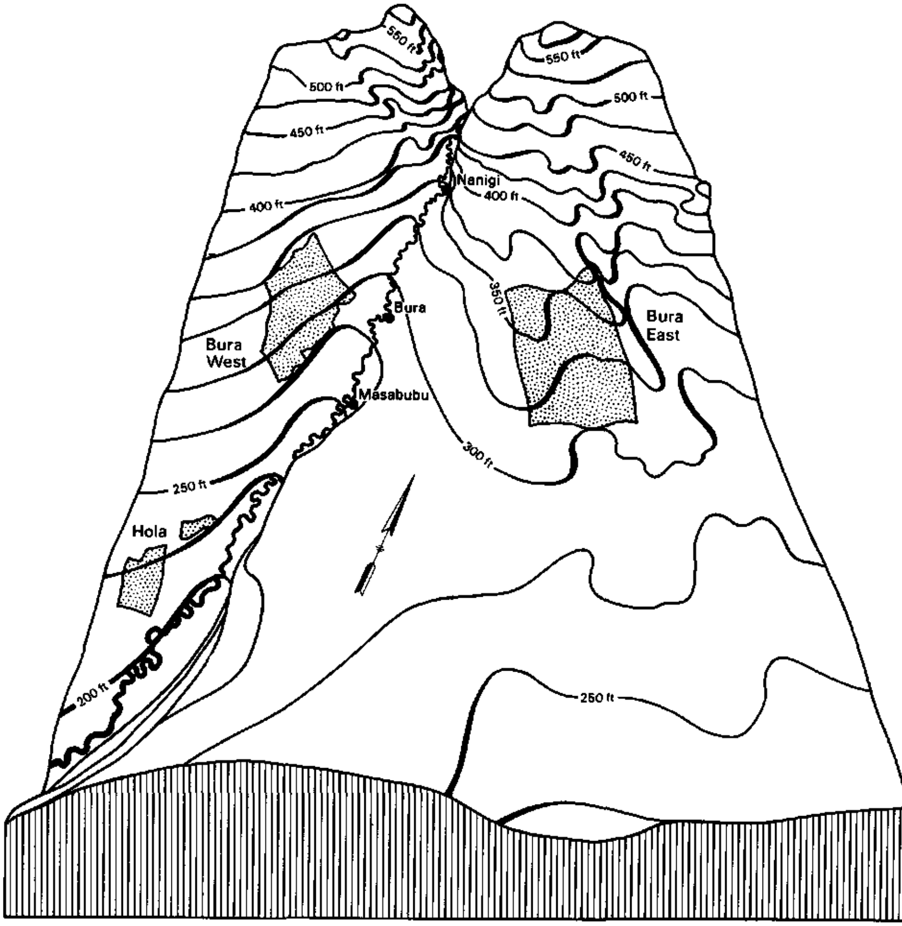


Fig. 10 Block diagram showing topography of the study areas.

Pf 3). The slightly high-lying land has soils with thick sandy topsoils. The low-lying areas have imperfectly drained to poorly drained soils. On the whole, the relief differences between the slightly high-lying and the slightly low-lying areas are very small - in places less than 1 metre. In general, the relief differences between the slightly high-lying land and the low-lying land in Bura West are less pronounced than those of the Bura East area. Figure 12 gives a crosssection showing the

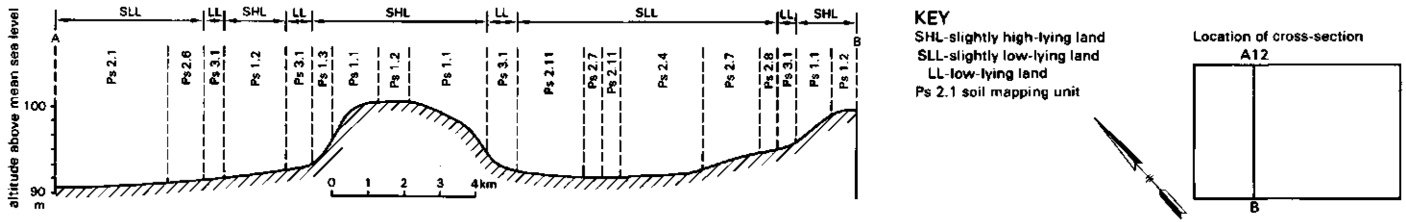


Fig. 11 Cross-section through cutline 12 (A to B) showing relationship between topography and soil mapping units in the Bura East area

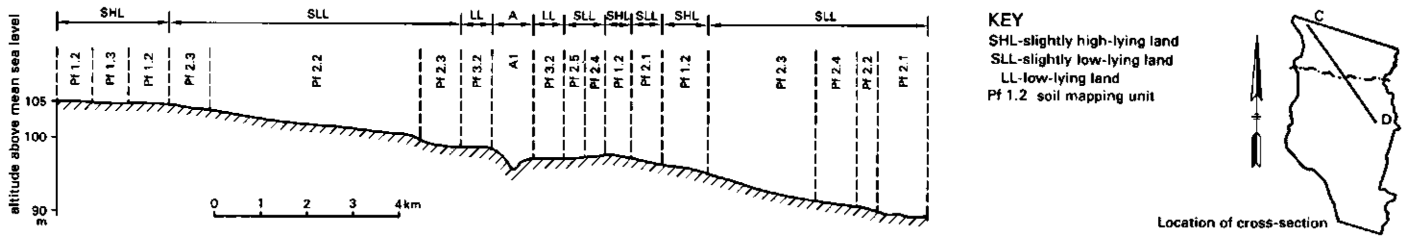


Fig.12 Cross-section through Bura Branch Canal area (NW-SE direction through line CD) showing relationship between topography and soil mapping units

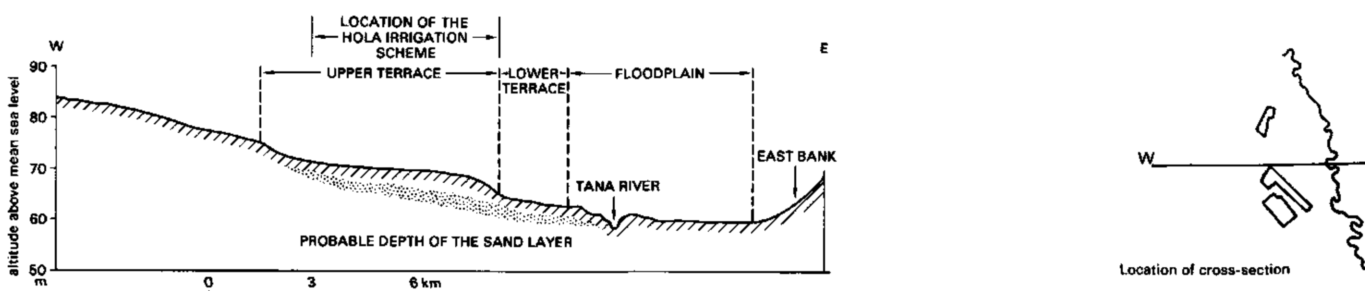


Fig. 13 A schematic cross-section showing the topographic position of the Hola Irrigation Scheme in relation to the Tana Floodplain

relationship between soil mapping units and topography in the Bura West area. From a geomorphological point of view the Bura West area can be described as mainly an old alluvial fan landscape. The alluvial fans originate from the Kitui hinterlands.

C. Hola area.
The Hola study area lies outside the floodplain and the lower terrace of Tana river. Physiographically it falls on a sedimentary plain of the upper Tana river terrace (map symbol Pt). It lies at an altitude of about 70 metres above the mean sea level. The slopes are very gentle ; less than 1 percent and the general slope direction is towards Tana river. Figure 13 gives a schematic crosssection showing the location of Hola Irrigation Scheme in relation to the Tana river floodplain.

2.2. CLIMATE.

2.2.1. Introduction.

The Bura East study area has no climatic recording station. The nearest station is Bura which is located approximately 26 kilometres west of the study area. The Hola study area has a meteorological station with comprehensive data for at least 20 years (1966-1985). In the Bura West study area a meteorological station was established recently and as a result the data recorded was not used in the long term climatic analysis. In view of the few meteorological stations that exist around the Bura West and Bura East study areas, it was found necessary to include the data recorded at Garissa which is located about 90 kilometres to the North West of the Bura study area. Rainfall data and other climatic data for Hola, Garissa and Bura can be found in publications of the Kenya Meteorological Department (KMD 1981, 1984) East African Meteorological Department (EAMD, 1966, 1975) and Woodhead (1968).

2.2.2. Precipitation.

2.2.2.1. Rainfall distribution.

The rainfall pattern in the study areas, like in most parts of Kenya occurring East of the Rift Valley, is controlled by the North-South movements of the intertropical convergence zone. This gives rise to two rainy seasons around the time of the equinoxes (Brown and Cochême, 1973). The "long rains" come during the period March to May and the "short rains" from October to December. Rainfall is low and erratic, with large variations from place to place and year to year.

The average monthly rainfall recorded at Hola, Garissa and Bura stations is given in table 2. From this data it is estimated that the long term average rainfall for the Bura West and Bura East study areas would be between 300 and 400 mm. Braun (1981) estimated this to be 340 mm.

Table 2. Mean monthly and annual rainfall in mm at Hola (station no.: 91.40006), Garissa (station no.: 90.39000) and Bura (station no.: 91.39000).

Month Station (No of years)	J	F	M	A	M	J	J	A	S	O	N	D	Years
Hola (20 years)	15.2	15.6	40.2	70.4	58.9	33.3	18.5	21.1	19.1	34.8	71.1	53.0	451.2
Garissa (41 years)	9.7	6.2	34.0	66.9	15.3	5.7	2.0	6.1	6.9	22.2	80.0	62.3	317.3
Bura (15 years)	17.3	4.8	51.7	101.3	21.7	11.3	7.4	5.0	8.4	24.9	98.4	65.7	418.0

source: KMD (1981, 1984), Anonymous (1985a)

2.2.2.2. Rainfall probability.

Using 51 years of rainfall data recorded at Garissa estimates of seasonal and annual rainfall probability given in Tables 3 and 4 were calculated.

Table 3. The amounts of rainfall likely to be exceeded annually and during the rainy season (P 0.10 indicates a frequency of 10%).

Season Probability	March-May	October-December	Annually
Po.10	239 mm	309 mm	605 mm
Po.20	193 mm	257 mm	492 mm
Po.50	104 mm	145 mm	295 mm
Po.80	39 mm	73 mm	180 mm
Po.90	26 mm	67 mm	104 mm

Source: Braun in: Muchena and Van der Pouw (1981a)

Table 4. The probability that certain amounts of rainfall are exceeded annually during the rainy seasons.

Rainfall	Probability (P)		
in mm	March-May	October-December	Annually
500	P0.02	P0.02	P0.18
400	0.02	0.02	0.29
300	0.04	0.16	0.49
250	0.10	0.22	0.63
200	0.18	0.31	0.76
150	0.27	0.49	0.86
100	0.55	0.69	0.94
50	0.71	0.94	1.00

Source: Braun in: Muchena and Van der Pouw (1981a)

For the study area seasonal potential evapotranspiration (Et) is in the order of 400 mm for the March-May and October-December seasons (Woodhead, 1968). From table 4 this amount is exceeded with a frequency of only 2% (P0.02). This means that it is only once in fifty seasons that seasonal rainfall exceeds the potential evapotranspiration. Therefore in the study area there is a large rainfall deficit over most years. It should be noted however, for short periods of the rainy seasons the rainfall can exceed potential evapotranspiration considerably. This happened in the period April-May 1979 when some 330 mm fell in a period of about 4 weeks (Muchena and Van der Pouw, 1981a).

2.2.3. Temperature.

The air temperature, and to a large extent the soil temperature, is almost entirely determined by the sun energy transmitted as visible and heat rays. The incoming energy is governed by a number of environmental factors such as cloudiness, vegetation, slope and aspect, and latitude (Russel, 1961). The average solar radiation for Hola, Garissa and Bura is given in table 5.

Table 5. Average solar radiation in cal/cm2/day at Hola, Garissa and Bura.

Month Station (No of years)	J	F	M	A	M	J	J	A	S	O	N	D	Year
Hola (17 years[1])	551	564	573	534	481	468	445	467	511	549	562	544	518
Garissa (18 years[2])	500	505	513	506	464	440	426	444	480	496	491	483	479
Bura (8 years[3])	544	568	586	520	496	471	459	474	504	524	532	550	519

sources: 1) Anonymous (1985 a) and Kenya Meteorological Department (1984)
2) Kenya Meteorological Department (1984)
3) ILACO (1975)

The solar radiation is measured with Gunn-Bellani radiation integrator. For all the three stations the maximum monthly radiation occurs in March and the minimum in July. The duration of daily sunshine measured at Hola and Garissa falls between 55-70% and 65-80% of the maximum potential sunshine possible respectively. The resulting air temperatures at the three stations are given in table 6.

Table 6. Mean monthly and annual temperatures in °C at Hola, Garissa and Bura.

Month Station (No of years)	J	F	M	A	M	J	J	A	S	O	N	D	Year
Hola (17 years)	28.6	29.5	29.8	29.4	27.7	26.2	25.8	25.8	26.6	28.0	28.6	28.4	27.9
Garissa (41 years)	28.8	29.6	30.5	30.1	28.9	27.4	26.7	26.8	27.6	28.8	29.0	28.5	28.6
Bura (8 years)	28.6	29.2	29.3	28.6	27.8	27.0	26.4	26.3	26.6	27.7	28.1	28.4	27.8

Sources: Anonymous (1985a), Kenya Meteorological Department (1984) and ILACO (1975)

The temperatures in the study areas are high throughout the year with little annual and seasonal variation (see figure 14.). Mean maximum temperatures do not fall below 31°C in any month and mean minimum monthly temperatures are above 20°C. The hottest months are February and March. The lowest temperatures occur during June, July and August. The absolute maximum and minimum temperatures are 41.4°C and 12.8°C respectively (KMD, 1984).

2.2.4. Evaporation and Evapotranspiration.

The U.S. class A pan evaporation data are available for Hola (1966-1982) and for Garissa (1962-1980). The mean measured annual evaporation is 2,712 mm and 2,490 mm for Garissa and Hola respectively. The estimated potential evaporation (Eo) of the two stations is 2,374 and 2,293 mm respectively (Woodhead, 1968). For the average annual potential evaporation of the Bura area, the average of the four values is used. This gives an annual potential evaporation of 2,467 mm. The estimated open-water evaporation for Hola, calculated by the Penman method, as modified for East Africa by Mc Culloch (1965), is 2,565 mm annually.

Table 7. gives the mean monthly and annual evaporation data for Hola and Garissa. The potential evapotranspiration is assumed to be two thirds of the potential evaporation (Braun, 1981; Sombroek et.al, 1982).

Table 7. Mean monthly and annual evaporation data in mm at Hola and Garissa.

Month Station		J	F	M	A	M	J	J	A	S	O	N	D	Year
Hola	Pan (Eo)	211	202	236	201	202	202	195	205	222	236	198	186	2490
(1966-1982)	Crop (Et)	141	135	157	134	135	135	130	137	148	157	132	124	1660
Garissa	Pan (Eo)	206	206	243	224	234	229	231	247	254	254	208	176	2712
(1962-1980)	Crop (Et)	137	137	162	149	156	153	154	165	169	169	139	117	1808

Et = 2/3 Eo

Source: Kenya Meteorological Department (1984) and Anonymous (1985a)

Figure 14. gives a composite diagram of the mean monthly precipitation (P), temperature (T), evaporation (Eo) and potential evapotranspiration (Et) for the Hola area as an illustration of the relationship between these factors in the study areas. From the figure, it is apparent that on average potential evapotranspiration exceeds the rainfall by a factor of about two or more throughout the year. From this data and the rainfall probabilities presented in chapter 2.2.2.2. it can be concluded that the chances of a successful rainfed crop production in the area is very small.

2.3 HYDROLOGY.

2.3.1. Surface hydrology.

Tana river is the only year round source of surface water in the study area. It draws its supply of water from Mount Kenya, and the Aberdare and Nyambene ranges. The water flow is regulated through several reservoirs built for hydro-power generation in its upper and middle reaches viz Masinga, Kamburu, Gitaru, Kindaruma and Kiambere. The latter is being constructed at the time of this study. Monthly discharges of the Tana river measured at Garissa are shown in Table 8. With regulation of water flow in the above reservoirs it is anticipated that there would be adequate water to irrigate large tracts of land within the Lower Tana area and the Tana Delta.

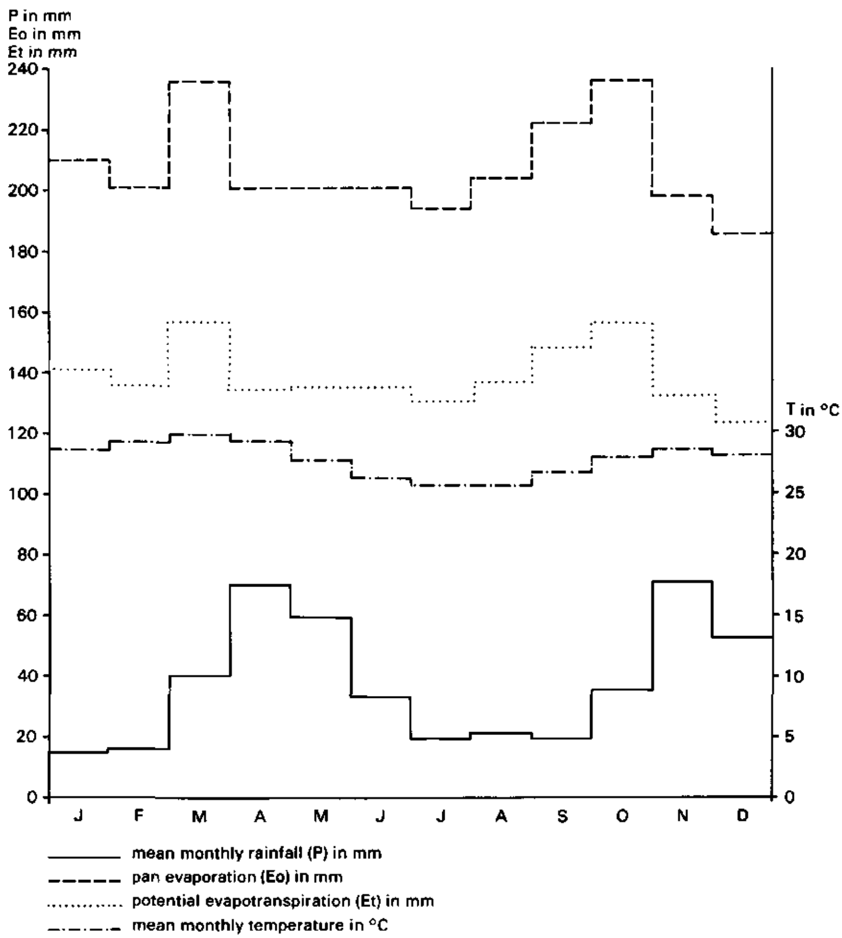


Fig. 14 Temperature, precipitation and evaporation at Hola (Station no. 91.40006). Source: Kenya Meteorological Department (KMD, 1981, 1984).

Table 8. Monthly discharges[1] of Tana River measured at Garissa (1944-1972) in m3/sec.

Month	Discharge	Month	Discharge
January	120	July	112
February	77	August	90
March	79	September	79
April	239	October	103
May	395	November	306
June	205	December	248

Source: ILACO (1975).

In the Bura West and Hola study areas the drainage system consists of ephemeral streams (Lagas) flowing from the Kitui uplands in the West and draining in the Tana floodplain (see figure 2). Within the study area these lagas form broad flat valleys. Laga Walesa occurs north of the Bura West area while Laga Hiraman crosses through the area. Laga Dakaji forms the main drainage system between the Bura West and Hola study areas. Laga Thua (sometimes referred to as Galole) passes south of the Hola Irrigation Scheme. These Lagas only carry water after heavy rainfall.

In the Bura East area the drainage is systematically away from the Tana river. It is to the south-east following the depressional strips forming the low-lying land. The relief differences in the area are so gentle and the substratum of the land is apparently so impermeable that much of the low-lying land is imperfectly to poorly drained. After heavy rains much water accumulates in some parts of the area for considerable time.

2.3.2. Geohydrology.

There is no data available on occurrence of groundwater in the area. Borings made at Korokora which is situated between Garissa and the study areas did not reach groundwater at a depth of 20-30 metres (Acres/ILACO, 1967). Deep profile pits (5-6 metres and augered to 10 metres) made in the Bura East area by the author did not show evidence of groundwater at depths of 10 metres. However, occurrence of a water table in the area immediately adjacent to the river has been reported (Acres/ILACO, 1967). In general the groundwater table in the study areas is believed to be very deep (more than 30 metres) as has been found to be the case in Garissa (Unpublished reports of the Ministry of Water Development).

[1] The discharges given here were before construction of the other dams except Kindaruma.

2.3.3. Water Quality.

2.3.3.1. Sediment Load.

By comparison with some rivers in other parts of the World, the Tana river is not particularly heavily sediment laden (Acres/ILACO, 1967, ILACO, 1975). However, as agricultural development in its upper and middle reaches proceeds, clearing, overgrazing and cultivation of land without appropriate conservation practices could result in considerable aggravation of the sediment problem. Suspended sediment measurements carried out at Garissa (1948-1965) show that the water carries a heavy sediment load. The suspended load, mostly consisting of silt (55%) and fine sand (40%) amounts to 200-300 ppm during periods of low discharge (25-50 m^3/sec) while at discharges in order of 100 m^3/sec a sediment content of 1,400-1,500 ppm may be expected (ILACO, 1975). At periods of higher discharges the sediment contents may rise. Measurements carried out by Dune at Garissa indicate that discharge and sediment loads in the Tana river can increase from 500 ppm at 25 m^3/sec through 1,300 ppm at 200 m^3/sec to a maximum of some 2,700 ppm at 1,000 m^3/sec (MacDonald, 1977).

2.3.3.2. Chemical Composition.

General water quality criteria.
The suitability of water for irrigation is determined by the concentration and composition of its dissolved constituents (Richards, 1954; Ayers and Westcot, 1985). Therefore quality of irrigation water is an important consideration in any irrigation development. The characteristics of irrigation water that appear to be most important in determining its quality are: (a) total concentration of soluble salts; (b) relative proportion of sodium to other cations; (c) concentration of boron or other elements that may be toxic; and (d) under some conditions the bicarbonate concentration as related to the concentration of calcium plus magnesium. The total concentration of soluble salts can be adequately expressed in terms of electrical conductivity (EC). In general, waters with EC values below 750 micromhos/cm are considered satisfactory for irrigation (Richards, 1954, Ayers and Westcot, 1985). With waters in the range of 750 to 2,250 micromhos/cm satisfactory crop growth is possible under good management and favourable drainage conditions. The relative proportion of sodium to other cations is expressed in form of sodium adsorption ratio (SAR). Low-sodium water (SAR-less than 10) can be used for irrigation without endangering the development or increasing the levels of exchangeable sodium. Boron is essential for the normal growth of all plants but the quantity required is very small and if exceeded it can be injurious to the plant. The measure of the hazard of waters with high-bicarbonate concentration is the residual sodium carbonate (RSC) expressed as (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++}). Waters with more than 2.5 me/litre RSC are considered not suitable for irrigation purposes. Waters containing 1.25 to 2.5 me/litre are marginal and those

Table 9. Chemical composition of Tana River Water.

Location of Sampling	Date	pH	EC	Milli-equivalents per litre							Boron ppm	SAR	RSC
				Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Cl^{-}	SO_4^{--}	HCO_3^{-}			
	16- 1-63	7.5	190	1.50	nd	0.05	0.69	0.33	0.20	nd	0.21	nd	nd
Garissa		8.8	160	0.71	0.19	0.05	0.75	0.75	0.20	0.90	nd	3.2	0.1
	1964	8.6	180	0.14	0.34	0.05	0.83	0.88	nil	0.75	nd	1.1	0.3
		8.0	220	0.62	0.74	0.02	1.20	0.06	0.30	0.38	nd	1.4	1.0
		8.5	180	0.62	0.57	0.05	0.80	0.80	0.06	0.78	nd	.3.0	0.4
		8.3	190	0.69	0.30	0.06	0.87	0.87	0.16	0.97	nd	3.7	nil
	3-10-58	7.2	160	0.12	0.68	0.09	0.28	0.30	nil	1.45	nd	0.4	0.65
Bura		7.6	150	0.08	0.68	0.06	0.32	0.46	nil	1.45	nd	0.5	0.69
	6- 7-62	7.3	300	0.75	0.32	0.05	0.78	0.25	0.47	2.17	0.04	0.4	1.1
	1- 7-63	7.3	290	0.70	0.49	0.05	0.73	0.22	0.43	2.19	0.05	0.4	1.0
	8- 8-86	7.8	210	0.40	0.20	0.10	1.5	0.90	0.02	1.80	nd	2.7	1.2
	1955	7.8	160	0.09	0.43	0.08	0.39	trace	nil	1.38	nd	1.4	0.86
	16-11-57	7.9	140	0.66	0.31	0.06	0.37	0.40	nil	1.30	nd	0.5	0.33
Hola	18- 1-58	7.6	160	0.78	0.39	0.18	0.48	0.46	nil	1.36	nd	0.6	0.19
	26- 2-58	8.2	140	0.73	0.31	0.06	0.41	0.06	nil	1.23	nd	0.7	0.19
	19- 7-58	7.6	110	0.56	0.39	0.16	0.80	0.46	nil	1.30	nd	0.6	0.35
		7.8	120	0.60	0.40	0.14	0.82	0.48	nil	1.34	nd	0.6	0.34
(Intake)	4 -11-86	7.8	150	0.40	0.20	0.05	0.60	0.50	0.04	1.20	nd	1.09	0.6
(Canal)		7.8	220	0.40	0.50	0.09	0.89	0.60	0.02	1.90	nd	1.33	1.0
(Drain)		7.9	220	0.50	0.30	0.03	0.89	0.50	trace	2.00	nd	1.41	1.2

EC= Electrical Conductivity in micromhos/cm
ppm= parts per million
SAR= Sodium adsorption ratio
RSC= Residual Sodium carbonate value
nd= not determined
Source: Data prior to 1986 is obtained from Acres/ILACO (1967) and ILACO (1975). The other data has been collected by the author.

containing less than 1.25 me/litre are safe.

Quality of the Tana River Water.
The chemical composition of Tana river water sampled at different points and different times are given in Table 9. The average EC

value of the water for 20 measurements is 182 micromhos/cm with a range between 110 and 300 micromhos/cm. The average SAR value is 1.3 while the range is 0.4 to 2.7. The average residual sodium carbonate content is 0.6 me/litre while the range is 0 to 1.2 me/litre. The boron content is about 0.1 ppm. These values remain well below the critical levels. According to Richards (1954) the Tana river water is classified as low-salinity/low sodium water (class C1-S1). Therefore it is considered to be of excellent quality for irrigation purposes. However, as it has been rightly pointed out by Acres/ILACO (1967), the Tana river water contains some salts. With every application of irrigation water to the land some salts will be added to the soil. It should also be noted that the water is of such low salinity that it may reduce infiltration rates of the soils by causing surface structure to slake (FAO, 1976; Ayers and Westcot, 1985).

2.4 VEGETATION AND LAND USE.

2.4.1. Vegetation.

The general aspect of the vegetation in the study area and its surrounds is described as one of grey deciduous bush usually branching from near the ground with few well-defined trunks, on average 1.5 metres to 4.5 metres high, well spaced, with a more or less continuous ground cover of grasses up to knee high (Acres/ILACO, 1967). The vegetation is in a drought dormant condition for the greater part of the year, when ever-green bushes such as Dobera spp, Salvadora persica, Cadaba spp etc. are outstanding. However, the tall riverine trees in close proximity to the Tana river retain their leaves throughout the year. Locally trees may be found. Many of the deciduous bush species have spines or thorns.

The vegetation type in the area has been indicated in the National Atlas of Kenya (Survey of Kenya, 1970) as bushed grassland with wooded grassland along the Tana river. It has been classified according to the structure (physiognomic) classification used by Pratt et.al. (1966) for the classification of East African Rangelands. The same classification has been adopted by the Kenya Soil Survey as a basis for vegetation mapping (Van de Weg, 1978). It is based on the percentage cover by trees and shrubs without taking account of the ground cover of grasses and herbs. The physiogomic vegetation type is determined using the diagram shown in figure 15. The percentage cover and species composition in an area of approximately one hectare is estimated.

The vegetation in the Bura East area was investigated at the same sites where soil observations were made. The main reason for this was to use the vegetation as a guide for assessing soil conditions. This is in line with the common saying that "only the plant knows what is best for itself".

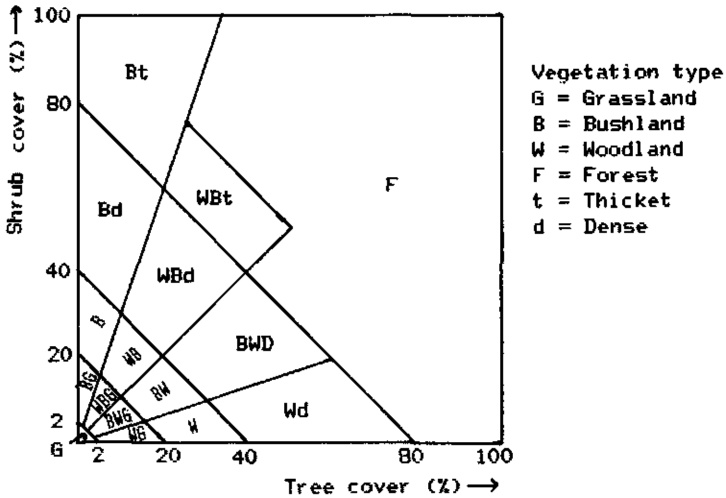


Fig. 15. Physiognomic classification of woody vegetation types (after Van de Weg, 1978)

The vegetation was described in terms of physiognomy, botanical composition and homogeneity of an area of about one hectare around each soil observation site. For the physiognomy the cover percentages of trees (more than 6 metres high) shrubs (smaller than 6 metres including the woody herbs) and grasses were estimated. The botanical composition was described by estimating the relative cover of the various species. A modified Braun-Blanquet scale was used for the cover (Braun and Ochung, 1979). A vegetation map on scale 1:100,000 was prepared (see Muchena and Van der Pouw, 1981a) showing six major vegetation units and their floristic composition. The main physiognomic vegetation types found in the area are bushland, bushed grassland grading to grassland and dwarfshrub grassland. Detailed descriptions of the vegetation types and their floristic composition is given in Muchena and Van der Pouw (1981a).

The vegetation of the Bura West and Hola areas was described and mapped by Acres/ILACO (1967) during the survey of the Lower Tana area. As in the Bura East area the vegetation was investigated to provide guidelines and restraints during the course of the soils investigations. It was classified on the basis of morphology as proposed by Greenway (1943) for classification of East African Vegetation. Eleven major vegetation associations were identified. Only six of these vegetation types are found within this study area viz:

- Semi-desert scrub consisting of Acacia recifiens, Commiphora spp, Blepharis sp. Enteropogon Macrostachyus, Salsola dendroides and Sporobolus ioclados.
- Deciduous scrubland comprising Acacia recifiens, Aristida adescensionis, Blepharis linarifolia, Commiphora sp. Cordia

sp and Sporobolus ioclados. A notable feature is occurrence of Termitaria in this area.
- Shrub thicket consisting of Boscia Coriacea, Commiphora spp, Dactyloctenium aegyptium, Indigofera spinosa and Combretum sp.
- Open bushland with Acacia recifiens, Chloris spp. Cordia sp. Neuracanthus sp., Acacia horrida, Cadeba sp, Grewia tenax, Salvadora persica and Commiphora sp.
- Shrub grassland with Acacia recifiens, Sporobolus helvorus, Chrysopogon aucheri and Schoenefeldia transiens.
- Valley grassland comprising Cyperus rotondus, Sporobolus helvorus, Echnichloa haploclada and Lintonia nutans.

Before the Bura West and Hola areas were cleared for irrigation agriculture, they were covered mainly with open bush and rather dense scrub vegetation with some areas of shrub grassland. The original vegetation types can be seen from the adjacent non-irrigated areas which have not been cleared. Fig. 16 shows the typical vegetation cover in the uncultivated areas between area I and area II of the Hola Irrigation Scheme.

2.4.2. Land use.

The land use in the Bura East area consists of grazing and browsing by domestic animals (sheep, goats and cattle) and wildlife. The herds of domestic animals are moved to graze in the area whenever there is fresh grazing and/or drinking water is available. There are only temporary settlements by the Somali herdsmen. The wildlife is more permanent in the area but it may also move out seasonally. The herbivores observed consists of Hunters Hartebeest (Damaliscus hunteri), Topi (Damaliscus Korrigum), Reticulated Giraffe (Giraffa Camelopardis reticulata), Warthog (Phacochoerus aethiopicus), Gerunuk (Litocranius walleri), Dikdik (Rhynchotrapus Kirkii), Oryx (Oryx beisa), Lesser Kudu (Tragelaphus imberbis) and Elephant (Loxodonta africana) (Braun, 1981 in: Muchena and Van der Pouw, 1981a).

Most of the vegetation is burnt by the herd attendants wherever possible. This creates a variety of different growth stages of the vegetation. This is beneficial for both domestic and wild animals.

The Bura West and the Hola study areas are under irrigation. The non-cultivated areas and the immediate surrounds are under natural vegetation and are used for grazing domestic livestock. Wildlife is also present in these areas. The area west of Bura and Hola extends into the Tsavo ecosystem. Within this ecosystem the herbivores comprise Oryx, Gerunuk, Lesser Kudu, Elephants, Giraffe, Zebra, Warthog and Ostrich (Van Wijngaarden, 1985).

The other wildlife found within the study areas or their immediate surrounds include lion, hyena, baboon, hunting dog, hippo and crocodile. Hippo and crocodile are very common along the Tana river.

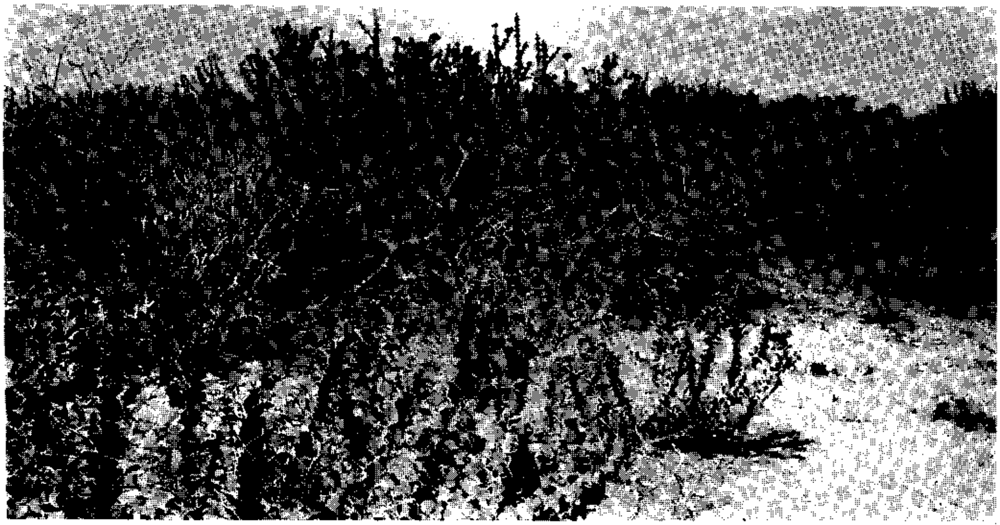


Fig. 16. Typical vegetation cover on uncultivated sites between area I and area II of the Hola Irrigation Scheme.

Fig. 17. A good stand of an irrigated cotton crop at Hola - cotton variety BPA.75.

The land use pattern in the Tana floodplain is dominated by the rise and fall of the floods twice yearly. Where the land is cultivated crops such as bananas, maize, green grams, tobacco, tomatoes, cow peas, sugarcane and cassava are grown. The relative height above the high flood water level determines which crop is grown. Levees close to or on the river bank are used for banana cultivation. Higher levees are planted to mango and occasionally coconut. Maize, beans and grains are grown on the transition of the levee/basin after the recession of the flood. Usually rice is grown in the depressions (basins and oxbows). The crop production is traditional with few, if any, inputs.

Along the Lower Tana area, there are minor irrigation schemes (Wema, Hewani, Oda and Ngao) where rice is the main crop grown during the long rains. Yields are very low and highly variable. Irrigated rice yields average 1,400 kg/ha (Grabowsky and Poort, 1980). The variation in yields is primarily due to land preparation, water management and the level of inputs.

In both the Bura West and Hola irrigation schemes cotton is the main cash crop (see fig. 17.). It is sown in February and March in a phased programme over the entire schemes and harvested from May to September. In the Hola Irrigation Scheme tenants are allocated 1.6 ha in areas I, II and III and 1.2 ha in the extension area. From September to January tenants are allowed to grow 0.6 ha of maize, often intercropped with cowpeas and/or green grams, and 0.1 ha of groundnuts.

In the Bura West each tenant farmer is allocated a total of 1.25 ha of land consisting of two parcels each measuring approximately 0.625 ha where cotton is grown on both plots (1.25 ha) as the main crop for cash during the long rains season (February to September) in rotation with maize as the main subsistence crop during the short rains season (October to January). However, the maize crop is grown only on one of the early planted cotton plots (0,625 ha).

Table 10. Cropping pattern and intensity at Bura West and Hola

Crop	Cropping Intensity		Cropping
	Hola	Bura West	Period
Cotton	100 %	100 %	February-September
Maize 1)	41 %	48 %	October-January
Groundnuts	7 %	--	October-January
Overall cropping intensity	148 %	148 %	

1)Interplanting maize with cowpeas is recommended.
Source: Anonymous (1984b and 1985a).

Bura West tenants are further allocated an additional 0.05 ha for their vegetable plots.

The rotation, organized on a block basis, is early cotton-maize-late cotton-fallow. The currently adopted cropping patterns and intensities at Bura West and Hola are shown in table 10. Land preparation is carried out after removal of the previous crop residues. For cotton it is done in January to March and consists of ploughing, harrowing, ridging and ditching for water conveyance in the fields. Occasionally land levelling is done.

At present 872 ha are irrigated at Hola while about 2,500 ha are irrigated at Bura West. For both schemes irrigation water is pumped from Tana river and conveyed to the irrigated areas through the Bura West main canal which starts at Nanigi and the Laini canal for Bura West and Hola respectively.

Production yield levels for cotton at Bura West since 1982 have been in the order of 2,000 to 2,500 kg seed cotton per hectare (see fig. 18b). The average cotton yields at Hola from 1962 to 1984 are shown in Figure 18a. The yields range from 775 kg per hectare in 1962 to a maximum of 3,181 kg/ha in 1971. From the figure it can be noted that until 1968 the cotton yields were rather low. From then onwards there was a steady increase until 1977 when the yields declined sharply. This decline was due to a water shortage. In 1982 the yields were low again due to water shortage. A number of factors have been observed as possible causes of reduction in yields, namely water shortage, cultural practices (weeding, time of planting, spraying etc.) and possibly the soil conditions. The contribution of the soil factors in yield reduction has not received adequate attention, which the present study tries to remedy.

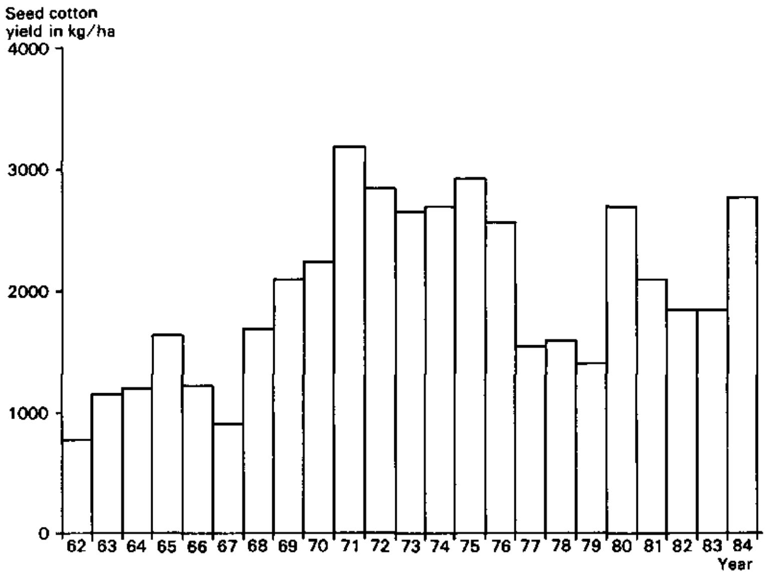


Fig. 18a Average seed cotton yields at Hola Irrigation Scheme (source: National Irrigation Board Annual reports).

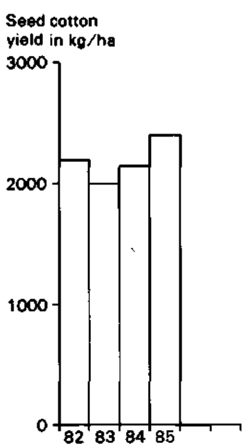


Fig. 18b Average seed cotton yields at Bura West Irrigation Scheme (Source: National Irrigation Board Annual reports)

3. SOILS.

3.1. SOIL GENESIS AND CLASSIFICATION.

3.1.1. Soil genesis aspects.

Jenny (1941) considered the five main factors of soil formation as being climate, relief (topography), parent material, organisms (vegetation, soil fauna and human beings) and time (the relative age of the soil). He considered the factors to be interdependent. However, in a given landscape, at a given moment the effectiveness of the five soil forming factors may be variable (Buol et. al. 1980, Gerard, 1981). In the semi-arid and arid regions, the major factors affecting soil formation are climate, topography and time, with vegetation (which is heavily dependent upon climate) and parent material playing secondary roles (Dregne, 1976). In order to understand the pattern of soils in the study areas, the obvious trends in soil genesis are summarised in relation to soil forming factors.

A. Influence of climate and time.
Climate, particularly temperature and precipitation, is perhaps the most influential factor of soil formation. Temperature and precipitation affects the rate of chemical and physical processes, for example weathering, which are responsible for profile development.

The present day climate in the study areas is hot and semi-arid and cannot possibly account for all the pedogenetic processes that have taken place in the soils of the area. Within the area there are soils with argillic, natric and cambic B-horizons with accumulations of calcium carbonate. With regard to the argillic B-horizon, arguments have arisen about whether or not it could develop in soils of arid regions. Early views in the Soviet Union, Australia and the United States were that clay-accumulation subsoils did not develop in dry climates (Jackson, 1957 quoted in Dregne, 1976). Later Nikiforoff (1937) claimed that clay formation did occur, in situ, in well developed zonal soils of deserts but that clay eluviated from the surface horizon was unlikely to contribute significantly to the clay content of the subsoil. More recently, Smith and Buol (1968) and Gile and Grossman (1968) have found evidence that clay illuviation in subsoils does occur in the arid regions. While this finding can probably be used to support the occurrence of argillic horizons in the study areas, the issue is complicated further by the fact that soils with argillic horizons are found on the same landscapes with soils with cambic B-horizons. A possible explanation is given below.

The sediments from which the soils are developed are calcareous. Field observations reveal that the upper horizons of soils with argillic or natric horizons are non to slightly calcareous while the horizons below are strongly calcareous with or without carbonate concretions and/or soft powdery lime. The bulk of the soils with cambic B-horizons are moderately to strongly calcareous throughout. The latter soils have concentrations of calcium carbonate in form of concretions and/or soft powdery lime in the subsoil. The presence of calcium carbonate concentrations in the subsoils can only have formed under conditions more moist than the environment under which the soils are to-day. In that case, the argillic and natric horizons are relicts of earlier humid climates rather than a consequence of the present semi-arid to arid climate. This is in agreement with Gethin Jones and Scott (1959, in the Atlas of Kenya) who stated that the soil development in the area took place in a more humid climate in the past, possibly in one or more of the pluvial phases of Pleistocene or the late Tertiary. On aerial photographs of the area the general terrain shows up as regular grey with a "white dot" pattern on the higher levels while the low stretches are homogeneously dark grey. The "white dots" represent places with flattened fossil termite mounds. This density of "white dots" would also indicate that at some period in the Pleistocene there was more biomass production (as forage for the termites) than nowadays (cf Sombroek, Mbuvi and Okwaro, 1975), and hence a more humid climate in the past.

The formation of cambic B-horizons rather than argillic B-horizons in soils in the same landscape may probably be ascribed to differences in the carbonate content of the sediments on which the soils are developed. It is reported in literature that soils developing in the high-carbonate sediments found extensively in the arid regions form argillic horizons at a much slower rate than soils developing in low-carbonate sediments (Gile and Hawley, 1972; Dregne, 1976).

Climate, through erosion, has influenced the topography in the area. It has also influenced vegetation. The interaction of climate with these other factors of soil formation is discussed in the following paragraphs.

B. Influence of topography and hydrology.
The topography of the land may be such as to hasten or delay the work of climatic factors. In smooth flat landscapes excess water is removed less rapidly than on sloping landscape. Sloping topography encourages natural erosion of surface layers.

In the Bura East area, the soil-topography pattern concerns broad relatively homogeneous and largely parallel stretches occurring in a NW to SE direction (see soil map - appendix 5). It seems that this broad topographical/hydrological NW to SE pattern has remained practically unaltered since Pleistocene times when it was formed (Sombroek et.al., 1975). Consequently the differences in relief and hydrological conditions have influenced soil formation in the area (see fig. 19.). Soils in the low-lying stretches (mapping units Ps 3.1. and Ps 3.2.) which receive seepage and run-off from the higher-lying land have poorer drainage conditions. The poor drainage conditions facilitates formation of 2:1 clay minerals which are predominant in these

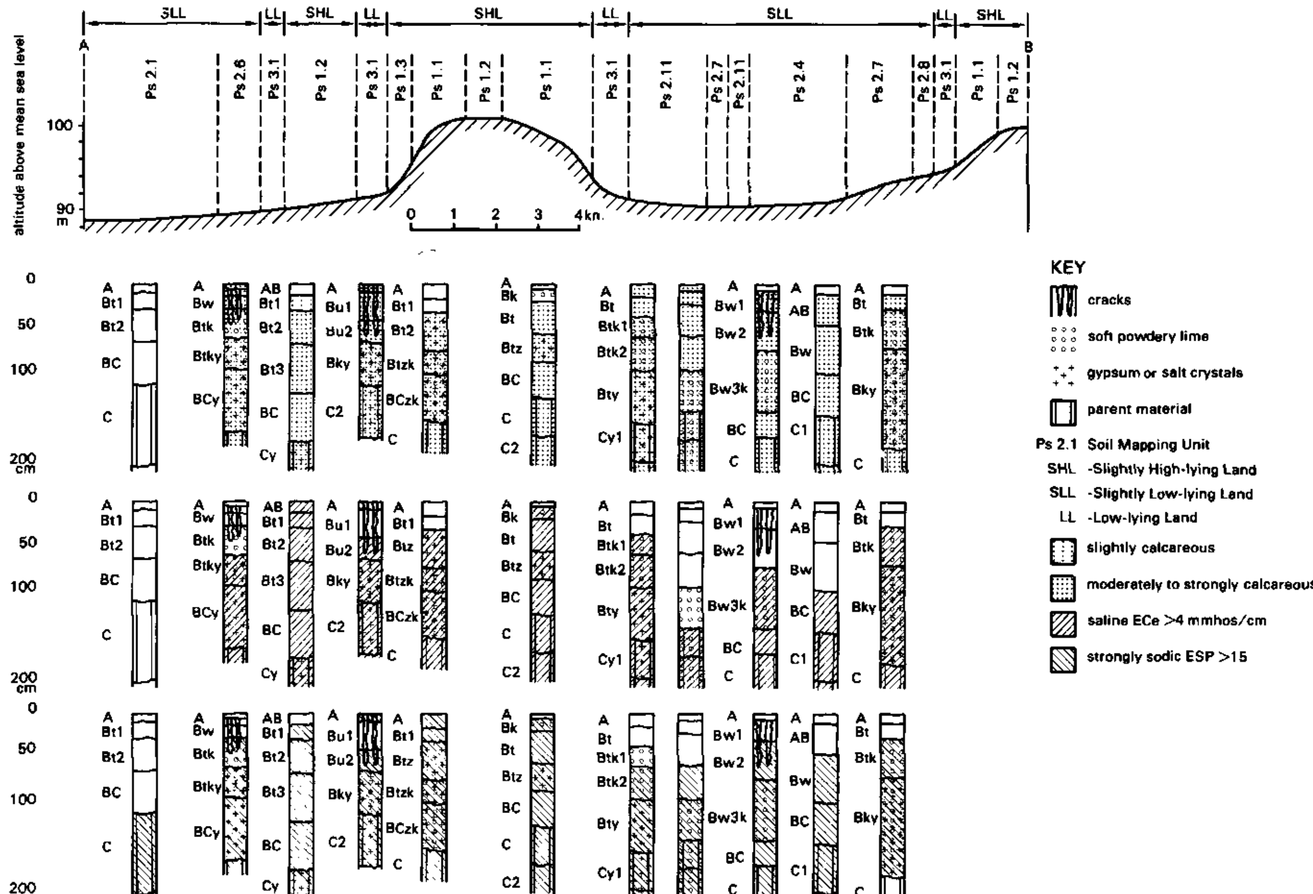


Fig. 19 Cross-section through cutline 12 (A to B) showing relationship between topography and soils (calcareous ness, salinity, sodicity etc) in the Bura East area

soils.

In the Bura West and Hola areas the hydrological conditions seem to be better than those at Bura East. The better drainage conditions are reflected in the formation of kaolinite in soils of the former areas. Clay mineralogy analytical data indicate that kaolinite and illite are the predominant clay minerals in the surface horizons of the bulk of the soils in the Bura West and Hola areas with an exception of VERTISOLS. The VERTISOLS, which occur on the low-lying areas have poorer drainage conditions and their clay mineralogy is predominantly of 2:1 type.

The soils found on the "slopes" of the slightly higher-lying land in the Bura West area, have thinner non-saline, and non-sodic upper soil layers overlying natric B-horizons, than those occurring on the "tops" (see figure 20.). Makin et.al. (1969) attributed this to soil erosion. They postulated that erosion following a main phase of solodization would have effected the truncation of an extensively occurring solod, leaving remnant ridges, i.e. high-lying land (cf. mapping unit Pf 1.1.). Along the sides of these high-lying areas, limited erosion of the sandy topsoil would have caused the natric horizon to appear not far below the surface (cf. mapping unit Pf 1.2.). Subsequent local erosion of the loose sandy layer exposed the natric horizon (cf. mapping unit Pf 1.3.). Where erosion was most severe, the sandy top and the natric sub-surface were removed to expose intensely saline-sodic subsoils which have subsequently been only slightly leached (cf. mapping unit Pf 2.2. and Pf 2.3.).

The occurrence of varying depths of the coarse-textured non-saline, surface horizons of the SOLONETZ (mapping units Pf 1.1. to Pf 1.3.) and the presence of a petrocalcic horizon at fluctuating depths in the Calcaric CAMBISOLS (cf. mapping unit Pf 2.1.) is suggestive of a soil and landscape development resulting from truncation caused by erosion.

C. Influence of vegetation.

The role of the present vegetation cover in the soil formation in the study areas is not an obvious one. Whereas plants are considered to play a significant role in soil genesis, their influence is made complex because of the interaction with the other soil forming factors. Within the study areas, the distribution, type and species composition of the vegetation is strongly influenced by climate, topography, human beings and the soils.

As mentioned under A these soils were probably formed in more humid climatic conditions than the present semi-arid climate. In view of this, it is presumed that during that period a more luxurious vegetation existed in the area which together with the other soil forming factors enhanced soil formation as we observe it today. Accumulation of organic matter, nutrient cycling and structure stability are enhanced by vegetation. The organic matter content of these soils is low (organic C ranging between

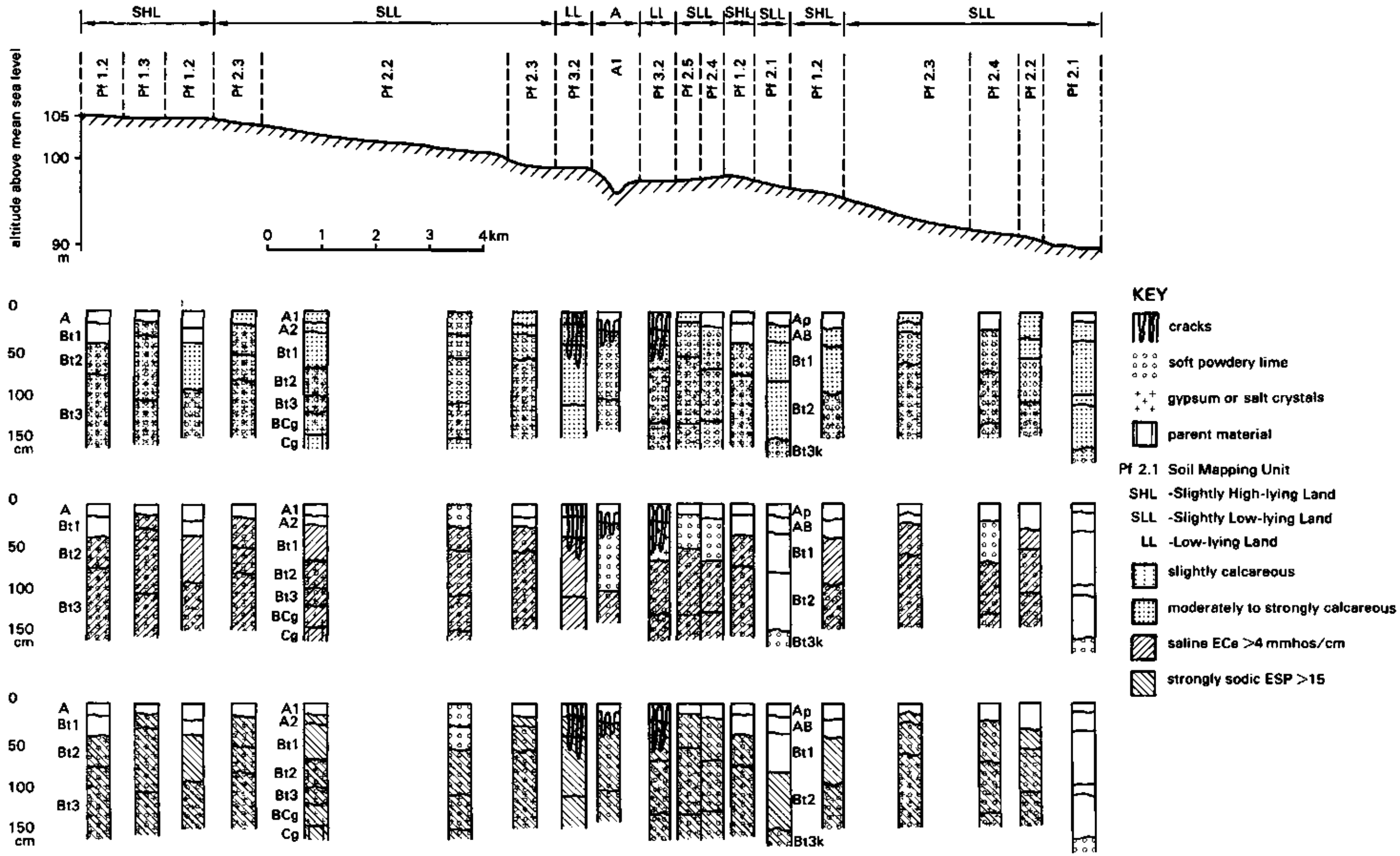


Fig. 20 Cross-section through Bura Branch Canal area (NW-SE direction through line CD) showing relationship between soils (calcareousness, salinity, sodicity etc) and topography

1.0 and 0.2%), mainly due to rapid decomposition under the prevailing high temperatures. Plant roots were observed in both the surface and subsurface horizons of most of the soils and these played a role in structure formation. Vegetation also plays a key role in protecting the soil against erosion. In the Bura West and Bura East areas the presence of thicker surface horizons in soils of the high-lying land can be attributed to the protection of this layer against erosion by the existing dense vegetation cover. Where there is no vegetation or very little vegetation cover, the A-horizon is very thin or absent altogether.

D. Influence of parent material.
The nature of the parent materials profoundly influences the characteristics of soils developed on them. The chemical and mineralogical compositions of parent materials often not only determine the effectiveness of weathering forces but in some instances partially control the natural vegetation (Brady, 1984, p. 419). The presence of lime, high sodicity and high salinity in these soils is a reflection of the calcareous, saline and sodic nature of the sediments on which they have developed. The soils are developed on Plio-Pleistocene bay sediments or sediments derived from the Plio-Pleistocene bay deposits (Sombroek et.al., 1982) which are strongly saline and sodic and hence give rise to the Na-Mg rich soils.

E. Influence of man.
The influence of human activity on soil formation in the study areas is limited. Overgrazing and burning may have contributed to destruction of organic matter in the soils of the three areas. Overgrazing has also probably induced accelerated erosion particularly in the soils of the high-lying areas of Bura West and Bura East. In the Hola area, where the soils have been under irrigation for about 31 years, changes in some soil properties such as salinity, sodicity and organic matter content have taken place. The organic carbon content has changed from about 0.2% to 0.7% in topsoils of non-irrigated soils to about 1.2% to 1.5% in topsoils of irrigated soils. For changes that have taken place in salinity and sodicity the reader is referred to chapter 4.

3.1.2. Micromorphological observations.

The arrangement of soil constituents was studied in thin sections (size 5x5 cm) made from undisturbed samples. The samples were collected from sites selected on the basis of macromorphological features observed in the field. The study concentrated on detecting phenomena such as clay illuviation, surface crusting etc.

For the descriptions of the micromorphology the terminology outlined in the "Handbook of Soil Thin Section Description" (Bullock et.al., 1985) and Brewer (1964) is used. The respective micromorphological descriptions are presented in table 11. The genesis of the features observed is discussed in the following

Table II: Micromorphological descriptions

Sample Lab.no.	Profile/ Site/ Map unit	Soil classification (FAO, 1987)	Horizon Field Designation	Depth in cm	Related distribution of coarse and fine constituents	Plasmic fabric	Pedofeatures	Remarks 1)
A. Cracking clay soil								
114	GU2-1	Chromi-haplic VERTISOLS	A	5- 10	porous porphyric	granostriated b-fabric	Few rounded carbonate nodules	Many vughs and interconnected vughs, few planar voids, granular and crumb micro-structure.
128	Bura West	salic-sodic phase	Bu1	30- 40	dense porphyric	porostriated and granostriated b-fabric	Common rounded carbonate nodules	Common planar voids, few vughs, weak to moderate angular blocky microsturcture with some vughy microstructure.
	Unit Pf 3.2							
115			Bu2	85- 90	dense porphyric	granostriated b-fabric with some undifferentiated b-fabric	Few rounded carbonate nodules. Calcium carbonate infillings in voids	Planar voids, few vughs, weak to moderate angular blocky microstructure
B. Natric horizons of calcareous soils								
123	Pit 9 Hola Unit Pt5	Calcari-haplic SOLONETZ salic phase	Bt3k	110-115	dense porphyric	crystallitic b-fabric with some porostriated b-fabric	Common carbonate nodules, sometimes coated with oxides of iron and manganese, few fragmented clay coatings, groundmass poorly sorted but locally concentrated.	Common planar voids, some vughs and interconnected vughs, moderately developed angular and subangular blocky peds.
126	Pit 12 Hola Unit Pt1	Calcari-haplic SOLONETZ salic phase	Bt1	30- 35	porous porphyric	porostriated and granostriated b-fabric	Some deformed, microlaminated fragmented clay coatings-quite common. Some sign of gleying. No calcium carbonate	Common vughs, few planar voids and channels. Vughy microstructure with some weakly to moderately developed subangular blocky peds.
124	Pit 14 Hola Unit Pt4	Calcari-haplic SOLONETZ salic phase	Bt1k	55- 60	dense porphyric	undifferentiated b-fabric with some porostriated and granostriated b-fabric	Isolated carbonate nodules masked by iron and manganese coating. Some infillings of skeleton grains in voids.	Common planar voids, few vughs and channels, moderately developed angular blocky peds with some vughy microstructure.
132	Pit 15 Hola Unit Pt4	Calcari-haplic SOLONETZ salic phase	Bt1k	40- 60	dense porphyric	porostriated b-fabric Crystallitic b-fabric in places masked by iron coating. In places granostriated b-fabric	Common carbonate nodules. Sometimes coated with oxides of iron and manganese. Calcium carbonate infillings in voids. Groundmass poorly sorted but locally concentrated forming unsorted coatings.	Common planar voids, few vughs and interconnected vughs. Moderately developed angular and subangular blocky peds; few granular elements.
116	M2-1 Bura West Unit Pf1.2	Calcari-haplic SOLONETZ salic phase	Bt1	35- 40	dense porphyric	porostriated and granostriated b-fabric with some stipplespeckled b-fabric	Common carbonate nodules, calcium carbonate infillings in voids. Some clay coatings in voids, some fragmented clay coatings and embedded grain cutans.	Common planar voids, some vughs, few channels and chambers. Moderately developed angular and subangular blocky peds.

Table 11 continued

Sample Lab.no.	Profile/ Site/ Map unit	Soil classification (FAO, 1987)	Horizon Field Designation	Depth in cm	Related distribution of coarse and fine constituents	Plasmic fabric	Pedofeatures	Remarks 1)
C. Cambic horizons								
108	S1-1 Bura West Unit Pf2.2	Chromi-calcaric CAMBISOLS salic-sodic phase	Bw1	35- 40	dense porphyric	undifferentiated b-fabric with some poro-striated and grano-striated b-fabric	Few carbonate nodules stained with oxides of iron and manganese, calcium carbonate infillings in voids.	Common planar voids, some vughs and few channels, weakly developed subangular and angular blocky peds with some vughy microstructure
113	C1 Bura West Unit Pf2.1	Chromi-calcaric CAMBISOLS	Bw2k	90- 95	porous porphyric	undifferentiated b-fabric with some weakly expressed granostriated b-fabric	Some carbonate nodules and infillings of calcium carbonate in voids. Some of the carbonate nodules are coated with oxides of iron; very few fragments of plant remains.	Many vughs, few planar voids and channels. Vughy microstructure with some weakly developed subangular and granular peds.
D. Surface crusts								
109 110 111	S1-3 Bura West Unit Pf2.2	Chromi-calcaric CAMBISOLS salic-sodic phase	Ap	0- 5	dense porphyric	undifferentiated b-fabric with some grano-striated b-fabric	Some carbonate nodules coated with oxides of iron and manganese. Sharp boundaries between the nodules and the plasma. Some infillings of calcium carbonate in voids. Densely packed plasmic fabric in places subangular or rounded, isotic and without interaggregate pores. Skeleton grains strongly embedded in the groundmass. Some single faecal pellets.	Some planar voids in densely packed areas; subangular and granular elements which are strongly isotic.
107	S1-1 Bura West Unit Pf2.2	Chromi-calcaric CAMBISOLS salic-sodic phase	Ap	0- 5	porous porphyric	undifferentiated b-fabric	Dense, fragmented subangular aggregates without inter-aggregate pores, stained with oxides of iron and manganese and organic matter. Some feacal pellets in channels and chambers. Very few fragments of shell and plant material.	Planar voids in densely packed areas; plasma is isotic in these areas. Some crumb and granular peds.

1) The composition of skeleton grains in all the samples is dominated by quartz, with commonly occurring weakly weathered feldspars (alkali and plagioclase) and a few grains of hornblende.

paragraphs, where the samples have been divided according to the phenomenon being investigated as follows:
A). samples from a cracking clay soil (VERTISOL);
B). samples from natric horizons of calcareous soils (SOLONETZ);
C). samples from cambic horizons (CAMBISOLS) and
D). samples from surface crusts.

A. Cracking clay soil (VERTISOL).
The three thin sections studied were from the A-horizon (5-10 cm), Bu1-horizon (30-40 cm) and Bu2-horizon (85-90 cm) of profile GU 2-1, located at Bura West study area. The soil material is fine textured, the fine material being predominantly clay sized. The related c/f distribution pattern is dense porphyric with granostriated and porostriated b-fabric. The soil material has a granular and crumb microstructure in the A-horizon and a weak to moderate angular blocky microstructure in the B-horizon. The interaggregate pores consist of common irregular vughs and interconnected vughs in the A-horizon and common smooth planar voids and few irregular vughs in the B-horizon. Carbonate nodules are present in all thin sections. They usually have clear external boundaries and are randomly distributed.

Interpretation.
Upon dessication the soil mass in these cracking clay soils breaks apart into peds along surfaces of weakness. Planar voids develop between these peds. The ped surfaces are polished and grooved and meet the concept of slickensides as given in the United States Department of Agriculture Soil Taxonomy (Soil Survey Staff, 1975). Ped surfaces develop into slickensides when, during moist conditions, the peds slide along each other as a result of soil stress caused by swelling of the soil material. The common occurrence of planar voids seems to be related to a great extent to the swell and shrink properties of the soil. Occurrence of porostriated b-fabric may be induced by the shearing of the soil material as has been observed in many other cracking clay soils (Brewer, 1964; Siderius, 1973; Blokhuis et.al., 1970; Sehgal and Stoops, 1972; Nettleton and Sleeman, 1985; Kooistra, 1982). The granostriated b-fabric has been formed as a result of stress leading to reorientation of clay domains around resistant bodies such as skeleton grains.

Carbonates are accumulating or have accumulated in both the A- and B-horizons. Due to the vertic properties of the soil the larger carbonate nodules are rounded off. Blokhuis et. al. (1968/1969) attributed the presence of such carbonate nodules in the A-horizon of VERTISOLS in Sudan as having been churned upwards from below the present churning zone, where they have been formed in situ. This is a possible explanation of the presence of carbonate nodules in the A-horizon in this profile.

B. Natric horizons of calcareous soils (SOLONETZ).
The micromorphology of some natric horizons of calcareous soils in the Bura West and Hola study areas was investigated by means of thin sections from profiles 9, 12, 14, 15 and N2-1. The

samples were taken from the Bt3k (110-115 cm), Bt1 (35-40 cm), Bt1k (55-60 cm), Bt1k (40-60 cm) and Bt1 (35-40 cm) horizons respectively.

The thin sections in general show a moderately developed angular and subangular blocky microstructure. The interaggregate pores consist of common planar voids and a few vughs and interconnected vughs except for the Bt1-horizon of profile 12 which has common vughs and a few planar voids. The latter horizon has a vughy microstructure with weak to moderately developed subangular blocky peds. The related c/f distribution pattern is predominantly dense porphyric with variable plasmic fabric - porostriated, granostriated, crystallitic and undifferentiated b-fabrics. The undifferentiated b-fabric observed here corresponds to the undulic type of Brewer (1964), since the plasma is not completely isotropic at higher magnifications.

Fragmented clay coatings are found in profiles 9, 12 and N2-1. The groundmass of the sample from profile 15 is poorly sorted and is locally concentrated forming coatings and deformed coatings of clay and organic matter. Similar features are also observed in the thin section derived from profile 9 (see fig. 21). Carbonate nodules are common in all profiles with an exception of the Bt1-horizon of profile 12 where no carbonate nodules were observed. The majority of the carbonate nodules have accumulations of sesquioxides of iron and manganese. The sesquioxides are predominantly those of manganese and are usually mainly present in the outer zones of the nodules (see fig. 22 and 23). The nodules usually have clear external boundaries.

Interpretation.
A natric B-horizon is one that contains illuvial layer-lattice clays and has a columnar or prismatic structure in some part of the B-horizon or a blocky structure with tongues of an eluvial horizon in which there are uncoated silt or sand grains extending more than 2.5 cm into the horizon and has a saturation with exchangeable sodium of more than 15 percent within the upper 40 cm of the horizon (Soil Survey Staff, 1975; FAO, 1974 and 1987).

Little has been reported in literature on the micromorphology of natric horizons of soils of arid regions (Allen, 1985). The presence of macrostructure can be easily recognized and described in the field. However, in the field it is sometimes difficult to differentiate between clay cutans, pressure faces and/or slickensides, particularly in soils that have swelling clay minerals. These can however, be differentiated in thin sections. Illuvial clay occurs as plasma concentrations on the faces of peds, skeleton grains or in the walls of voids (Brewer, 1964). Pressure faces and slickensides are manifest in granostriated and porostriated b-fabric respectively.

From the thin sections studied, evidence of clay translocation is observed in the samples from Bt3k-horizon (profile 9), Bt1-horizon (profile 12) and Bt1-horizon (profile N2-1) in the form

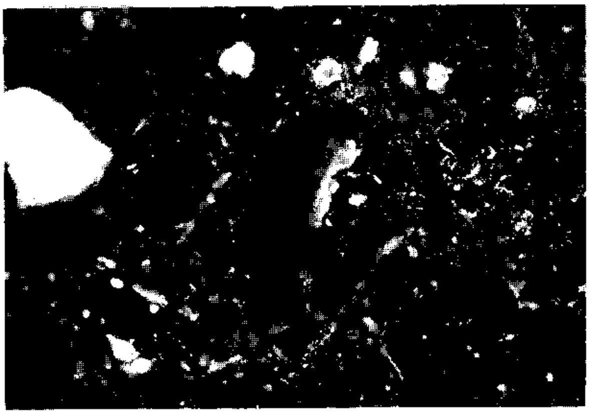


Fig. 21. Deformed coatings of clay in Bt1 horizon (35-40 cm) of a Calcari-haplic SOLONETZ. Crossed polarizers. (Frame width = 1.5 mm).

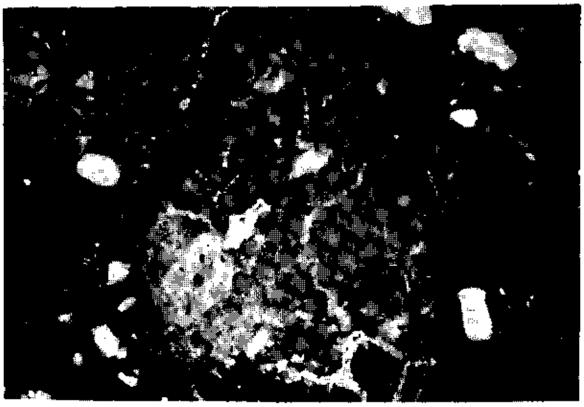


Fig. 22. A calcitic nodule with manganese segregation in a Chromi-haplic VERTISOL. Crossed polarizers. (Frame width = 1.5 mm).

Fig. 23. A calcitic nodule with infilling of sesquioxides of manganese in a Chromi-calcaric CAMBISOL. Crossed polarizers. (Frame width = 1.5 mm).

of fragmented clay coatings (see fig. 24). The thin sections derived from profile 14 and 15 do not show clear evidence of illuvial clay. However, in the Bt1k (profile 15) there is a tendency of the plasma to be locally concentrated forming coatings and deformed coatings of clay and organic matter.

A probable explanation for the occurrence of the deformed coatings of clay and organic matter may be associated with the clay mineralogy of the above soils and the presence of high amounts of sodium on the exchange complex. The soils have high clay content (48% to 56%) and the mineralogy is predominantly 2:1 type (illite-montmorillonite intergrade). They are also strongly saline and strongly sodic. Upon wetting, the clay is peptized due to the high amount of sodium on the exchange complex. This dispersed clay can subsequently flow into the subsoil through voids where it may accumulate and produce poorly sorted coatings which are hardly recognisable as clay coatings. Repeated wetting and drying may lead to deformation of these poorly sorted coatings and subsequently lead to formation of features observed in the thin section of profile 15. It may also be postulated that the presence of these poorly sorted coatings may help in creating textural differences between the surface horizons from which the dispersed clay originates and the lower horizons where it has accumulated. The resulting textural difference may lead to interpretation as clay increase due to illuviation.

The presence of crystallitic b-fabric in the sample taken from the deeper Bt3k horizon of profile 9 together with carbonate nodules (see fig. 25) indicates secondary accumulation of calcium carbonate probably due to decalcification of the overlying horizons. Occurrence of carbonate nodules and infillings of calcium carbonate in voids confirms the strong calcareous nature of the soils represented by profile 9, 14 and 15. This also justifies addition of the symbol "k" in the horizon designation to denote the secondary accumulation of carbonates. Absence of calcium carbonate in the Bt1 horizon of profile 12 also confirms the observations made in the field - no reaction with diluted hydrochloric acid. Hence the horizon designation Bt1 without k. The horizons below this one are calcareous suggesting that this horizon has probably been decalcified.

The occurrence of carbonate nodules with accumulations of sesquioxides of iron and manganese has been reported in soils of semi-arid regions by many authors (Kooistra, 1982; Sehgal and Stoops, 1972; Blokhuis et. al. 1968/1969; Gile et. al., 1966; Nettleton et. al., 1969; Brewer, 1964 among others). The formation of iron and manganese accumulations in soils is influenced by temporary and periodic changes in redox potential and pH. The presence of iron and manganese coatings on the carbonate nodules and the presence of manganese segregations inside the nodules in these soils indicates that the soils have in the past been subjected to alternating reducing and oxidizing conditions favourable for precipitation of iron and manganese. The presence of granostriated and porostriated partial b-fabric coupled with the

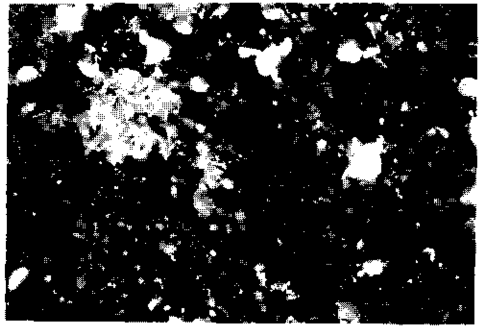


Fig. 24. Fragmented clay coatings (papules) formed as a result of slaking in a Bt3k horizon (110-115 cm) of a Calcari-haplic SOLONETZ. Crossed polarizers. (Frame width = 1.6 mm).

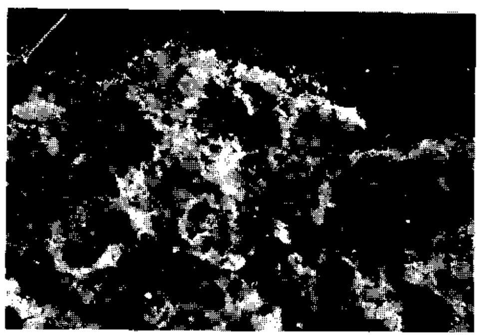


Fig. 25. A calcitic nodule in Bt3k horizon (110-115 cm) of a Calcari-haplic SOLONETZ. Crossed polarizers. (Frame width = 1.6 mm).

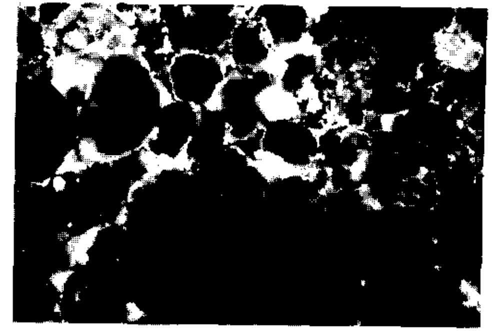


Fig. 26. Dense aggregates and framented dense aggregates in an Ap-horizon (0-5 cm) of a Chromi-calcaric CAMBISOL. Crossed polarizers. (Frame width = 1.6 mm).

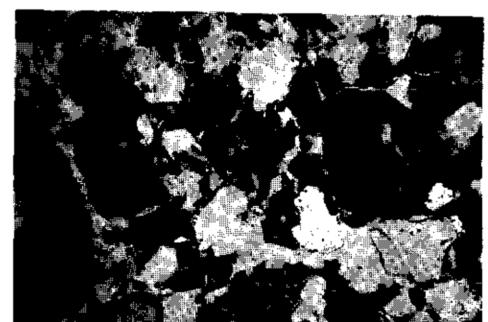


Fig. 27. Remnants of a slaking crust in an Ap-horizon (0-5 cm) of a Chromi-calcaric CAMBISOL. Plane polarised light. (Frame width = 1.6 mm).

presence of moderately developed angular blocky microstructure reflect the vertic characteristics of these soils.

C. Cambic horizons (CAMBISOLS).
For the micromorphological analysis of cambic horizons in Cambisols encountered in the study area two samples were studied, one from the Bw2K horizon (90-95 cm) of profile C-1 and the other from the Bw1 horizon (35-40 cm) of profile S1-1. Both profiles are located at the Bura West area. The thin section of Bw2k shows a vughy microstructure with weakly developed subangular and granular microstructure while that of the Bw1 shows weakly developed subangular and angular peds with some vughy microstructure. Both thin sections have undifferentiated b-fabric with some porostriated and granostriated partial b-fabrics. The groundmass of the Bw2k thin section shows a dense porphyric c/f related distribution pattern. Both thin sections show presence of carbonate nodules, some of which have accumulations of sesquioxides of iron and manganese and also show common infillings of calcium carbonate in voids.

Interpretation.
Occurrence of porostriated and granostriated partial b-fabrics indicates some degree of stress in these soils although this is less pronounced than in the thin sections from the cracking clay soil and from the natric horizon. The dense porphyric c/f related distribution pattern of the plasma in the Bw1 (profile S1-1) confirms the relatively low porosity of these soils due to slaking resulting from dispersion of clay due to presence of salts and high amounts of sodium on the exchange complex.

The presence of carbonate nodules and infillings of calcium carbonate in voids confirms the calcareous nature of these soils as observed in the field through a strong reaction with diluted hydrochloric acid. The use of symbol "k" can also be added to the designation of Bw1 horizon of profile S1-1 to denote the accumulation of calcium carbonate. The presence of accumulations of sesquioxides of iron and manganese on the carbonate nodules is indicative of existence of alternating oxidizing and reducing conditions causing accumulation of iron and manganese compounds. No clay cutans were observed in these thin sections which is in conformity with the field observations.

D. Surface crusts.
The micromorphology of surface crusting phenomena was investigated in four samples collected from plough layers (Ap-horizon) at Bura West at the depth of 0-5 cm. The thin sections show densely packed areas with subangular and granular elements and locally showing crumbs. The interaggregate pores consist of planar voids in densely packed areas. The dense fragmented subangular to granular aggregates have no intra-aggregate pores. They are stained with oxides of iron and manganese and organic matter. The plasma consists mainly of undifferentiated b-fabric. The groundmass has mainly a dense porphyric c/f related distribution pattern. Some carbonate nodules with sharp boundaries are pres-

ent. These nodules are coated with sesquioxides of iron and manganese. Some infillings of calcium carbonate in the voids are observed. Skeleton grains are strongly embedded in the groundmass which is isotic (opaque).

Interpretation.
The presence of the densely packed aggregates which, even when fragmented remain relatively non-porous (see fig. 23 and 24) is an indication of crust formation in these soils. The sharp boundary between the carbonate nodules and the plasma is indicative of the movement of soil material which probably takes place due to peptization of the clay caused by presence of high amount of sodium on the exchange complex. From the above observations one can conclude that these soils can be easily compacted.

Presence of accumulations of iron and manganese oxides on the carbonate nodules, as in the previous cases, reflects past occurrence of alternating reducing and oxidizing conditions in the soil leading to precipitation of iron and manganese. Presence of carbonate nodules and the infillings of calcium carbonate in the voids confirms the calcareous nature of these soils as observed in the field. The presence of channels, granular peds and faecal pellets in some parts of these thin sections shows the influence of biological activity in these soils.

3.1.3. Soil classification.

For purposes of soil correlation and accommodation of the soils encountered in the study areas into an internationally recognized framework of classification, the FAO-UNESCO Legend for the Soil Map of the World Project (FAO-UNESCO, 1974), the FAO-Revised Legend (FAO, Fourth Draft, 1987) and the U.S. Department of Agriculture Soil Taxonomy (Soil Survey Staff, 1975) were applied.

Within the study areas the following major classification units are recognized: FLUVISOLS, VERTISOLS, CAMBISOLS, CALCISOLS, SOLONETZ and LUVISOLS according to the FAO-Revised Legend and FLUVENTS, VERTISOLS, ORTHIDS and ARGIDS according to the Soil Taxonomy.

For the purpose of presentation and ease of reference the terminology of the FAO-Revised Legend (FAO, 1987) will be used. A brief summary of the required characteristics for the particular soil classification units that occur in the study areas is given below:

A. FLUVISOLS.
These are soils developed from alluvial deposits and having no diagnostic horizons other than an ochric, a mollic or an umbric A-horizon, a histic H-horizon or a sulfuric horizon or having sulfidic materials within 125 cm of the surface. The alluvial materials are fluviatile, marine and lacustrine sediments and are characterised by one or more of the following properties: an organic matter content that decreases irregularly with depth or

that remains above 0.35 percent to a depth of 125 cm; receiving fresh materials at regular intervals and/or showing fine stratification. The FAO-Revised Legend provides seven subgroups. In the study area alluvial soils occur only in the Bura West Area along Laga Hiraman. They are classified as Calcaric FLUVISOLS (Map unit A1). They are calcareous from a depth of 20 cm to 30 cm from the surface onwards. Some of these soils show vertic properties and to indicate this a third level modifier - verti is used. Hence the classification of the soils as Verti-calcaric FLUVISOLS. These soils are moderately to strongly sodic from a depth of 20 cm onwards and hence are mapped as sodic phase. According to the FAO-UNESCO (1974) Legend these soils were classified as Calcaric FLUVISOLS. According to the Soil Taxonomy (Soil Survey Staff, 1975) they were classified as Vertic TORRIFLUVENTS.

B. VERTISOLS.
These are soils mainly dark in colour, fine in texture and alkaline or near alkaline in reaction; they expand and contract appreciably with changes in moisture and commonly lack distinct horizons in their profiles. They have 30% or more clay in all horizons to a depth of at least 50 cm and have cracks at least 1 cm wide from the surface to a depth of 50 cm or more. The clay minerals are dominantly of the montmorillonite type. Alternating swelling and shrinking of these soils due to wetting and drying produces polished and grooved surfaces called "slickensides". These are characteristic features in these soils.

The FAO-Revised Legend discerns five subgroups. Two of these are found in the study area, viz Haplic and Calcic VERTISOLS. Third level modifiers have been introduced as follows: Those Calcic or Haplic VERTISOLS which have moist value of more than 3 and chromas of more than 2 in the soil matrix throughout the upper 30 cm have been classified as Chromi-calcic VERTISOLS (cf map units Pf 3.1., Pf 3.2., Pt 8., Pt 9 and Ps 3.1.) and Chromi-haplic VERTISOLS (cf map units Pf 3.2., Pt 7., and Pt 8.). These soils are saline and sodic and have consequently been mapped as salic and sodic phases.

According to the FAO-UNESCO (1974) Legend these soils were classified as Chromic VERTISOLS. These soils have been classified as Typic TORRERTS according to the Soil Taxonomy (Soil Survey Staff, 1975).

C. CAMBISOLS.
These soils do not have a clear migration of clay particles or weathering products in the profile, but have an A Bw C - sequence of horizons, the Bw-horizon being "cambic". A cambic horizon is defined as an altered horizon which shows already soil structure and shows some evidence of alteration reflected in stronger chromas or redder hues or higher clay content than the underlying horizon; grey reduction colours or artificial drainage; less carbonate than the underlying horizon of calcium carbonate accumulation and has enough thickness that its base is at least 25 cm below the soil surface. It lacks the properties that meet

the requirement of an argillic, natric or spodic B-horizon. CAMBISOLS may have an ochric or an umbric A-horizon. However, they should not have salic properties, characteristics diagnostic for VERTISOLS and lack hydromorphic properties within 50 cm of the surface.

In the Revised FAO-Legend ten subgroups are separated. In the study areas three subgroups are found, namely Calcaric, Gleyic and Vertic CAMBISOLS. At the third level modifiers are used to depict other prominent characteristics of the soils that have not been diagnostic for the subgroup level. Those Vertic and Gleyic CAMBISOLS which are calcareous[1] below 50 cm but within 125 cm of the surface classify as Calcari-vertic CAMBISOLS (cf map units Pt 3., Ps 2.3., Ps 2.4. and Ps. 2.15.) and Calcari-gleyic CAMBISOLS (cf map unit Pt1). The Calcaric CAMBISOLS which have a strong brown to red B-horizon (rubbed soil has a hue of 7.5 YR and chroma of more than 4 or a hue redder than 7.5 YR) are classified as Chromi-calcaric CAMBISOLS (cf map units Pt 1., Pt 2., Pf 2.1. Pf 2.2. Pf 2.3. and Ps 2.4.). Some of the soils are saline or sodic or both within 100 cm from the surface and are therefore mapped as salic phase, sodic phase or salic-sodic phase respectively.

According to the FAO-UNESCO (1974) Legend these soils were classified as Haplic XEROSOLS. They were classified as Natric or Typic CAMBORTHIDS according to the Soil Taxonomy (Soil Survey Staff, 1975).

D. CALCISOLS.

These are soils having a calcic or gypsic horizon or both or concentrations of soft powdery lime or redistribution of gypsum within 125 cm of the surface. The calcic-horizon consists of secondary carbonate enrichment over a thickness of 15 cm or more and has a calcium carbonate equivalent content of 15 percent or more and at least 5 percent greater than that of a deeper horizon. The gypsic-horizon is a horizon of secondary calcium sulphate enrichment that is more than 15 cm thick and has at least 5 percent more gypsum than the underlying C-horizon. It should be noted that in the study areas, the soils may be calcareous, contain calcium carbonate concretions and accumulations of soft powdery lime but have in general a calcium carbonate equivalent content of less than 15 percent. Therefore the

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[1]It should be noted that in the Revised Legend (FAO, 1987; Ammended Fourth Draft) gleyic and vertic subgroups of CAMBISOLS key out before Calcaric CAMBISOLS. Hence the definition of the third level modifier calcari may as well include soils which are calcareous at least between 20 cm and 50 cm from the surface. Otherwise the position of calcaric subgroup in the key should be changed to appear before gleyic and vertic subgroup.

identification of CALCISOLS in the area is mainly on the basis of occurrence of concentrations of soft powdery lime. CALCISOLS may not have other diagnostic horizons apart from an ochric A-horizon or a cambic or argillic B-horizon occurring within the calcic or gypsic horizon. They lack the characteristics that are diagnostic for VERTISOLS and PLANOSOLS, lack high salinity and lack hydromorphic properties within 100 cm of the surface.

In the FAO-Revised Legend three subgroups are separated. In the study areas only one subgroup is found, namely Haplic CALCISOLS. At the third level two modifiers have been used to depict other characteristics of the soils. Those Haplic CALCISOLS that show vertic properties within 50 cm of the surface have been classified as Verti-haplic CALCISOLS (cf map units Ps 2.5., Ps 2.6., Ps 2.8. and Ps 2.15.). Those Haplic CALCISOLS which show an increase in clay within 125 cm of the surface classify as Luvi-haplic CALCISOLS (cf map units Ps 2.5., Ps 2.6. and Ps 2.15.). Some of these soils are saline and sodic and are therefore mapped as salic and sodic phases respectively.

According to the FAO (1974) Legend, these soils were classified as Haplic XEROSOLS. The soils were classified as Typic and Natric CAMBORTHIDS, according to the Soil Taxonomy (Soil Survey Staff, 1975).

E. SOLONETZ.

These are mineral soils having a natric B-horizon without an albic E horizon which shows hydromorphic properties in at least a part of the horizon and an abrupt textural change. The natric B-horizon has the same characteristics as an argillic B-horizon (see under LUVISOLS) except that it has high exchangeable sodium percentage (greater than 15%) and columnar or prismatic structures.

The FAO-Revised legend provides five subgroups. In the study areas three of them have been found, viz. Mollic, Gleyic and Haplic SOLONETZ. A third level modifier "calcari" has been introduced for those Haplic, Mollic or Gleyic SOLONETZ which are calcareous within 125 cm of the surface. Thus in the study areas we have Calcari-haplic SOLONETZ (cf. map units Pt 1., Pt2., Pt 3., Pt 4., Pt 5., Pt 6., Ps 2.9., Ps 2.10., Ps 2.12., Ps 2.13., Pf 1.1., Pf 1.2., Pf 1.3., Pf 2.4. and Pf 2.5); Calcari-gleyic SOLONETZ (cf map units Ps 1.1., Ps 1.2., Ps 1.3., Ps 2.10., Ps 2.13., Ps 2.14 and Ps 2.17.) and Calcari-mollic SOLONETZ (only occurring in the irrigated parts of map unit Pt 6.). These soils are saline and have consequently been mapped as salic phase.

According to the FAO (1974) Legend these soils were classified as Gleyic and Orthic SOLONETZ. They were also classified as either Typic, Aquic or Ustollic NATRARGIDS according to the Soil Taxonomy (Soil Survey Staff, 1975).

F. LUVISOLS.

These are soils with an A Bt C - sequence of horizons, the Bt-horizon being "argillic". The argillic horizon is characterised by illuviation of silicate clay minerals. In case of LUVISOLS this horizon must have a cation exchange capacity by (NH_4OA_c) of 16 me or more per 100 g of clay and a base saturation of 50 percent or more throughout the Bt-horizon.

The Revised FAO Legend discerns seven subgroups of LUVISOLS. In the study areas two subgroups are found, namely Gleyic and Chromic LUVISOLS. At the third level those soils that are calcareous between 50 cm and 125 cm of the surface are classified as Calcari-gleyic LUVISOLS (cf map units Ps 2.2., Ps 2.7. and Ps 2.11.) and Calcari-chromic LUVISOLS (cf map unit Ps 2.17.). Those soils that are saline and sodic have been mapped as salic and sodic phases.

According to the FAO (1974) Legend these soils were classified as Luvic XEROSOLS. They were classified as Typic HAPLARGIDS and Typic PALEARGIDS according to the Soil Taxonomy (Soil Survey Staff, 1975).

3.2. GENERAL SOIL DESCRIPTIONS.

3.2.1. Structure of the map legends.

One of the important products of a soil survey is the soil map. The users of soil survey information such as land use planners, agronomists, ecologists, agricultural extension workers etc, would therefore expect to get from it a quick insight of the spatial distribution of the main soils, a description of their main features that can be recognized in the field and an indication of their limitations. Bearing this in mind and also taking into account the fact that a soil map should be comprehensive in the sense that it is a basic scientific document that should still be useable many years after its preparation, the Kenya Soil Survey adapted a "physiognomic-lithomorphic" approach to soil mapping and presentation of soil map legends (Van de Weg and Mbuvi, 1975; Muchena and Van de Weg, 1982; Sombroek and Van de Weg 1980 and 1983; and others).

In the legend construction, landforms are taken as the first entry. These are supposed to give the user a preliminary insight into differences of physiography and altitude. The importance of landforms in soil mapping has been stressed by various authors (Soil Survey Staff, 1951; Vink, 1963 and 1975; Young 1976; Sombroek and Van de Weg, 1980 and 1983; Sombroek et.al. 1982 and others). The first symbol in the soil map legend represents this element.

The second entry and subsequent symbol in the legend is the geology (surface lithology) or parent material; the third entry is a description of the main soil unit, soil association or soil complex of the individual mapping unit. This descriptive terminology is applied to allow the interested non-soil specialist to gain an insight in the features of the soils concerned without being put off by the complicated terminology of soil taxonomists. The description refers mainly to the characteristics of the subsoil, usually the B-horizon to 100 cm depth or less if the bedrock occurs at a shallower depth. The following characteristics are described in the map legend in the sequence as indicated:

- drainage condition
- depth (usually effective soil depth)
- colour (moist condition)
- mottling if present
- consistence (moist condition and only for deep soils)
- calcareousness if present
- salinity, sodicity if present
- stoniness if present
- rockiness if present
- cracking if present
- texture

other characteristics are added as necessary.

The mapping unit description is followed by the taxonomic classification of the soils concerned. This is meant to facilitate the soil specialist to correlate the soil unit with soils in different areas and will also ensure the extrapolation of agronomic research data.

The above approach has been adapted in the construction of the legend of the soil maps of the three areas used in this study. However, a major deviation from the normal Kenya Soil Survey map legends is that in the third entry (soil descriptive entry) the subsoil and the topsoil has been described separately. Calcareousness, salinity and sodicity have also been described separately. This was done because of the importance attached to these characteristics in evaluating the suitability of the soils for irrigation.

The first symbols used in the map legends stand for the landform. Since all the three areas are situated on plains (usually symbol P), it was found necessary to use an additional letter case to subdivide the plains according to the nature of their origin. Hence the use of the symbols: Ps - sedimentary plain formed mainly by sheetwash; Pf - sedimentary plain of large alluvial fans and Pt - sedimentary plain of upper river terrace. Symbol A, in case of Bura West, is used to denote floodplain. Within the physiographic unit plains, the soils have been grouped according to their relative position in the landscape: Arabic numerals are used to separate different soils occurring within the same landscape unit.

The second entry symbol which is usually used by the Kenya Soil Survey to indicate the type of parent material, has been omitted since the parent materials within the study areas considered are of almost the same origin.

At the end of each mapping unit a taxonomic classification of the soils concerned is given according to the terminology of the FAO-UNESCO (1974) Legend for the Soil Map of the World, the Revised Legend (FAO, 1987) and the U.S. Department of Agriculture Soil Taxonomy (Soil Survey Staff, 1975).

3.2.2. Soils of the Bura East Area.

3.2.2.1. Introduction.

The area falls under one physiographic Unit - Sedimentary Plain (symbol Ps). Within this unit, the soils have been grouped according to their relative position in the landscape as follows:

- Soils of the slightly high-lying land (units Ps 1.1. to Ps 1.3.);
- Soils of the slightly low-lying land (units Ps 2.1. to Ps 2.17.);
- Soils of the low-lying land (units Ps 3.1. and Ps 3.2.).

All the soils are developed on Tertiary/Quaternary marine/lacustrine sediments. The distribution of the soils is shown on the reconnaissance soil map of the proposed Bura East Irrigation Scheme presented as appendix 5. Detailed descriptions of the individual mapping units are given in appendix 2. Descriptions of the representative profile pits and analytical data are given in a separate annex to this report. A short description of the various soils encountered in each of the landscape units is given below. The soil classification given is according to the FAO Revised Legend for the Soil Map of the World (FAO, 1987).

3.2.2.2. Soils of the slightly high-lying land.

These slightly high-lying areas are the highest and most prominent features in the landscape. The soils are imperfectly drained, very deep[a], brown to dark greyish brown, firm clays. The texture of the topsoil varies from sandy clay loam to clay whereas that of the subsoil is predominantly clay. The topsoil, about 10-15 cm on average, is non-saline and non-to slightly sodic. Its structure is subangular blocky to crumb. The topsoil often overlies a pronounced hardpan (columnar or prismatic structure and extremely hard when dry). The subsoil (B-horizon) is moderately to strongly calcareous, moderately to strongly saline and moderately to strongly sodic.

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[a]Soil depth descriptions in use at the Kenya Soil Survey (KSS) refer to the depths of the soil profile to hard rock or an indurated layer. The soil depth is not always synonymous to effective soil depth, for instance a SOLONETZIC soil may be described as very deep, but the effective soil depth, being the upper non-sodic layer, may be considered as shallow.

The soil reaction is alkaline. The pH-H_2O [a] ranges between 7.2 and 8.6 in the topsoil and between 7.8 and 9.5 in the subsoil (B-horizon). The highest pH is found in the upper parts of the B-horizon. The Cation Exchange Capacity (CEC) ranges between 17 and 40 me/100 g soil. The CEC-clay[b] varies from 49 to 93 me/100 g.

Table 12: Some physical and chemical properties of soils of the high-lying land - Bura East.

Map Unit	Organic C%		Clay %		CEC-soil me/100g		CEC-clay me/100g	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Ps 1.1	0.2-0.4	0.1-0.2	20-30	40-56	17-33	15-40	70-71	49-87
Ps 1.2	0.2-0.6	nd	30-40	36-54	17-35	33-40	58-79	62-95
Ps 1.3	0.4-0.7	0.1-0.3	26-32	32-40	17-20	20-40	70-78	49-54

Map Unit	pH-H2O (1:2.5)		EC(1:2.5) mmhos/cm		ECe mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Ps 1.1	7.5-8.5	8.5-9.5	0.5-4.0	5.0-10.0	2.3-17	7.0-24	12-18	15-68
Ps 1.2	7.2-8.0	7.8-8.5	1.3-5.5	5.0- 9.5	5.5-17	9.5-24	3-28	32-44
Ps 1.3	8.2-8.6	7.8-9.0	0.5-1.2	4.5- 6.0	0.5- 4.5	16 -24	5-15	50-70

Topsoil (A-horizons); Subsoil (B-horizons); nd=not determined

The organic matter content is low (%C less than 0.7). The soils have low infiltration rates. Table 12 gives a summary of the range of some physical and chemical properties of these soils.

The soils are classified as Calcari-gleyic SOLONETZ, salic phase.

3.2.2.3. Soils of the slightly low-lying land.

These are in general moderately well drained to imperfectly drained, very deep, friable to firm clays with colours varying from reddish brown to very dark greyish brown. The texture of the topsoil is mainly sandy clay to clay while that of the subsoil is predominantly clay.These soils have a surface layer (usually 10-20 cm thick) which is characterised by either porous massive, crumb or subangular blocky structure. The subsoils (B-horizons) have mainly either prismatic structure or coarse angular blocky structure. The deeper parts of the profile (usually the C-horizons) are characterised by angular or subangular blocky structures, many slickensides or pressure faces, and are normally strongly calcareous. The degree of calcareousness, salinity and

[a]pH-H_2O is at the soil:water ratio of 1:2.5.

[b]CEC-clay is not corrected for the organic matter.

sodicity of these soils varies widely with depth and from soil to soil (see appendix 5 and Table 13).

The soil reaction is neutral to alkaline with pH-H_2O ranging between 6.5 and 8.8 in the topsoil and 7.2 and 10.0 in the subsoil. In most cases the upper parts of the B-horizon have the highest pH-values. The CEC-soil in general ranges between 20 and 40 me/100 g in the topsoil and 30 and 62 me/100 g in the subsoil. Lower values of CEC-soil (8 me/100 g) may be found in soils that have coarse textures (see unit Ps 2.17.). The CEC-clay varies from 42 to 117 me/100 g in the topsoil and 46 to 103 me/100 g in the subsoil. The soils have low organic matter content (%C varies from 0.2 to 0.9 in the topsoil and decreases with depth). These soils have variable infiltration rates, which to a great extent are determined by the prevailing soil conditions.

These soils fall under the following classification units: Gleyic or Calcari-gleyic or Calcari-chromic LUVISOLS, Calcari-gleyic or Calcari-vertic or Chromi-calcaric CAMBISOLS, Verti-haplic or Luvi-haplic CALCISOLS and Calcari-gleyic or Calcari-haplic SOLONETZ, with either sodic, salic or salic-sodic phases.

3.2.2.4. Soils of the low-lying land.

These soils are found on the lowest parts of the landscape. They are poorly drained to very poorly drained, deep to very deep, dark greyish brown to dark grey, firm to very firm, clay soils, They are characterised by crumb or subangular blocky structures in the topsoil and coarse prismatic structures in the subsoil (B-horizon). Deep cracks and slickensides are common. They are moderately to strongly calcareous throughout. These soils are non-to slightly saline and non-to slightly sodic from the surface to depths varying from 30 cm to 40 cm. They are moderately to strongly saline and sodic from 30 to 40 cm onwards.

The soil reaction is alkaline with pH-H2O varying from 8.1 to 8.6 in the topsoil and 8.1 to 9.0 in the subsoil. The highest pH values are reached in the upper parts of the B-horizon. The CEC-soil ranges between 41 and 44 me/100 g in the topsoil. In the subsoil it ranges between 37 and 55 me/100 g. The CEC-clay varies from 67 to 72 me/100 g in the topsoil and from 52 to 78 me/100 g in the subsoil. The organic matter content is low (% C varies from 0.4 to 0.6 in the topsoil and decreases rapidly with depth to less than 0.1%). These soils are waterlogged during the rainy seasons.

They are classified as Chromi-calcic VERTISOLS. They are saline and sodic and are therefore mapped as salic-sodic phase.

Table 13: Range of some physical and chemical properties of soils of the slightly low-lying land - Bura East.

Map Unit	Organic C%		Clay %		CEC-Soil me/100g		CEC-clay me/100g		$pH-H_2O$ (1:2.5)		EC(1:2.5) mmhos/cm		ECe mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Ps2.1	0.2-0.6	0.2-0.4	50-60	46-68	30-33	33-45	55-61	49-93	6.5-7.3	7.2-8.6	<0.1	0.2-0.4	nd	nd	4-6	8-15 (35)
Ps2.2	0.2-0.6	nd	40-44	44-60	24-25	24-33	54-63	53-61	8.0-8.3	8.2-9.5	0.4-0.6	0.4-0.5	nd	0.3-0.5	1-2	2-14
Ps2.3	0.2-0.4	nd	54-58	54-62	30-33	32-50	57-58	54-78	8.0-8.2	8.3-9.7	0.3-0.4	0.4-2.4	nd	0.5-14	1-3	9-62
Ps2.4	0.4-0.9	0.1-0.3	46-56	52-66	38-40	34-46	68-83	52-72	7.8-8.5	8.1-9.6	0.2-0.3	0.3-6.0	0.4-0.8	0.7-22	3-5	11-43 (57)
Ps2.5	0.6-0.7	0.2-0.4	48-54	54-64	20-31	30-48	42-64	56-75	8.1-8.4	8.7-10.0	0.2-0.3	0.4-5.0	0.4-1.4	0.6-12	3-8	21-44
Ps2.6	0.5-0.7	0.1-0.4	44-60	50-70	32-39	32-43	62-89	48-77	8.0-8.3	7.8-9.5	0.2-0.5	0.8-8.0	0.5-0.9	0.5-22	2-4	15-38 (64)
Ps2.7	0.4-0.5	0.2-0.4	34-46	42-60	29-38	40-51	83-85	54-95	7.8-8.0	8.6-9.5	0.2-0.4	0.6-6.0	0.5-0.9	4.3-23	4-10	30-66
Ps2.8	0.5-0.6	nd	48-56	52-68	35-66	51-62	68-117	83-103	8.4-8.7	8.1-9.1	0.3-0.5	1.4-9.0	0.6-1.3	2.8-23	3-6	29-52
Ps2.9	0.5-0.8	0.3-0.4	30-48	42-68	18-37	35-60	55-77	52-89	7.7-8.4	8.6-9.3	0.4-0.9	1.1-11.0	0.5-1.0	1.4-24	2-8	18-47
Ps2.10	0.8-0.9	nd	44-48	52-68	32-42	38-53	66-94	62-86	8.2-8.4	8.2-9.2	0.6-0.7	1.2-9.0	1.1-1.4	2.1-24	3-8	19-55
Ps2.11	0.5-0.9	0.1-0.4	44-52	46-66	27-40	31-54	62-77	46-83	8.3-8.8	8.2-9.0	0.2-0.4	0.9-11.5	0.5-1.0	2.0-30	4-6	12-49
Ps2.12	0.6-0.9	nd	44-54	48-64	28-40	32-40	52-80	46-67	8.0-8.7	7.5-9.4	0.3-0.8	0.9-8.0	0.4-1.3	0.4-21	1-4	6-65
Ps2.13	0.5-0.8	nd	46-50	48-72	30-33	33-55	66-71	57-86	8.5-8.8	8.0-9.0	0.4-1.4	0.7-7.5	0.7-1.5	12-18	8-12	16-42
Ps2.14	0.6-0.8	nd	48-50	56-62	33-48	39-51	69-95	64-92	8.0-8.9	8.1-8.9	1.5-2.0	1.3-5.0	0.9-1.4	12-14	4-7	15-45
Ps2.15	0.4-0.8	0.1-0.4	42-50	48-72	35-39	30-50	74-87	51-74	8.1-8.5	7.9-9.0	0.1-0.5	0.4-9.0	0.5-1.3	2.1-20	3-4	14-57
Ps2.16	0.5-0.7	nd	40-50	50-62	27-28	24-30	55-56	46-55	7.6-8.6	8.3-8.9	0.2-0.3	0.3-7.5	nd	6.0-30	4-5	12-72‡
Ps2.17	0.2-0.5	0.1-0.2	16-58	40-66	8-29	21-32	47-50	50-63	7.2-7.8	7.7-9.3	0.1-0.2	0.2-3.5	nd	6.5-17	2-6	11-55

nd = not determined

Note: () deeper subsoil (C-horizon); nd = not determined

‡ For one component of the Association only

3.2.3. Soils of the Bura West Area.

3.2.3.1. Introduction.

Physiographically the area is divided into two units:

A. a Floodplain (symbol A) which is found along the streambed of Laga Hiraman and

B. a Sedimentary Plain/large alluvial fan complex (symbol Pf) which forms the bulk of the area.

The soils of the floodplain are developed on young alluvial deposits whereas those of the sedimentary plain are developed on old alluvial deposits.

Within the sedimentary plain the soils have been grouped according to their relative altitude and position in the landscape as follows:

- Soils of the slightly high-lying land (units Pf 1.1. to Pf 1.3.);
- Soils of the slightly low-lying land (units Pf 2.1. to Pf 2.5.);
- Soils of the low-lying land (units Pf 3.1. to Pf 3.3.).

The distribution of the soils is shown on the soil map of the Bura West Irrigation Scheme presented as appendix 6. Detailed descriptions of the individual soil mapping units are given in appendix 2. Descriptions of the representative profile pits and analytical data are given in a separate annex to this report. A short description of the various soils occurring in each of the landscape units is given below. The soil descriptions follow the sequence used in the legend of the soil map.

3.2.3.2. Soils of the slightly high-lying land.

These are in general moderately well drained to imperfectly drained, very deep, dark reddish brown to dark greyish brown soils of varying textures. The texture of the topsoil varies from sand to sandy clay(clay content 7% to 47%) while that of the subsoil (B-horizon) ranges between sandy clay loam to clay (clay content 23% to 58%). The depth of the coarse textured upper parts of the solum is very variable. The soils on the highest parts of the landscape (cf unit Pf 1.1.) have this layer with a thickness on average between 50 cm and 90 cm. For the other soils the thickness of this layer is in general between 15 cm and 40 cm. This coarse textured layer overlies a natric B-horizon which has columnar or prismatic structures and is very hard to extremely hard when dry. The upper part of the natric horizon is often capped by a bleached and cemented layer which is extremely hard when dry. The lower part of the solum (B-horizon) is moderately to strongly calcareous, strongly saline (ECe vary from 18 to 45 mmhos/cm) and moderately to strongly sodic (ESP varies from 10 to 62).

The soil reaction of the topsoil varies from slightly acid (pH-H_2O 6.4) to alkaline (pH-H_2O 8.3) while that of the subsoil ranges between mildly alkaline (pH-H_2O 7.7) and strongly alkaline (pH-H_2O 9.0). Usually the upper parts of the B-horizon have the highest pH values. The CEC-soil ranges between 4 and 20 me/100 g in the topsoil and between 14 and 34 me/100 g in the subsoil. The CEC-clay varies from 42 to 73 me/100 g in the topsoil while that of the subsoil ranges between 40 and 77 me/100 g. The organic matter content is low (%C is less than 0.5). The range of some physical and chemical properties of these soils is given in Table 14.

Table 14. Range of some physical and chemical properties of soils of the slightly high-lying land - Bura West.

Map Unit	Organic C%		Clay%		CEC-soil me/100g		CEC-clay me/100g	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pf 1.1	0.1-0.2	nd	7-17	23-35	4- 9	14-22	46-57	40-72
Pf 1.2	0.1-0.4	0.1-0.3	14-43	29-58	5-20	16-32	42-73	42-69
Pf 1.3	0.1-0.5	<0.1	17-47	28-58	12-20	16-34	54-72	42-77

Map Unit	pH-H2O(1:2.5)		EC (1:2.5) mmhos/cm		ECe mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pf 1.1	6.4-7.7	7.7-8.9	0.1-0.2	0.2- 2.0	0.3-1.4	1.2-13.0	2- 6	15-33
Pf 1.2	7.0-7.8	7.9-8.9	0.1-0.2	0.2- 3.5	0.3-1.3	1.0-18.0	3-14	10-45
Pf 1.3	6.9-8.3	8.4-9.0	0.3-4.7	0.5-11.5	1.8-9.7	3.5-45	6-17	22-62

The soils are classified either as Haplic SOLONETZ or Calcari-haplic SOLONETZ. The former soils (cf unit Pf 1.1.) are in places saline within a depth of 1 metre from the surface and are therefore mapped as partly salic phase. The latter soils are saline and are mapped as salic phase.

3.2.3.3. Soils of the slightly low-lying land.

These are in general well drained to moderately well drained, very deep, dark red to dark reddish brown, friable to firm sandy clay to clay soils. The texture of the topsoil varies from sandy clay loam to sandy clay (clay content ranges between 26% and 56%) while that of the subsoil is predominantly sandy clay to clay (clay content ranges between 35% and 70%). The upper parts of the solum (usually A-horizons) have mainly either porous massive, crumb or subangular blocky structures. The lower parts of the solum (B-horizons) have either subangular and angular blocky structures or prismatic structures which break into angular and subangular blocky elements.

The bulk of the soils are calcareous throughout. Some of the soils (cf map unit Pf 2.1.) have either a weakly cemented layer of calcium carbonate concretions or a strongly cemented layer (petrocalcic horizon) at varying depths but usually deeper than 125 cm. The degree of salinity and sodicity varies widely with depth and from soil to soil (see table 15).

The soil reaction varies from slightly acid (pH 6.4) to strongly alkaline (pH 8.9) in the topsoil while in the subsoil it varies from moderately alkaline (pH 7.9) to very strongly alkaline (pH 9.9). The CEC-soil ranges between 13 and 35 me/100 g in the topsoil and between 23 and 48 me/100 g in the subsoil. The CEC-clay varies from 36 to 73 me/100 g in the topsoil whereas that of the subsoil varies from 40 to 74 me/100 g. The organic matter content is low (%C varies from 0.3 to 0.8 in the topsoil and decreases with depth).

The soils are classified as Chromi-calcaric CAMBISOLS and Calcari-haplic SOLONETZ. The SOLONETZ are saline and are mapped as salic phase while the CAMBISOLS are mapped as either partly sodic or salic-sodic phases.

Table 15. Range of some physical and chemical properties of soils of the slighlty low-lying land - Bura West.

Map Unit	Organic C%		Clay %		CEC-soil me/100g		CEC-clay me/100 g	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pf 2.1 Pf 2.2+	0.3-0.6	0.2-0.3	26-48	35-61	13-26	23-29	36-56	40-73
Pf 2.3	0.5-0.7	0.1-0.4	41-56	50-70	24-35	33-48	55-73	53-74
Pf 2.4	0.5-0.8	nd	42-47	53-62	25-27	28-38	52-60	52-67
Pf 2.5	0.4-0.5	nd	34-44	46-60	23-30	29-38	53-68	65-68

Map Unit	pH-H2O(1:2.5)		EC(1:2.5)mmhos/cm		ECe mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pf 2.1 Pf 2.2+	6.4-8.0	7.9-9.0	0.1-0.2	0.2-1.3	0.5-1.1	0.4- 5.4	1-4	2-17
Pf 2.3	7.2-8.7	8.4-9.3	0.1-0.2	2.1-8.0	0.9-1.3	5.1-22	2-5	13-48
Pf 2.4	7.5-8.8	9.0-9.9	0.2-0.4	0.5-7.5	1.0-2.4	2.0-23	3-5	25-46
Pf 2.5	7.5-8.9	8.9-9.7	0.2-0.3	0.5-7.5	1.0-1.1	2.0-22	3-4	26-50

3.2.3.4. Soils of the low-lying land.

These soils are found on the lowest parts of the sedimentary plain. They are in general imperfectly drained, very deep, dark reddish brown to dark greyish brown, firm to very firm clay soils. The texture of the topsoil ranges between sandy clay to clay with a clay content varying from 47 to 59 percent. The subsoil is predominantly clay (clay content varies from 51 to 71 percent). When dry, these soils have cracks more than 1 cm wide extending from the surface into the subsoil (B- or C-horizons) at depths ranging between 50 cm and 110 cm. They are characterised by crumb or subangular blocky structures in the topsoil and coarse prismatic structures in the subsoil. The prismatic structures tend to break into angular blocky peds when dry. The deeper parts of the solum may have only angular blocky structures. Slickensides are common in the subsoil. Materials washed down from the surface layers along the cracks are observed in the subsoil. These soils are strongly calcareous throughout. The topsoil, on average 15 cm to 20 cm is non-saline and non sodic whereas the subsoil is saline and sodic.The degree of salinity and sodicity varies with depth from soil to soil but usually increases with depth (see table 16).

Table 16: Range of some physical and chemical properties of soils of the low-lying land - Bura West.

Map Unit	Organic C%		Clay %		CEC-soil me/100g		CEC-clay me/100g	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pf 3.1	0.5-0.7	nd	53-55	56-65	30-40	35-42	55-56	59-65
Pf 3.2	0.5-1.3	0.2-0.3	47-57	51-71	30-42	33-48	54-78	60-75
Pf 3.3	0.4-0.5	nd	52-59	56-69	33-34	37-48	58-64	69-70

Map Unit	pH-H2O (1:2.5)		EC (1:2.5) mmhos/cm		ECe mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pf 3.1	8.6-8.7	8.5-9.5	0.1-0.4	0.5-7.0	1.0-1.1	1.4-24	1-5	27-45
Pf 3.2	8.4-9.1	8.4-9.3	0.2-0.5	0.5-8.5	0.8-1.2	1.2-26	4-8	15-40
Pf 3.3	8.5-8.8	7.8-9.3	0.2-0.3	0.5-4.8	0.8-1.0	1.4-14	2-4	24-36

The soil reaction varies from moderately alkaline (pH 8.4) to very strongly alkaline (pH 9.1 to 9.5) in both topsoil and subsoil. The CEC-soil ranges between 30 and 42 me/100 g in the topsoil and between 33 and 48 me/100 g in the subsoil. The CEC-clay varies from 54 to 78 me/100 g in the topsoil and from 59 to 75 me/100 g in the subsoil. The organic matter content is low (%C varies from 0.4 to 1.3 in the topsoil and decreases with depth).

The soils are classified as Chromi-haplic and Chromi-calcic VERTISOLS. They are saline and sodic and are consequently mapped as salic-sodic phases.

3.2.3.5. Soils of the Floodplain.

These soils are found along the streambed of the Laga Hiraman. They are relatively low-lying and are periodically inundated by the Laga Hiraman. They are imperfectly drained, very deep, dark brown to brown, firm to very firm stratified clay soils. The texture is predominantly clay with a clay content ranging between 54 and 72 percent. The structure of the topsoil varies from massive to subangular blocky while that of the subsoil is either prismatic or angular blocky. They crack intensively during the dry season but they do not have properties diagnostic for VERTISOLS. The topsoil (0-20/30 cm) is non-to slightly calcareous whereas the subsoil is slightly to moderately calcareous. They are non-saline to depths varying from 70 to 100 cm from the surface (ECe 0.5-2.4 mmhos/cm). The topsoil (0-20/30 cm) is non-to slightly sodic (ESP varies from 6 to 10) while the subsoil is moderately to strongly sodic (ESP varies from 14 to 30).

The soil reaction varies from moderately alkaline (pH 8.4) to strongly alkaline (pH 8.9) in the topsoil whereas that of the subsoil varies from moderately alkaline (pH 8.4) to very strongly alkaline (pH 9.2). The CEC-soil ranges between 33 and 47 me/100 g in the topsoil and between 36 and 54 me/100 g in the subsoil. The CEC-clay varies from 71 to 72 me/100 g and 72 to 75 me/100 g in the topsoil and subsoil respectively. The organic matter content is low (organic C is less than 0.4%).

The soils are classified as Verti-calcaric FLUVISOLS. Since they are sodic within a depth of one metre, they are mapped as sodic phase.

3.2.4. Soils of the Hola Irrigation Scheme.

3.2.4.1. Introduction.

The Hola Irrigation Scheme lies outside the floodplain and the Lower terrace of river Tana. It falls under a sedimentary plain which represents the upper terrace of river Tana (symbol Pt). All the soils are developed on old alluvial deposits, hence there is only one physiographic unit. On the basis of morphological characteristics, the soils of this unit can be divided into three groups viz:

Group I - Soils with a cambic horizon (units Pt 1, Pt 2 and Pt 3);

Group II - Soils with a natric horizon (units Pt 4, Pt 5 and Pt 6);

Group III - Cracking clay soils (units Pt 7, Pt 8 and Pt 9).

The distribution of the soils is shown on the soil map presented as appendix 7. Detailed descriptions of the individual soil mapping units are given in appendix 2. Descriptions of the representative profile pits and analytical data are given in a separate annex to this report. A short description of the soils according to the above grouping is given below.

3.2.4.2. Soils of Group I (units Pt 1, Pt 2 and Pt 3 - predominantly CAMBISOLS).

These are well drained to moderately well drained, very deep, dark reddish brown to dark brown, friable to firm clay soils. The texture of the topsoil varies from sandy clay to clay (clay content 39% to 61%) while that of the subsoil is predominantly clay (clay content 43% to 73%). They are characterised by topsoils with porous massive, crumb or subangular blocky structure. The upper parts of the subsoil (B-horizons) have prismatic structures which break into subangular or angular blocky peds. The deeper subsoil may have only angular or subangular blocky structure. The soils are calcareous throughout. Salinity and sodicity varies from soil to soil and increases with depth (see table 17). The topsoils are non-saline and non-to slightly sodic while the subsoils are slightly to strongly saline and moderately to strongly sodic.

The soil reaction is mildly to moderately alkaline (pH 7.8 to 8.4) in the topsoil, whereas it is moderately alkaline (pH 8.1) to very strongly alkaline (pH 9.1 to 10.1) in the subsoil. The CEC-soil ranges between 21 and 40 me/100 g in the topsoil and between 19 and 43 me/100 g in the subsoil. The CEC-clay varies from 34 to 77 me/100 g and 35 to 58 me/100 g in the topsoil and subsoil respectively. The organic matter content is higher in the irrigated soils than in the non-irrigated soils. Organic carbon content varies from 0.5% to 1.6% in the topsoil and from 0.1% to 0.9% in the subsoil.

The soils are classified as Chromi-calcari CAMBISOLS, Calcari-gleyic CAMBISOLS, Calcari-vertic CAMBISOLS and partly Calcari-haplic SOLONETZ. They are mapped as either salic or salic-sodic phases.

3.2.4.3. Soils of Group II (units Pt 4, Pt 5 and Pt 6 - SOLONETZ).

These are moderately well drained to imperfectly drained, very deep, reddish brown to dark greyish brown, firm sandy clay to clay soils. The texture of the topsoil varies from loamy sand to clay (clay content 15 to 51 percent) while that of the subsoil (B-horizon) varies from sandy clay to clay (clay content 39 to 68 percent). They have topsoils with porous massive, crumb or weak subangular blocky structures overlying subsurface horizons with prismatic structures which break to angular blocky peds. These prismatic structural aggregates are very hard to extremely hard when dry. The soils are non-to slightly calcareous in the topsoil (0-20/35 cm) and moderately to strongly calcareous in the subsoil. The topsoil, on average about 10-15 cm, is non-saline and non-to slightly sodic. The subsoil (B-horizon) is slightly to strongly saline and strongly sodic (see table 18).

Table 17. Range of some physical and chemical properties of soils of Group I - Hola.

Map Unit	Organic C%		Clay %		CEC-soil me/100g		CEC-clay me/100 g	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pt 1+								
Pt 2	0.9-1.6	0.2-0.9	39-53	43-71	21-30	19-25	34-77	35-58
Pt 3	0.4-1.6	0.1-0.8	49-61	53-73	27-40	22-43	52-65	36-57

Map Unit	pH-H20(1:2.5)		EC(1:2.5) mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pt 1+						
Pt 2	8.0-8.4	8.1-10.1	0.2-0.6	0.1-3.0	5- 8	19-63
Pt 3	7.8-8.3	8.4- 9.8	0.2-1.4	0.3-2.5	7-10	15-62

Table 18: Some physical and chemical properties of soils of Group II - Hola.

Map Unit	Organic C%		Clay %		CEC-soil me/100g		CEC-clay me/100 g	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pt 4	1.1-1.5	0.2-0.7	15-44	39-64	10-32	22-40	72-73	45-67
Pt 5	1.0-1.3	0.1-0.6	30-43	42-66	20-26	18-22	60-66	33-40
Pt 6	0.9-1.0	0.1-0.8	42-51	46-68	25-27	25-40	49-58	41-71

Map Unit	pH-H20 (1:2.5)		EC (1:2.5) mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pt 4	7.7-8.5	8.4- 9.5	0.2-0.6	0.4-6.5	7- 9	16-50
Pt 5	8.0-9.0	8.6- 9.9	0.2-0.5	0.5-7.5	7-19	16-65
Pt 6	7.9-8.9	8.3-10.2	0.2-0.5	0.2-7.0	3-12	14-57

The soil reaction is mildly alkaline (pH 7.7) to strongly alkaline (pH 9.0) in the topsoil and moderately alkaline (pH 8.3) to very strongly alkaline (pH 9.1 to 10.2) in the subsoil. The CEC-soil varies from 10 to 32 me/100 g and 18 to 40 me/100 g in the topsoil and subsoil respectively. The CEC-clay ranges between 49 and 73 me/100 g in the topsoil and between 32 and 71 me/100 g in the subsoil. The organic carbon content ranges between 0.9 and 1.5 percent in the topsoil and between 0.1 and 0.8 percent in the subsoil. The range of some physical and chemical properties of these soils is given in table 18.

The soils are classified as Calcari-haplic SOLONETZ and Calcari-mollic SOLONETZ. The latter soils are found only in the irrigated parts of unit Pt 6. These soils are saline within a depth of one metre from the surface and are subsequently mapped as salic phase.

3.2.4.4. Soils of Group III (units Pt 7 to Pt 9 - VERTISOLS).

These are moderately well drained to imperfectly drained, very deep, dark reddish brown to brown, firm to very firm clay soils. The texture of the topsoil varies from sandy clay to clay (clay content 43 to 54 percent) whereas that of the subsoil (B-horizon) is predominantly clay (clay content 47 to 76 percent). The topsoil is characterised by a crumb or subangular blocky structure. The structure of the subsoil is coarse prismatic that breaks into angular blocky peds. Slickensides are common in the subsoil. When dry, these soils have cracks, 1-3 cm wide, occurring from the surface to depths varying from 60 to 100 cm. In places where these cracks are wider than 3 cm the surface material falls into them, forming small micro depressions (sink holes). These soils are calcareous throughout. The topsoils (usually 10 to 20 cm) are non saline and non to slightly sodic. The subsoils are slightly to strongly saline and moderately to strongly sodic. Salinity increases with depth. The depth at which salinity starts is greater in the irrigated soils than in the non-irrigated soils (see appendix 7).

The soil reaction varies from moderately alkaline (pH 8.1) to strongly alkaline (pH 9.0) in the topsoil and from strongly alkaline (pH 8.5) to very strongly alkaline (pH 10.1) in the subsoil. The CEC-soil ranges between 22 and 37 me/100 g in the topsoil and between 20 and 36 me/100 g in the subsoil. The CEC-clay varies from 53 to 76 me/100 g and 35 to 73 me/100 g in the topsoil and the subsoil respectively. The organic matter content is higher in the irrigated soils (% C varies from 1.2 to 1.6) than in the non-irrigated soils (% C varies from 0.3 to 0.7).

The soils are classified as Chromi-calcic VERTISOLS and Chromi-haplic VERTISOLS with inclusions of Calcari-vertic CAMBISOLS. They are saline and sodic and hence are mapped as salic-sodic phase.

Table 19: Range of some physical and chemical properties of soils of Group III - Hola.

Map Unit	Organic C%		Clay %		CEC-soil me/100g		CEC-clay me/100g	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pt 7	1.4-1.5	0.1-0.4	43-50	57-76	30-32	30-36	65-70	45-61
Pt 8	0.7-1.5	0.2-0.6	44-54	47-70	22-37	20-30	53-69	35-52
Pt 9	0.9-1.3	0.7-1.5	47-53	47-67	26-40	28-36	55-76	42-73

Map Unit	pH-H20(1:2.5)		EC (1:2.5) mmhos/cm		ESP	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pt 7	8.3-9.0	8.5- 9.8	0.2-1.1	0.5-7.5	3-12	12-55
Pt 8	8.1-9.0	8.7-10.1	0.2-0.6	0.5-6.0	5-16*	20-59
Pt 9	8.1-8.8	8.6-10.1	0.2-0.4	0.2-6.4	3- 6	9-62

*non-irrigated area outside the scheme.

3.3. SOIL PROPERTIES.

3.3.1. Introduction.

This chapter discusses in more details the properties of the soils in the Bura East, Bura West and Hola study areas, with special emphasis on those properties that are of importance to irrigated agriculture. The soil properties have been grouped into three categories, viz physical properties (grain size distribution, structure, bulk density and porosity, infiltration, hydraulic conductivity, water retention and available moisture); chemical properties (soil reaction, salinity and sodicity, ion exchange characteristics and available nutrients); mineralogical characteristics (mineralogy of the clay fraction, calcium carbonate content and gypsum content).

3.3.2. Physical properties.

3.3.2.1. Grain size distribution.

Grain size distribution commonly referred to as texture, is an important soil characteristic to be considered when appraising soils for agricultural development. Texture influences soil properties such as moisture and nutrient retention, water infiltration, drainage, tilth etc. and soil qualities such as susceptibility to erosion. However, its effects on these properties may be modified by soil structure, nature of the clay minerals and organic matter, and lime content.

The following particle sizes of the fine earth fraction are applied; sand (2.0-0.05 mm), silt (0.05-0.002 mm) and clay (smaller than 0.002 mm). The textural classes used are according to the Soil Survey Manual (Soil Survey Staff, 1951). A diagrammatic presentation of these textural classes is given in figure 41. The grain size distributions of the major soil classification units found in the study areas are given in figures 28 to 40. A notable textural feature of all the soils is their low silt content (less than 20 percent). The highest silt content is found in soils of the Bura West area (see figures 30, 34 and 37). The soils of the Bura East and the Hola Irrigation Scheme have in general silt contents of less than 10 percent.

Differences in the sand and clay content occur in both vertical and horizontal directions within the various soil classification units. The SOLONETZ and LUVISOLS have in general coarser textured topsoils (sand/loamy sand to sandy clay) than the VERTISOLS, CALCISOLS and CAMBISOLS (mainly sandy clay to clay). The SOLONETZ, occurring in the slightly high-lying land in both the Bura West and the Bura East areas (cf. figures 28 and 30) have a wider textural variation than those found in the slightly low-lying land (cf. figures 29 and 31). The SOLONETZ found at the Hola Irrigation Scheme have a grain size distribution similar to those found in the low-lying land in the Bura East and Bura West areas (cf. figure 32). These SOLONETZ also appear to be more fine textured i.e. more clayey than those found in the slightly high-lying land in the Bura East and Bura West areas. The bulk of the

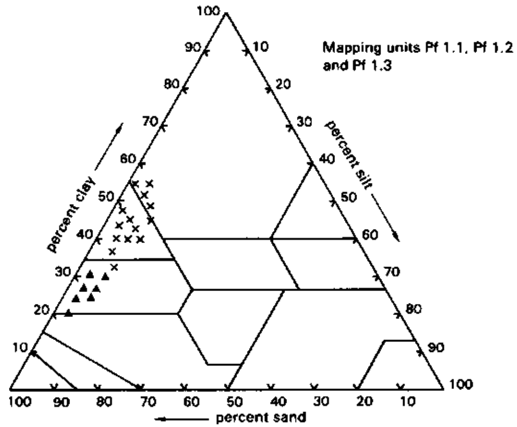


Fig. 28 Grain size distribution of Calcari-gleyic SOLONETZ-slightly high-lying land-Bura East

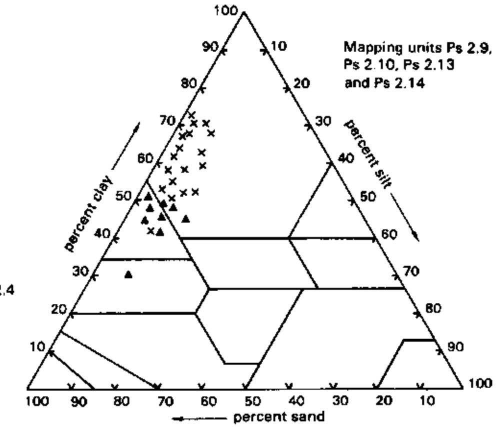


Fig. 29 Grain size distribution of Calcari-haplic SOLONETZ-slightly low-lying land-Bura East

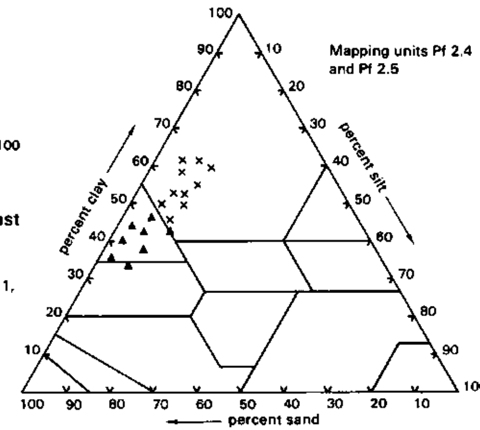


Fig. 31 Grain size distribution of Calcari-haplic SOLONETZ-slightly low-lying land-Bura West

▲ Topsoil (A-horizon)
× Subsoil (Btn-horizons)

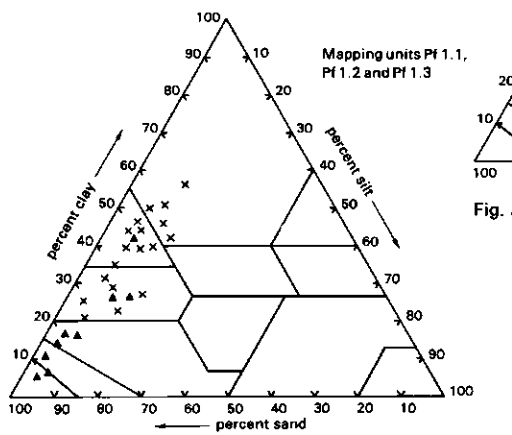


Fig. 30 Grain size distribution of Calcari-haplic SOLONETZ-slightly high-lying land-Bura West

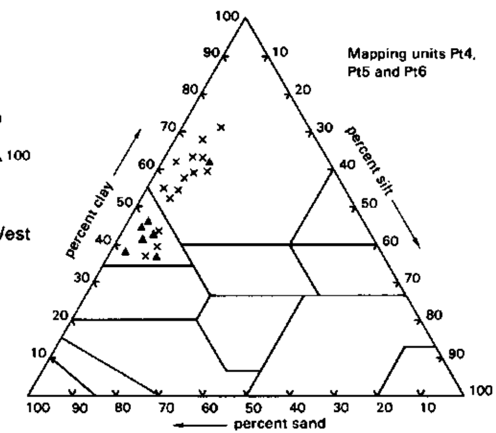


Fig. 32 Grain size distribution of Calcari-haplic SOLONETZ-Hola Irrigation Scheme

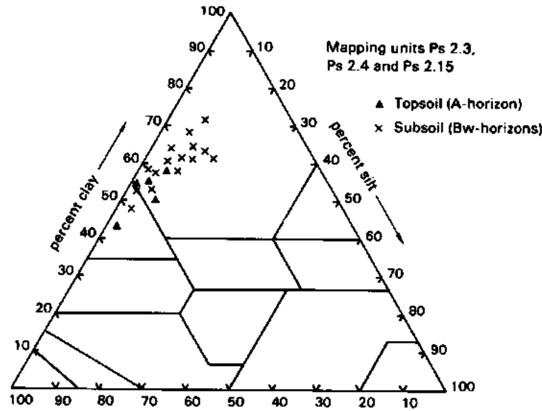


Fig. 33 Grain size distribution of some CAMBISOLS-Bura East

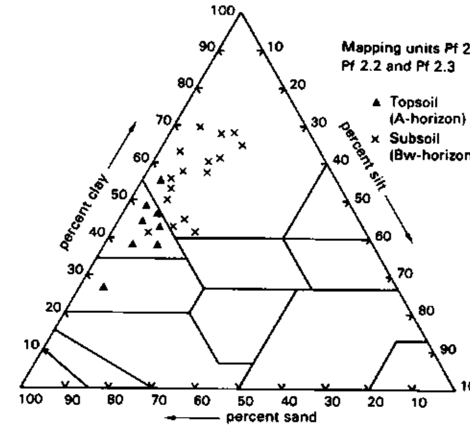


Fig. 34 Grain size distribution of some CAMBISOLS-Bura West

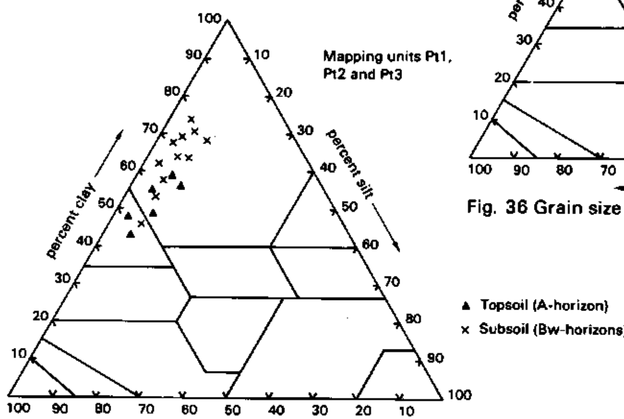


Fig. 35 Grain size distribution of some CAMBISOLS-Hola Irrigation Scheme

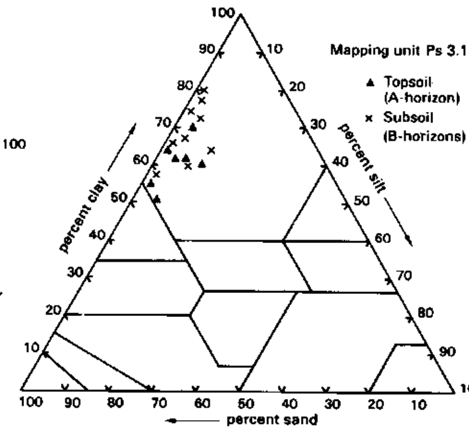


Fig. 36 Grain size distribution of VERTISOLS-Bura East

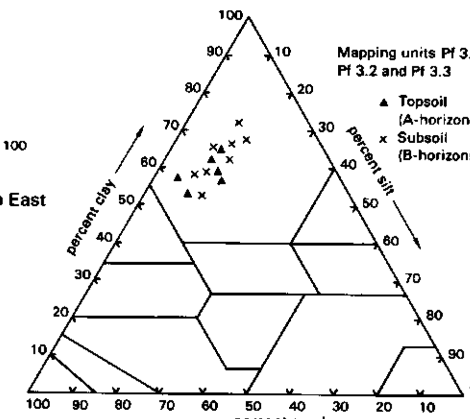


Fig. 37 Grain size distribution of VERTISOLS-Bura West

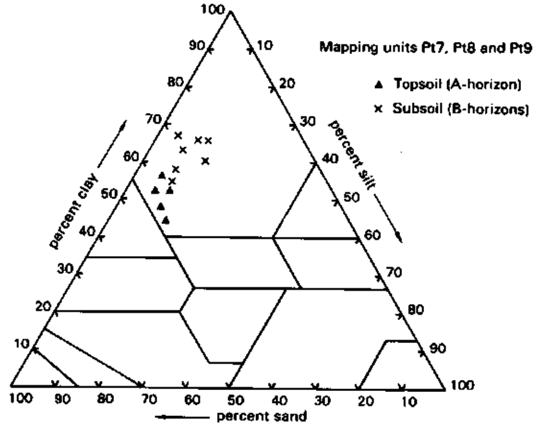


Fig. 38 Grain size distribution of VERTISOLS-Hola Irrigation Scheme

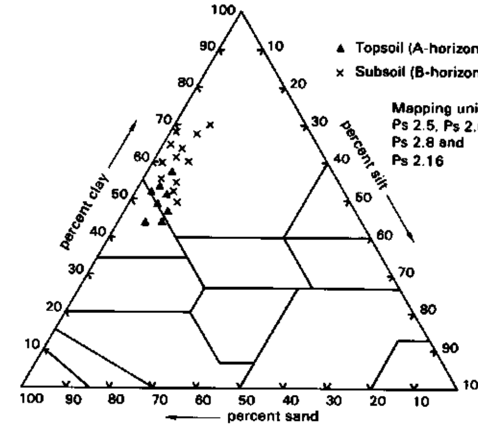


Fig. 39 Grain size distribution of CALCISOLS-Bura East

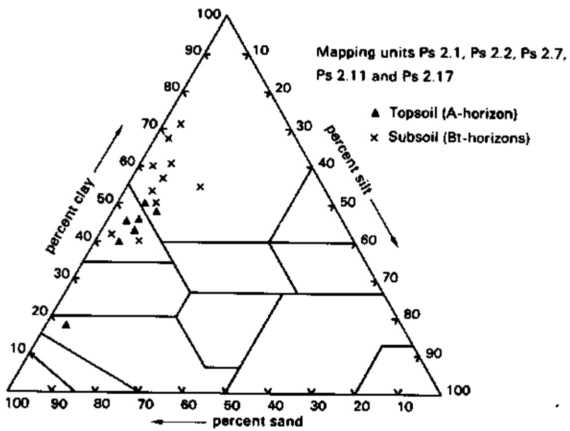


Fig. 40 Grain size distribution of LUVISOLS-Bura East

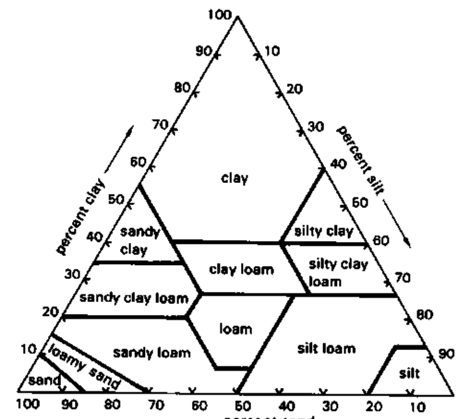


Fig. 41 Textural classes (after USDA Soil Survey Staff, 1951)

CAMBISOLS, CALCISOLS and VERTISOLS have predominantly clayey textures. In the vertical direction, the general trend appears to be that the percentage of clay increases with depth. Figures 42, 43 and 44 give the clay distribution of some representative profiles of the soils of the Bura East, Bura West and Hola areas respectively.

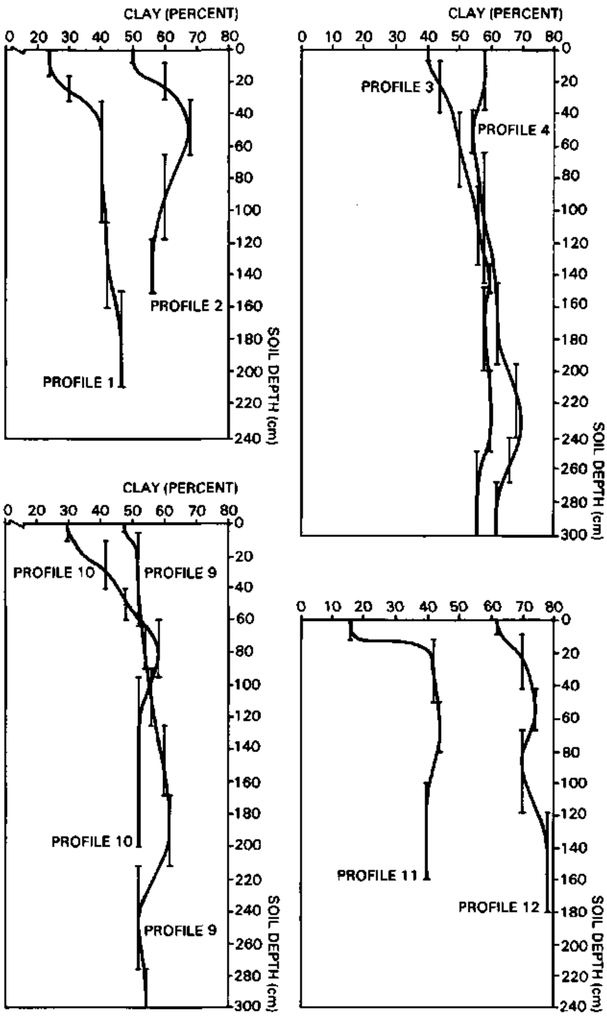
The greatest vertical textural difference is found in the SOLONETZ and LUVISOLS. The shape of the clay distribution curve of these soils may be described as a "clay-bulge" (cf figure 42, profiles 1, 2, 3, 10 and 11; figure 43, profiles 13 and 16 and figure 44 profiles 20, 22, 23 and 24). The occurrence of the "clay-bulge" in these soils is attributed to the pedogenetic process of clay illuviation. The clay distribution curves for CAMBISOLS (profiles 4, 5, 14, 15, 19 and 21), CALCISOLS (profile 9) and VERTISOLS (profiles 12,17, 18, 25 and 26) show a more gentle clay increase. In the case of profiles 19, 21, 25 and 26 (see figure 44) the clay content decreases sharply at depths ranging between 200 and 300 cm. This decrease in clay content is attributed to internal stratification of parent material. Deep augerholes made in the Hola Irrigation Scheme revealed that sand occurs at depths below approximately 2.5 to 4 metres. The occurrence of this sand is important for the long term subsurface drainage of these soils. In contrast, deep profile pits plus augerholes (up to 10 metres) made in the Bura East area did not show any pronounced textural differentiations. The texture of all the deep profiles examined in the Bura East area is clay throughout (clay content varied from 50 to 70 percent). The deeper subsoil usually has a slightly higher clay content than the upper subsoil layers.

No deep profile pits were dug in the Bura West area. However, augerholes made to depths of 2.5-3.0 metres did not reveal any occurrence of coarse textured soil layers in most of the soils with an exception of the CAMBISOLS of mapping unit Pf 2.1. and the Calcaric FLUVISOLS of mapping unit A1. The soils of mapping unit Pf 2.1. have a weakly cemented layer of calcium carbonate concretions at varying depths showing up in gravelly textures. The soils of mapping unit A1 have in places, thin layers of sand.

The relationship between texture and other soil properties such as cation exchange capacity, hydraulic conductivity etc. is discussed in the respective paragraphs that follow.

3.3.2.2. Soil structure and structure stability.

Soil structure.
The field concept of soil structure commonly used by pedologists (soil surveyors) describes structure as "the aggregation of primary soil particles, which are separated from adjoining aggregates by planes of weakness (Soil Survey Staff, 1951). According to this concept, soil materials without such compound particles are considered to have no structure and are described as either massive or of "single grain nature". Soil micromorphol-

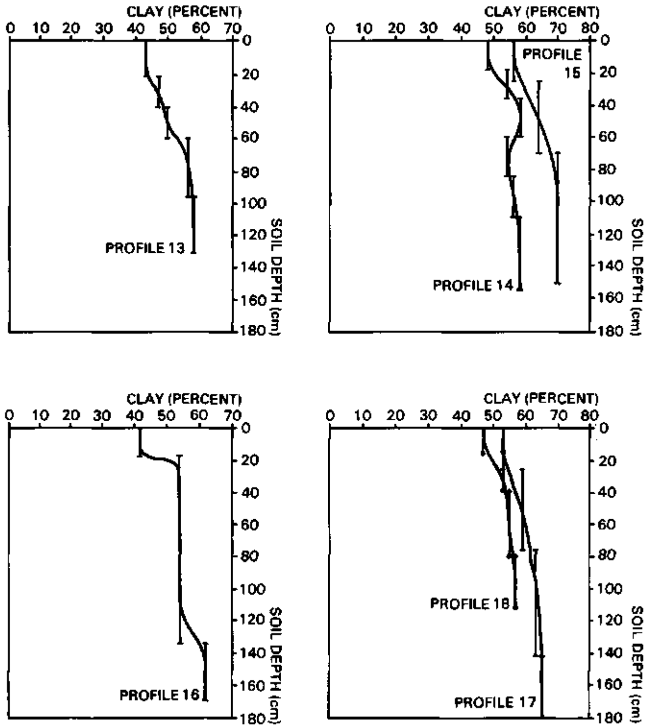


KEY

PROFILE DESCRIPTION NO.	MAPPING UNIT	SOIL CLASSIFICATION (FAO,1987)
1	Ps 1.1	gleyic SOLONETZ
2	Ps 2.1	gleyic LUVISOL
3	Ps 2.2	gleyic LUVISOL
4	Ps 2.3	gleyic CAMBISOL
5	Ps 2.4	vertic CAMBISOL
9	Ps 2.8	haplic CALCISOL
10	Ps 2.9	haplic SOLONETZ
11	Ps 2.17	chromic LUVISOL
12	Ps 3.1	calcic VERTISOL

The profile description numbers correspond to those of the representative profile pits given in appendix 2

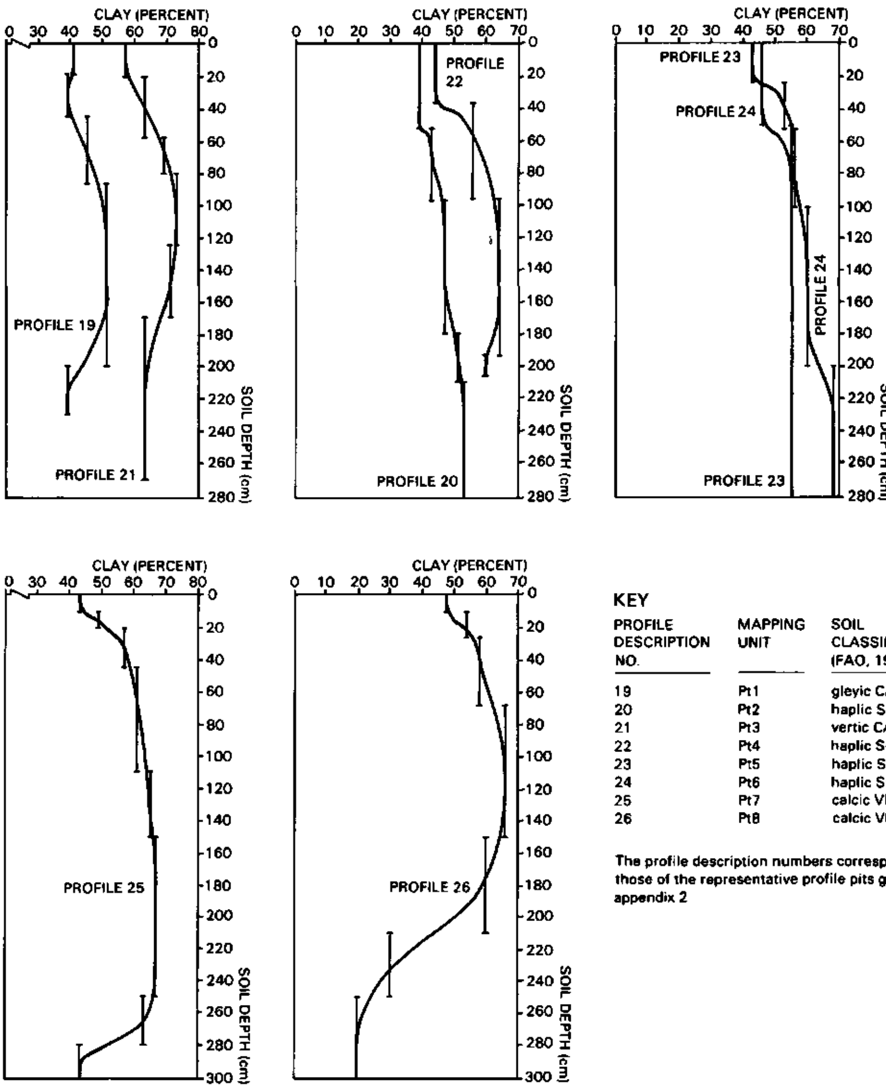
Fig. 42 Clay distribution in some representative profiles- Bura East area



PROFILE DESCRIPTION NO.	MAPPING UNIT	SOIL CLASSIFICATION (FAO, 1987)
13	Pf 1.2	haplic SOLONETZ
14	Pf 2.1	calcaric CAMBISOL
15	Pf 2.2	calcaric CAMBISOL
16	Pf 2.4	haplic SOLONETZ
17	Pf 3.1	calcic VERTISOL
18	Pf 3.2	haplic VERTISOL

The profile description numbers correspond to those of the representative profile pits given in appendix 2

Fig. 43 Clay distribution in some representative profiles-Bura West area



KEY

PROFILE DESCRIPTION NO.	MAPPING UNIT	SOIL CLASSIFICATION (FAO, 1987)
19	Pt1	gleyic CAMBISOL
20	Pt2	haplic SOLONETZ
21	Pt3	vertic CAMBISOL
22	Pt4	haplic SOLONETZ
23	Pt5	haplic SOLONETZ
24	Pt6	haplic SOLONETZ
25	Pt7	calcic VERTISOL
26	Pt8	calcic VERTISOL

The profile description numbers correspond to those of the representative profile pits given in appendix 2

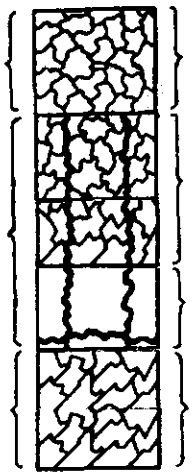
Fig. 44 Clay distribution in some representative profiles-Hola Irrigation Scheme ogists, however consider that voids in any soil material are part of soil structure (Kubiena, 1938; Jongerius, 1957; Brewer, 1964; Bullock et.al., 1985; among others). From this point of view, Brewer (1964) defined soil structure as "the physical constitution of the soil material as expressed by size, shape and arrangement of the solid particles and the voids. Particles include both the primary particles that form compound particles and the compound particles themselves. Fabric is the element of structure that deals with arrangement". The concept of structure as defined in the U.S. Soil Survey Manual (Soil Survey Staff, 1951) is comparable to Brewer's definition of pedality which is "the physical constitution of a soil material as expressed by size, shape and arrangement of peds". This, however differs from Brewer's original definition of basic structure in that it does not include the size, shape and arrangements of voids and primary particles as attributes of structure.

The original definition of basic structure (Brewer, 1964) has been modified slightly (cf. Bouma and Anderson, 1973; Burke et.al., 1985) to read "the physical constitution of soil material as expressed by the size, shape and arrangement of soil particles and voids and its associated properties". This definition too differs from that outlined in the U.S. Soil Survey Manual (Soil Survey Staff, 1951) in that it includes porosity as part of structure. Mc Keague and Wang (1982) reviewed the systems used for describing soil structure and came to the conclusion that soil porosity should be included as a basic aspect of structure description. They proposed some improvements in procedures for describing soil macrostructure in the field and suggested some refinements in definitions of terms related to pedality. For example, the "grade" aspect of pedality that includes both the degree to which the soil mass separates into peds and the strength of the peds was divided into two attributes, ped distinctness and ped strength. However, the proposed system requires extensive field testing and probably a series of revisions.

In this chapter, the "pedality" concept as defined by Brewer (1964), which is comparable to the definition outlined in the U.S. Soil Survey Manual (Soil Survey Staff, 1951) and also in the FAO (1977) Guidelines for Soil Profile Description, will be used in describing soil structure.

The importance of soil structure in influencing productivity can scarsely be overemphasized. Soil conditions and properties such as water movement, heat transfer, aeriation, bulk density and porosity etc. are influenced by structure.

The bulk of the soils of the three study areas in general exhibit a similar sequence of horizon development particularly with regard to soil structure. The topsoils have subangular blocky to crumb structures of varying sizes and grades. Occasionally porous massive topsoils are encountered. The immediate underlying subsoils are characterised mainly by either medium to coarse prismatic structures which break into angular and/or subangular peds or medium to coarse angular blocky structures. The deeper subsoils (in most cases the C horizons) have mainly angular blocky structures. Occasionally massive horizons are encountered. A schematic drawing of a typical structure profile is given below:



Structure stability.
The structure stability of soils when wetted by rain or irrigation water is important when evaluating soils for irrigated agriculture. Soils that have low stability of structure disperse and slake when they are wetted by rain or irrigation water (Richards, 1954). This phenomenon was observed in the irrigated soils at Bura West and Hola Irrigation Schemes. Figure 45 shows structure collapse of the topsoil caused by slaking after irrigating saline-sodic soils at Bura West. Micromorphological observations (see chapter 3.1.2.) carried out on samples taken from topsoils of Chromi-calcaric CAMBISOLS (mapping unit Pf 2.2.) in Bura West also showed evidence of crust formation due to dispersion and slaking of these soils. The surface crust formed may present a barrier to emerging seedlings and may subsequently result in poor crop stand.

The unstable structure of topsoils, particularly of the SOLONETZ soils which have a sodic horizon near the surface, renders them very susceptible to water erosion which leads to formation of gullies (see figure 47).

In the Bura West area, the Chromi-calcaric CAMBISOLS (mapping units Pf 2.1., Pf 2.2. and pf 2.3.) in dry conditions have a somewhat loose topsoil with very fine crumb or subangular blocky structure (see figure 48). This loose topsoil is very susceptible to wind erosion particularly when the ground cover is cleared and the soils are exposed.

Fig. 45. Structure collapse of the topsoil caused by slaking after irrigating saline-sodic soils in the Bura West area (similar features were observed at Hola Irrigation Scheme).

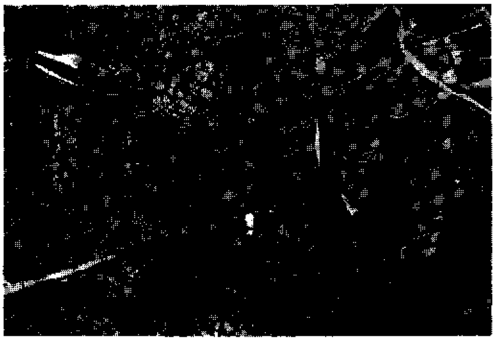


Fig. 46. Polygonal structure formed in furrows as a result of water ponding and secondary salinisation.

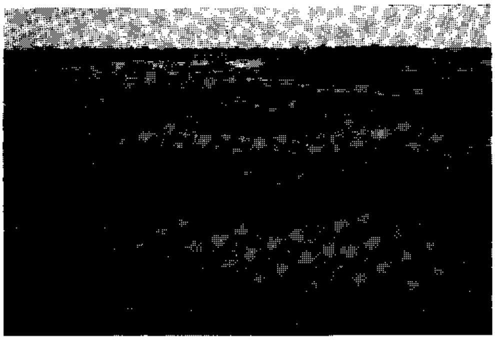


Fig. 47. Accelerated gully erosion of sodic soils due to low structure stability. Soils in the background have no vegetation due to presence of high levels of Na.

In the Bura East area, in order to study water transmitting properties of the soils in relation to structure stability, 15 profile pits covering different soil units were dug to a depth of about 5-6 metres and augered down to 10 metres. Examination of these profiles revealed that the morphological characteristics of most of them had a similar sequence of horizon development. The upper 1.5 to 3 metres of these profiles were observed to be relatively more stable than the underlying layers which in most cases formed the C-horizon. On wetting these lower parts of the profiles, the soil easily dispersed due to presence of high amounts of exchangeable sodium. After the profile pits were opened up and left for a few days, it was observed that these lower layers had started collapsing. Photographs of some of the deep profile pits showing the unstable C-horizons are given in figures 49, 50 and 51.

Although no specific tests on structure stability were carried out on these soils, their instability under wet conditions was also apparent when subsoil samples were shaken with water. Those samples which had a high pH and low electrical conductivity dispersed quickly and remained dispersed. From the above observations, it can be concluded that the structure stability of the deeper subsoil (below 1.5 metres) of the soils of the Bura East area is very low. This implies that difficulties may be expected in construction of irrigation or drainage canals or ditches. The dispersion of the subsoil also results in low hydraulic conductivity (see chapter 3.3.2.5.).

3.3.2.3. Bulk density and porosity.

Bulk density is the dry weight of a unit volume of soil. Porosity is the volume fraction of gas and liquid in soil, in other words the volume fraction not occupied by solid phase. Bulk density and porosity are closely related. Soils with low bulk densities are usually associated with high porosity. High bulk densities may inhibit root penetration and proliferation (Veihmeyer and Hendrickson, 1946; Zimmerman and Kardos, 1961) and may impede drainage. Bulk densities exceeding 1.65 g/cm^3 may result in low infiltration and permeability rates in medium and fine textured soils (FAO, 1979).

Table 20. Average bulk density (in g/cm3) and porosity (in %) of soils in some soil mapping units - Bura East area.

Mapping Units	0 - 15 cm		25 - 50 cm		60 - 85 cm	
	b.d.	porosity	b.d.	porosity	b.d.	porosity
Ps 2.1. to Ps 2.6.	1.16	56	1.32	50	1.31	51
Ps 2.7. to Ps 2.12	1.28	52	1.33	50	1.37	48

b.d. = bulk density

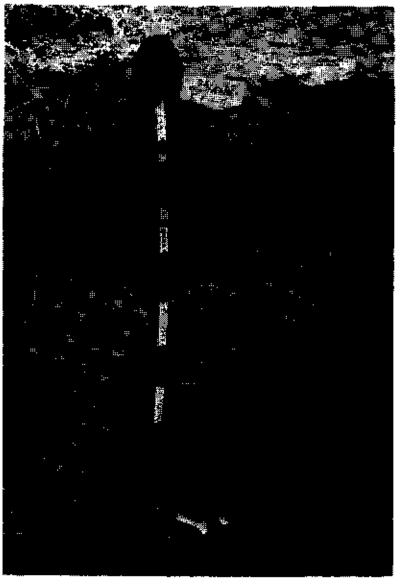


Fig. 48. Loose topsoil with very fine crumb structure over prismatic and blocky subsoil characteristic of Chromi-calcaric CAMBISOLS (mapping unit Pf 2.2.) in the Bura West area.

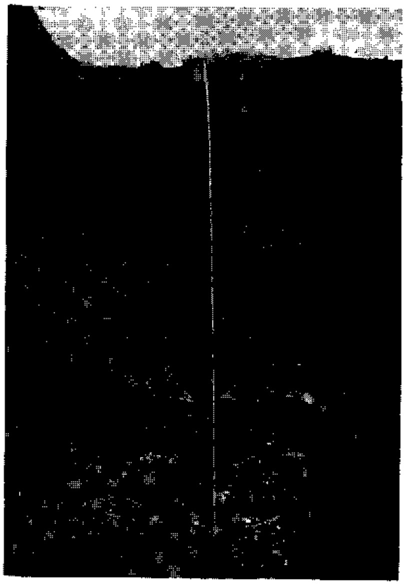


Fig. 49. Deep soil profile showing unstable clayey deeper subsoil of soils of unit Ps 2.4. (Calcari-vertic CAMBISOLS) - Bura East area.

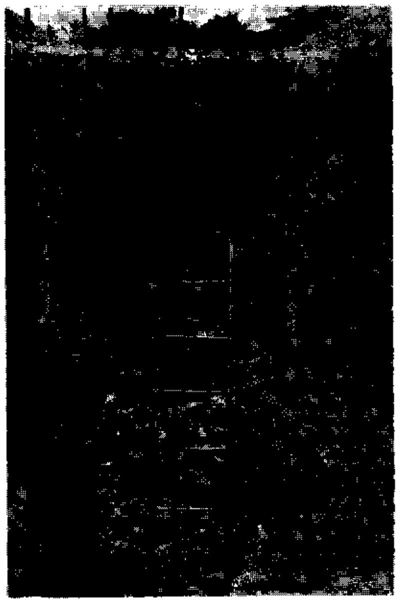


Fig. 50. Unstable clayey deeper subsoil of soils of unit Ps 2.6. (Verti-haplic CALCISOLS) - Bura East area.

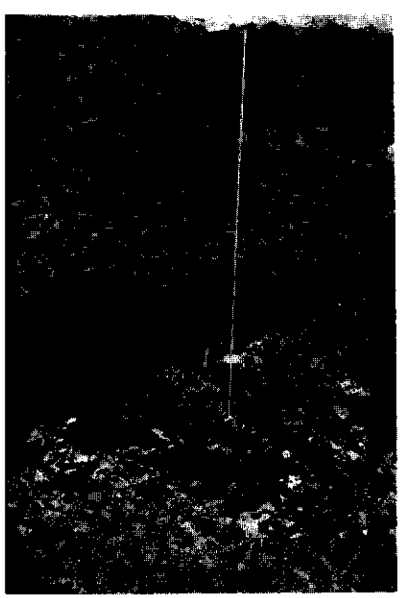


Fig. 51. Unstable clayey deeper subsoil of soils of unit Ps 2.11. (Gleyic LUVISOLS) - Bura East area.

Table 21: Average bulk density (in g/cm3) and porosity (in %) of soils in some soil mapping units - Bura West area.

Mapping Units	0 - 15 cm		25 - 50 cm		60 - 85 cm	
	b.d.	porosity	b.d.	porosity	b.d.	porosity
Pf 1.2.	1.50	43	1.51	43	1.51	43
Pf 2.1.	1.47	45	1.41	47	1.33	50
Pf 2.2.	1.24	53	1.50	44	1.65	38
Pf 2.3.	1.22	54	1.37	48	1.35	49
Pf 2.4.	1.38	48	1.35	49	1.42	47
Pf 2.5.	1.22	54	1.37	48	1.35	49
Pf 3.1.	1.33	50	1.38	48	1.39	48
Pf 3.2.	1.12	58	1.27	52	1.36	49

b.d. = bulk density

Bulk density was measured with cores of volume 100 m^3. The bulk density was usually measured in profiles where infiltration and hydraulic conductivity measurements were carried out. The porosity was calculated from the bulk density and particle density. The particle density was not determined but an assumed average value of 2.65 g/cm^3 which is used in Kenya (Hinga et.al., 1980) was applied. Burke et.al. (1985, page 17) point out that although considerable range may be observed in the density of individual soil minerals the values for most mineral soils vary between narrow limits viz 2.60 and 2.75 g/cm^3. Tables 20, 21 and 22 give the average bulk density and porosity of some soils of the Bura East, the Bura West and the Hola Irrigation Scheme respectively.

Table 22: Average bulk density (in g/cm3) and porosity (in %) of soils in some soil mapping units - Hola Irrigation Scheme.

Mapping Units	0 - 15 cm		25 - 50 cm		60 - 85 cm	
	b.d.	porosity	b.d.	porosity	b.d.	porosity
Pt 1	1.22	54	1.25	53	1.29	51
	(1.30)	(51)	(1.46)	(45)	(1.51)	(43)*
Pt 2	1.13	59	1.30	51	1.20	55
Pt 3	1.19	55	1.20	55	1.30	51
Pt 7	1.33	50	1.51	43	1.26	53
Pt 8	1.07	60	1.41	47	1.26	53
Pt 9	1.29	51	1.50	43	1.46	45

b.d. = bulk density
()* = values for the Calcari-haplic SOLONETZ component of the unit.

The range of bulk density measured is between 1.07 and 1.65 g/cm^3 while that of porosity is between 38 and 60 percent. The lowest values of bulk density are in general obtained in the topsoils except for soil mapping units Pf 1.2., Pf 2.1. and Pf 2.4.

The average bulk density values of the topsoils of mapping units Pf 1.2., Pf 2.1. and Pf 2.4. (see table 21) are somewhat higher than those of the other soils and are comparable to the average bulk densities of the subsoils. Since these soils were cultivated, the high bulk density values may probably be attributed to compaction due to ploughing.

In general, there is a tendency for the bulk density to increase and for the porosity to decrease with depth.

3.3.2.4. Infiltration.

The infiltration rate of a soil has been defined by Richards (1952) as the maximum rate at which a soil, in a given condition at a given time, can absorb rain. It may also be defined as the maximum rate at which a soil will absorb rain water or irrigation water impounded on the surface at a shallow depth when adequate precautions are taken regarding border or fringe effects (Parr and Bertrand, 1960). Quantitatively, infiltration rate is defined as the volume of water passing into the soil per unit area per unit of time. It thus has dimensions of velocity (often expressed as either mm/hour or cm/hour). According to the Soil Science Society of America Subcommittee on Permeability and Infiltration (Richards, 1952) the term infiltration capacity of a soil is the same as infiltration rate.

The infiltration rate is an important soil property in run-off studies and irrigation design. The infiltration rate depends on the physical condition of the soil and the hydraulics of the water in the profile, both of which may change rapidly with time. Parr and Bertrand (1960) have given a comprehensive review of research work on soil properties that affect water infiltration into soils and methods that are used in measuring infiltration rates. Infiltration is affected by various factors among which the most important are:

A. Surface conditions of the soil (surface crusting or surface sealing) and the amount of protection against the impact of rain.
B. Internal characteristics of the soil mass, including number and size of pores, depth and thickness of the permeable layer, degree of swelling of clay and colloids, content of organic matter and degree of aggregation.
C. Soil moisture content and degree of saturation.
D. Duration of rainfall or application of irrigation water.
E. Season of the year and temperature of soil and water.

Different methods are used to determine infiltration rates (cf Parr and Bertrand, 1960; Bertrand, 1965; FAO, 1979; Bouma and Dekker, 1978; Hansen et.al., 1979; Hagan et.al. 1967; among others). Both field and laboratory methods are used. For this study, infiltration tests were carried out in the field. For the Bura East area, which is about 30 kilometres away from the source of water, the single 4 inch (10 cm) cylinder infiltrometer was used. Fifteen or more rings were hammered 10 to 15 cm into the soil at each of the selected sites (26 sites in total) where representative profile pits were made. The rings were filled with 12-15 cm of water and the falling water level in the cylinders was recorded after 4, 8, 16, 30, 90, 120, 180, 240 etc. minutes.The results obtained on the first day were mainly "dry run" infiltration. The next day the cylinders were filled again with water for measuring a "wet run" infiltration.

For the Bura West and Hola Irrigation Scheme, where there was water nearby, infiltration measurements were carried out using the double ring infiltrometer method (see figure 3). Both rings (inner ring diameter 30 cm, outer ring diameter 55 cm) were hammered 10 cm into the soil at the selected sites. They were then filled with water and the falling water level in the inner cylinder was recorded after 15, 30, 60 seconds, 2, 4, 8, 16, 30. 60. 90. 120. 180, 240 etc. minutes until a more or less constant measurement was obtained. Infiltration tests were conducted at 8 sites each in both Bura West and Hola Irrigation Schemes. Most of the measurements were carried out during the dry season.

The results of the infiltration measurements expressed in mm/hour are given in the respective descriptions of the soil mapping units in appendix 2. The results indicate that the infiltration rates vary from soil to soil and within the same soil depending on the prevailing soil properties at the sites where the measurements were conducted. While interpreting the data obtained from measurements using ring infiltrometers one should also note that during placement of the rings into the soil, a certain degree of disturbance of natural structural conditions may take place. The resulting disturbances which may be manifested as shattering or compaction may cause a large variation in infiltration rates between replicated runs. Also the interface between the soil and the side of the metal ring may cause unnatural seepage planes which may result in abnormally high infiltration rates. Taking note of this, it was considered more appropriate to use the median infiltration rates obtained using the single ring infiltrometer method. For each of the sites where the measurements were conducted, the data obtained was ranked in order of magnitude and the average of the central 4 or 5 values was used as an indication of the infiltration rate. In the case of the measurements carried out using the double ring infiltrometer, the values given are those of the average infiltration rates which are more or less equivalent to the basic infiltration rates.

The average infiltration rate of the bulk of the soils of the Bura East area ranges between 10 and 18 mm/hour which, according to the classification suggested by Rickard and Cossens (1965) classify as medium to low. However, the SOLONETZ soils of unit Ps 1.1. had very low infiltration rates in the order of 3 mm/hour. These low infiltration rates can be attributed to the occurrence of a relatively non-porous, saline and sodic layer (hardpan) close to the surface. These soils too had a surface crust. The soils which exhibited vertic characteristics also gave higher infiltration rates (cf mapping units Ps 2.5., Ps 2.9., Ps 2.11.

and Ps 2.15.). The soils with cracks usually gave very high initial infiltration rates which decreased with time as the soil became swollen subsequently closing the cracks. The high infiltration rates was due to water flowing through the cracks. Bouma and Dekker (1978) and Bouma et.al. (1981) have described this phenomenon in terms of "short circuiting" or "bypass flow" and have suggested appropriate methods of determining water infiltration in cracking clay soils (cf. also Bouma and Wösten, 1979).

The infiltration tests carried out at Bura West and Hola Irrigation Schemes gave high initial infiltration rates (in order of 480 to 720 mm/hour within the first few minutes) which decreased gradually with time so that after about 4 to 6 hours the process became almost constant. The basic infiltration rates obtained for the Bura West and Hola Irrigation Scheme soils varied from 7 to 63 mm/hour and 4 to 57 mm/hour respectively. The great variation in the infiltration rates can probably be attributed to the prevailing soil conditions. Soils with loose topsoil overlying a cracking subsoil (e.g. mapping units Pt 9., Pf 3.2. and Pf 2.2.) tended to give high initial infiltration rates. However this decreased as the soils became wet because of the swelling of the clays. During the field measurements it was observed that upon wetting, the soils (particularly those of unit Pf 2.2. of the Bura West area) tended to slake, due to the presence of high exchangeable sodium, and form a surface crust. This surface crust once formed, substantially reduced the water intake. The water intake is also substantially reduced by the dispersed sodic subsoil layer. Acres/ILACO (1967) conducted infiltration tests on soils of unit Pt 1. and Pt 9. at Hola Irrigation Scheme using large infiltrometers (500 sq ft in area) and obtained high initial infiltration rates (some 120 mm/hour within the first 20 minutes) which decreased gradually so that after 6 hours the process almost stopped and only about 55-63 mm had infiltrated. These low infiltration rates were attributed to the presence of high percentage of exchangeable sodium in these soils.

FAO (1979) indicates that optimum infiltration rates for gravity irrigation are between 7 and 35 mm/hour. The bulk of the soils in the study areas have infiltration rates which fall within this range and are therefore considered neither too slow nor too fast for surface irrigation.

From the foregoing discussions, one may conclude that interpretations of infiltration measurements carried out using the conventional cylinder infiltrometer methods are only meaningful if related to the prevailing soil conditions at the time when the measurements were executed. The results obtained can be used to compare intake rates between soil units but may not be used to give absolute values. However because measurements were carried out during the dry season, they are probably overestimates i.e. under wetter conditions they may further decrease.

Recently better and more accurate methods of determining water infiltration have been developed (cf. Bouma and DeKker, 1978; Bouma, 1984; Bouma and Wösten, 1979; among others). However, these methods are more complicated than the conventional methods, and moreover need to be tested under the Kenyan conditions prior to their adaptation.

3.3.2.5. Hydraulic conductivity.

The hydraulic conductivity has been defined by Richards (1952) as the ratio of the flow velocity to the driving force for the viscous flow under saturated conditions of a specified liquid in a porous medium. It may also be defined as the proportionality factor in Darcys law for the flow of water in soil i.e. the factor relating water flux to hydraulic gradient (Bouma et.al., 1982; ILRI, 1980; Commission I (Soil Physics) of the ISSS , 1976). In soil surveys, the term permeability is used for vertical saturated hydraulic conductivity (Bouma et.al., 1982, FAO, 1985). Permeability has been defined by Richards (1952) as the specific property designating the rate or readiness with which a porous medium transmits fluids under standard conditions. Thus measurements of saturated hydraulic conductivity of a soil corrected for the density and viscosity of water and the gravitational constant would be a good measure of permeability. However, in most cases, the term permeability is used, particularly by soil surveyors, in a qualitative sense referring mainly to the state of the soil in relation to the readiness with which it transmits water vertically.

The average hydraulic conductivity of a soil profile is used to determine subsurface drainage and the likelihood of development of a perched water table (FAO, 1979). The hydraulic conductivity of the soil depend mainly on the geometry and distribution of water filled pores (Smedema and Rycroft, 1983; ILRI, 1980). It also depends on the viscosity and density of the soil water which are influenced by temperature and salt concentration. Hydraulic conductivity can be determined either from soil samples in the laboratory or from soil bodies in the fields. Bouma (1983) has reviewed different methods which are used to determine hydraulic conductivity.

In order to get an indication of the water transmitting characteristics of the soils encountered in the study areas, the horizontal hydraulic conductivity of the soils (mainly subsoil) was measured following the inversed augerhole method (ILRI, 1980). Two to five augerholes were drilled per selected site, to varying depths depending on the depth at which a horizon which was considered likely to limit drainability of the soils occurred. The selected sites were located near representative profile pits. The augerholes were filled with water and the drop of the water level with time was recorded. The hydraulic conductivity was calculated using the equation given by ILRI (1980, vol. III page 292). The results for individual soil mapping units are given in appendix 2. Data on the average hydraulic conductivity of the subsoil of soils of some mapping units are given in table 23.

The results of the hydraulic conductivity tests indicate that the hydraulic conductivity varies from soil to soil and also within the soil horizons in the same soil depending on the soil properties such as amount of exchangeable sodium etc. However, in interpreting the results of the hydraulic conductivity, it should be borne in mind that they do not represent absolute values. The measurements have been carried out under dry conditions rather than in saturated conditions. Owing to the arid and semi-arid conditions prevailing in the study areas, coupled with the fact that the groundwater level is very deep, it was not possible to determine the hydraulic conductivity under saturated conditions in the field. However, the data obtained from the tests carried out can be used to evaluate mutually differing permeabilities of the various soils. The data can also be interpreted in conjunction with the observed field soil morphological and chemical properties to give an indication of the internal drainage conditions of the soils.

The average hydraulic conductivity values of the soils of the Bura East area vary from 0.03 to 0.23 m/day in the subsoil. The

Table 23. Average hydraulic conductivity values of subsoils of soils of some mapping units.

Mapping Unit	Hydraulic conductivity (m/day)	Number of observations*	Mapping Unit	Hydraulic conductivity (m/day)	Number of observations*
Bura East area					
Ps 2.1.	0.07	5(1)	Ps 2.9.	0.05	10(2)
Ps 2.3.	0.03	5(1)	Ps 2.10	0.23	10(2)
Ps 2.4.	0.09	12(3)	Ps 2.11	0.15	10(2)
Ps 2.5.	0.11	10(2)	Ps 2.12	0.15	5(1)
Ps 2.6.	0.21	10(2)	Ps 2.15.	0.07	12(3)
Ps 2.7.	0.22	5(1)			
Bura West area					
Pf 2.1.	0.15	2(1)	Pf 3.1.	0.005	2(1)
Pf 2.2.	0.05	8(3)	Pf 3.2.	0.004	6(2)

* The figures shown in paranthesis () represent the number of different sites where the observations were made.

higher values of the hydraulic conductivity were obtained in soils which exhibit vertic characteristics (cf map units Ps 2.5., Ps 2.6., Ps 2.7., Ps 2.10., Ps 2.11. and Ps 2.12.) and are probably caused by cracks in these soils. During the measurements, it was observed that in some cases when the augerholes were filled with water and left overnight to wet, some of the soils caved in due to presence of horizons with high amounts of exchangeable sodium (see photographs in figures 49., 50. and 51.

in chapter 3.3.2.2.). As mentioned previously in chapter 3.3.2.2., although the saturated horizontal and vertical hydraulic conductivity of these deeper subsoils was not determined, it can be inferred from the observed structure collapse that they would be very slow. It was estimated that the true average vertical hydraulic conductivity of the Bura East soils in wet conditions is in the order of 0.05 m/day or even less (Muchena and Van der Pouw, 1981a). It is therefore reckoned that with such slow hydraulic conductivity a proper drainage may be very difficult to achieve.

The hydraulic conductivity values of the soils of the Bura West area vary widely from soil to soil and within the various soil horizons. The non-saline and non-sodic topsoils showed higher hydraulic conductivity values than the saline and sodic subsoils. For instance, the soils of mapping unit Pf 2.1. which are non-saline and non-sodic to depths of about 1 metre, had hydraulic conductivity values varying from about 0.6 to 1.0 m/day in the topsoil and about 0.15 m/day in the subsoil. The soils of mapping unit Pf 2.2. which are saline and sodic almost up to the surface exhibited hydraulic conductivities ranging between 0.02 and 0.07 m/day. The deeper subsoils of VERTISOLS (cf mapping units Pf 3.1. and Pf 3.2.) which are saline and sodic had the lowest values of hydraulic conductivity which is supportive of the poor internal drainage characteristics of these soils.

Although the hydraulic conductivity tests were not carried out in the soils of the Hola Irrigation Scheme during this study, measurements carried out earlier by Acres/ILACO (1967) in an experimental plot in soils of mapping unit Pt 1. showed that the hydraulic conductivity of the topsoil was moderately slow (0.12-0.9 m/day) whereas that of the subsoil was very slow (0.0001 m/day). Field observations made during this study, revealed presence of mottles in the deeper subsoil (85-115 cm) of some profiles made in these soils which is indicative of low permeability of the deeper subsoil. However, presence of sand at depths varying from below 2.5 and 4.0 metres in the soils of the Hola Irrigation Scheme is considered important for subsurface drainage.

3.3.2.6.Water retention and available moisture.

The capacity of a soil to store available water for the use of growing plants is important for judging its suitability for irrigation. The depth of water to apply in each irrigation and the interval between irrigations are both influenced by storage capacity of the soil (Hansen et.al., 1979; FAO, 1979). Soils retain moisture from infiltrated rain or irrigation water against the force of gravity. When gravitational water has been removed, the moisture content of soil is called field capacity (FC). FC can be expressed as a weight or a volume percentage and it is usually considered to be the upper limit of the available water storage capacity. Near the field capacity the water is loosely bound to the soil and plants can extract this water easily.

However, the force with which water is held in the soil increases with a decreasing moisture content and it becomes increasingly difficult for the plant to extract water from the soil. The soil moisture content when plants permanently wilt is called the permanent wilting point (PWP). The tension in the soil moisture when the soil is at permanent wilting is generally considered to be 15 atmospheres (Richards, 1954; FAO/UNESCO 1973; Hansen et.al., 1979; Russel, 1961; ILRI, 1980). PWP is considered as the lower limit of available water storage capacity in the soil.

There are divergent opinions in literature as to the specific moisture tension corresponding to field capacity (FC). Generally, depending on the texture of the soil, at FC soil moisture tension is normally between 0.1 and 0.33 atmospheres or pF 2.0 to 2.5 (FAO/UNESCO, 1973). Hereinafter, FC will be considered to correspond to a moisture tension of 0.1 atmospheres (pF 2.0).

To determine the soil moisture retention characteristics of the soils of the study areas, undisturbed ring samples and disturbed samples were taken at 26 sites (profile pits) in Bura East, 9 sites in Bura West and 8 sites in Hola Irrigation Scheme. The undisturbed samples were used for the determination of the water content of pF 0, 2.0, 2.3 and 2.7 while the disturbed samples were used for the determination of the water content of pF 3.7 and 4.2 (see appendix 1). Determinations were made for two or three horizons of each profile pit sampled, with at least 2 replicates. The average moisture contents at various pF values are given in table 24. Figures 52a to 52c show moisture retention curves of some soils of the Bura East, Bura West and Hola Irrigation Scheme respectively. The moisture retention curves of

Table 24: Average moisture content (in Vol %) at various pF values.

Mapping	pF					
Unit	0	2.0	2.3	2.7	3.7	4.2
Bura East area						
Ps 2.1. to Ps 2.6.	50.5	41.7	40.1	38.0	29.6	25.8
Ps 2.7. to Ps 2.12	48.6	37.8	35.7	33.5	27.6	24.8
Bura West area						
Pf 1.2.	41.8	33.9	nd	19.8	18.1	16.6
Pf 2.1.	35.8	23.4	nd	18.5	10.6	9.4
Pf 2.2.	39.7	30.6	nd	24.2	21.9	19.2
Pf 2.3.	45.7	42.2	nd	nd	30.3	26.8
Pf 2.4.	38.6	30.7	nd	21.5	18.7	16.9
Pf 2.5.	44.2	38.3	nd	34.0	28.3	25.3
Pf 3.1.	44.9	37.8	nd	35.2	30.8	26.2

Mapping	pF					
Unit	0	2.0	2.3	2.7	3.7	4.2
Hola Irrigation Scheme						
Pt 1	50.9	43.7	nd	40.0	29.8	26.8
Pt 2	48.3	43.3	nd	41.1	32.4	27.4
Pt 3	50.4	40.5	nd	35.8	30.2	26.7
Pt 7	54.4	40.2	nd	38.1	26.9	22.9
Pt 8	52.9	47.2	nd	44.6	37.0	32.8

nd = not determined.

the soils of the three areas have more or less similar shapes characterised by slightly curved lines. Such slight curves are typical of clays (cf. ILRI, 1980; Smedema et.al., 1983).

Figure 52 d shows the relationship between moisture content and the clay content at field capacity (pF 2.0) and permanent wilting point (pF 4.2). The regression analysis gave low correlation coefficients (r^2 = 0.512 for pF 2.0 and r^2 = 0.526 for pF 4.2) indicating that for the study areas the differences in water retention are not caused by differences in clay content. From the data no apparent differences between topsoil and subsoil were observed for most of the soils.

From the data in table 24 and the regression lines in figure 52 d an estimate of the available moisture can be made as mentioned before. The quantity of available moisture is defined as the difference between the soil moisture contents at field capacity (FC) and permanent wilting point (PWP). However, as indicated earlier, depending on the texture of the soil, at FC soil moisture tension is between pF 2.0 and pF 2.5. The moisture held at pF 4.2 is also not readily available to plants. For this reason sometimes the upper limit for readily available moisture is taken to be pF 3.7. This explains why various other pF-ranges are used to calculate available water contents (cf. Wielemaker and Boxem, 1982; Van de Weg and Mbuvi, 1975). In view of this the amount of available water have been calculated between pF 2.0 and pF 3.7, and between pF 2.0 and pF 4.2, respectively and the results are presented in table 25.

Table 25: Available water contents (in vol %)

Mapping Unit	pF-range		Mapping Unit	pF-range	
	2.0-3.7	2.0-4.2		2.0-3.7	2.0-4.2
Bura East area					
Ps 2.1. to Ps 2.6.	12.1	16.5	Ps 2.7. to Ps 2.12.	10.2	13.0

Table 25 continued.

Mapping Unit	pF-range		Mapping Unit	pF-range	
	2.0-3.7	2.0-4.2		2.0-3.7	2.0-4.2
Bura West area					
Pf 1.2.	15.8	17.3	Pf 2.4.	12.0	13.8
Pf 2.1.	12.8	14.0	Pf 2.5.	10.0	13.0
Pf 2.2.	8.7	11.4	Pf 3.1	7.0	11.6
Pf 2.3.	11.9	15.4			
Hola Irrigation Scheme					
Pt 1	13.9	16.9	Pt 7	13.3	17.3
Pt 2	10.9	15.9	Pt 8	10.2	14.4
Pt 3	10.3	13.8			

From the data in table 25 and figures 52a to 52d, it appears that the quantity of available moisture (difference between pF 2.0 and pF 4.2) is relatively small. The quantity of available moisture ranges between 11.4 percent and 17.3 percent. Acres/ILACO (1967) reported a similar range of available moisture (8.9 to 16.7 percent) for the soils of the Lower Tana area. They attributed the relatively low amounts of available moisture to the clayey nature of the soils which contain mainly small pores. This may be a probable explanation of the low amounts of available moisture held in soils of the three study areas.

3.3.3. Chemical Properties.

3.3.3.1. Soil reaction (pH).

Soil reaction, which is a measure of the degree of acidity or alkalinity of a soil, is usually expressed as the pH value which is defined as the negative logarithm of the hydrogen-ion activity. pH is measured in a soil/water suspension or extract.

In a non-saline, non-sodic soil pH-H_2O values of more than 7.5 in 1:2.5 soil:water suspension invariably indicate the presence of alkaline-earth carbonates, while values between 7,5 and 6.5 indicate "neutral" soils (almost) without alkaline-earth carbonates and (almost) without exchangeable hydrogen. Soils with a pH-H_2O of 6.5 or lower contain significant amounts of exchangeable hydrogen (acid soils).

In the study areas, soils that are acid or neutral throughout do not occur. However, in some mapping units (cf. units Pf 1.1., Pf 1.2., Pf 1.3., Pf 2.1., Ps 2.1. and parts of unit Ps 2.17.) soils occur that are non-calcareous to variable depths and show acid to neutral pH-values over that depth.

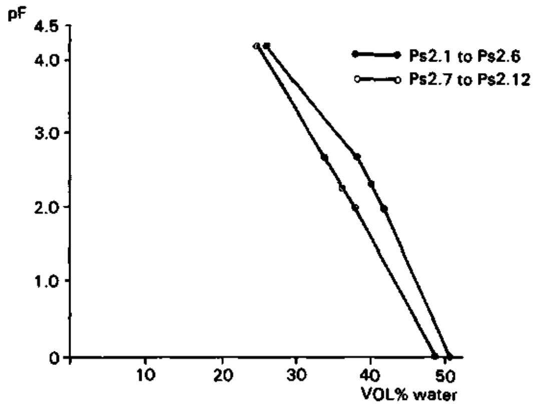
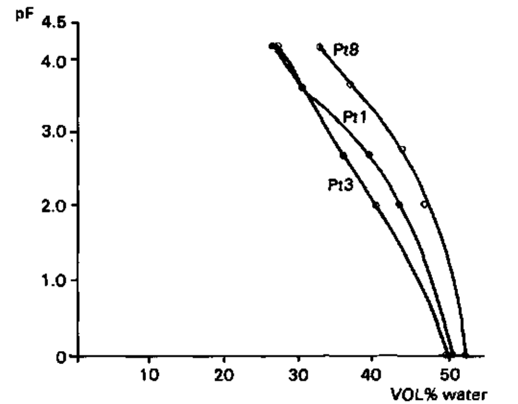


Fig. 52a Moisture retention curves of soils of the Bura East area



52c Moisture retention curves of soils of some mapping units-Hola Irrigation Scheme

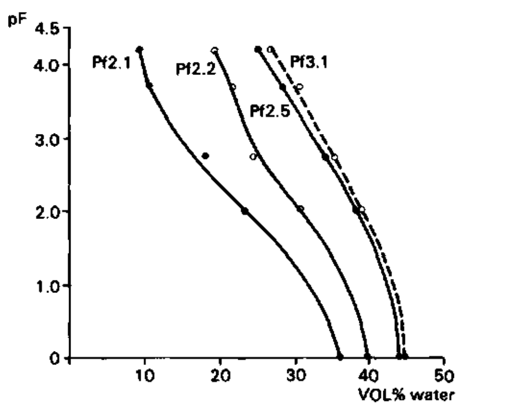


Fig. 52b Moisture retention curves of soils of the Bura West area

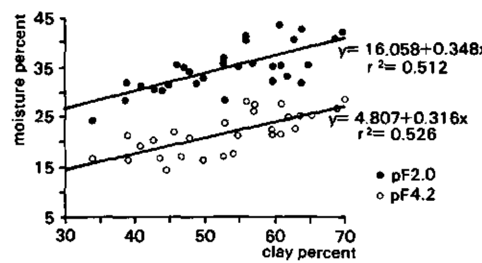


Fig. 52d Relationship between clay content and moisture at pF2.0 and pF4.2

The bulk of the soils have pH-values ranging between 7.5 and 10. A portion of these soils are non-saline and non-sodic to an appreciable depth over which they have pH values varying from 7.5 to 8.5 due to presence of free carbonates. In all the other soils high pH-values of 7.5 or more seem to be the result of the combined effect of free carbonates and high sodicity with or without high salinity.

Figures 53, 54 and 55 give some patterns of pH, sodicity and salinity in some representative profiles in the Bura East, Bura West and Hola areas. The relationships between pH, sodicity and salinity is discussed in the following chapter.

3.3.3.2. Salinity and sodicity.

Salt affected soils contain soluble salts and/or exchangeable sodium in the adsorption complex in such quantities that they interfere with the growth of most crop plants. According to United States Salinity Laboratory (Richards, 1954) the salt affected soils are separated into three groups: saline, saline-sodic and sodic soils.

Saline soils have an electrical conductivity of saturation extract (ECe) greater than 4 millimhos per centimeter at 25°C and an exchangeable sodium percentage (ESP) less than 15. The pH reading of a saturated soil is usually less than 8.5. Saline-sodic soils have ECe values greater than 4 mmhos/cm at 25°C and ESP values greater than 15. Sodic soils have ESP values greater than 15 and ECe values less than 4 mmhos/cm at 25°C.

The main cause of the formation and occurrence of saline-sodic soils is the accumulation of sodium ions (Na^+) in the solid and/or liquid phases of the soil i.e. the presence of dissolved sodium salts in the soil solution and/or exchangeable Na^+ ions in the soil adsorption complex (Richards, 1954; Buringh, 1960; Bresler et.al., 1982 among others). High salt concentration of the soil solution is harmful to plants in several ways; it limits their water and nutrient uptake, metabolism and results in physiological deteriorations. High sodium saturation of the soil causes increased hydration, dispersion and peptization of soil colloids, structural destruction, collapse of soil aggregates and consequently results in unfavourable physical properties such as low available moisture range, low infiltration rate, low saturated and unsaturated hydraulic conductivity etc.

In the study areas, the origin of the salts is attributed to the soil parent material which comprises sediments of lacustrine and marine origin. The degree of salinity and sodicity of the soils encountered is discussed below.

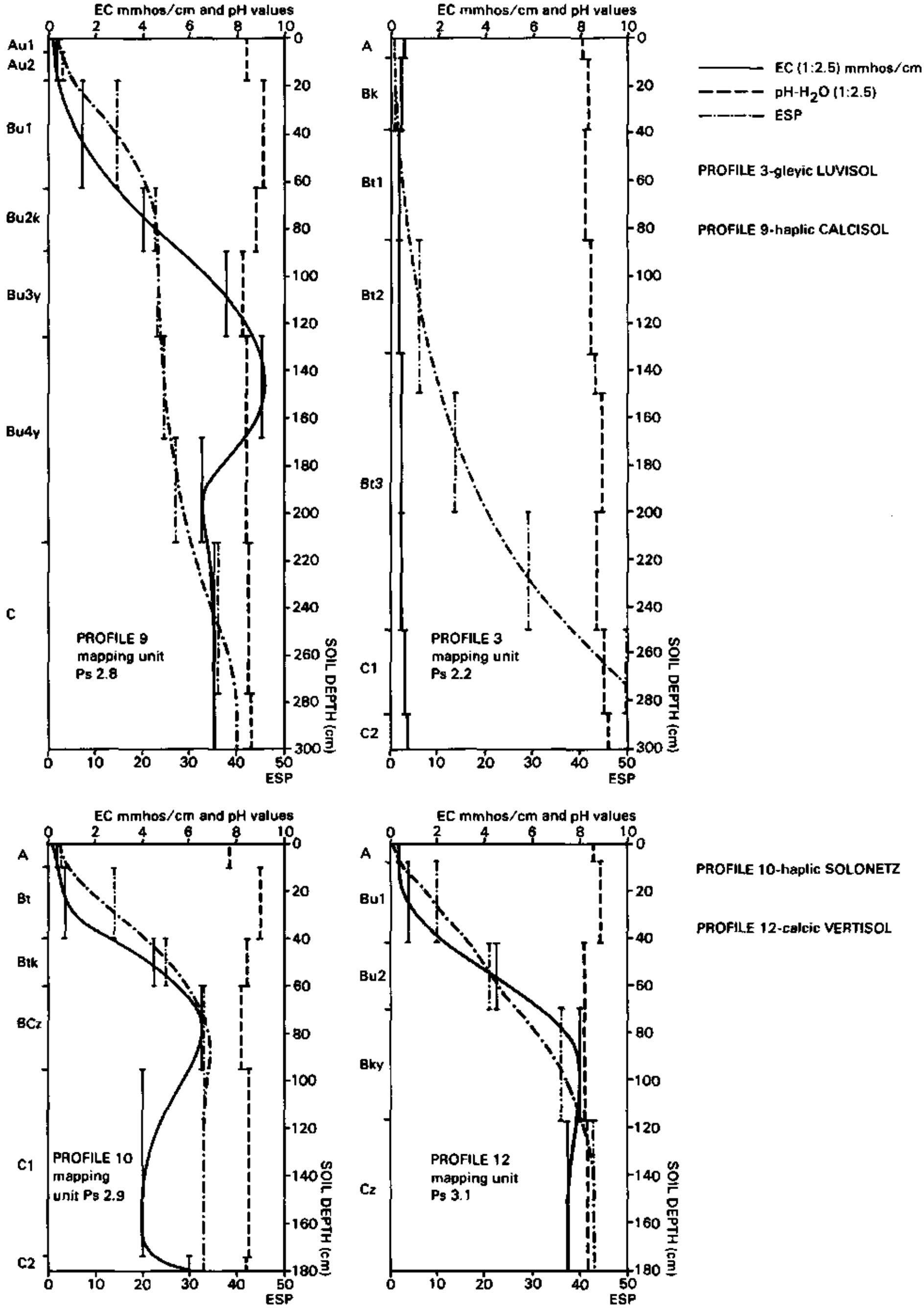


Fig 53 pH, sodicity and salinity patterns of some representative profiles-Bura East area

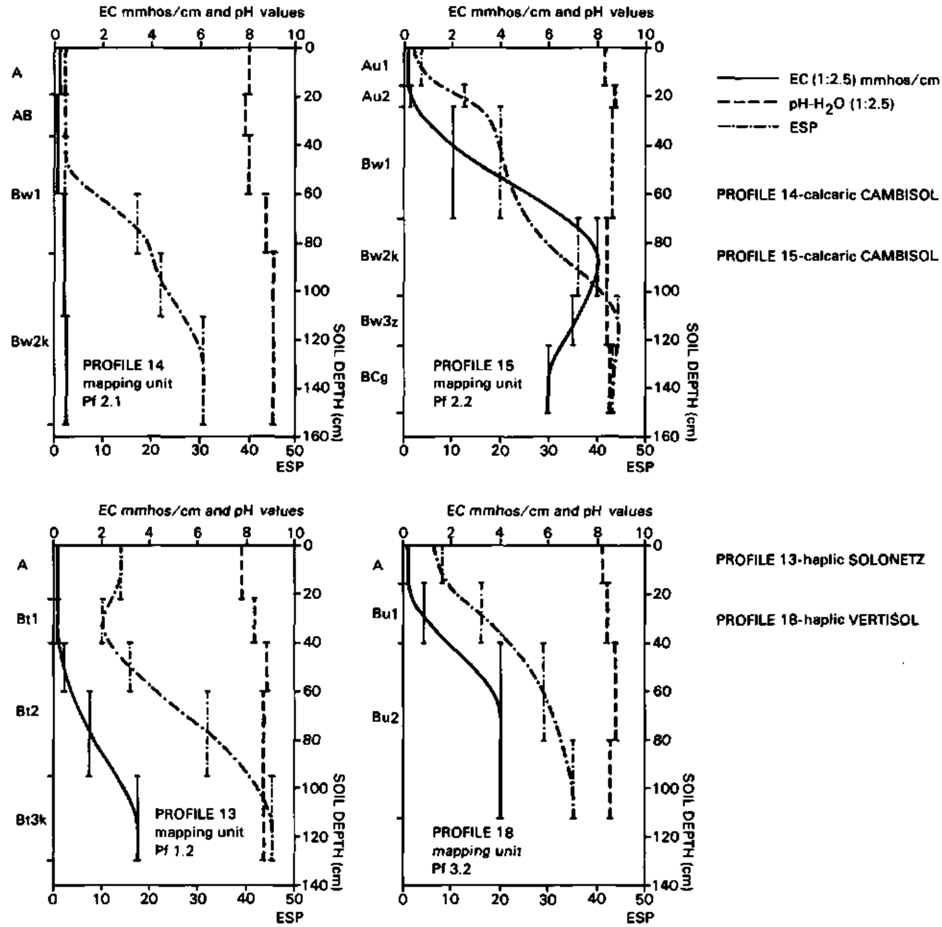


Fig 54 pH, sodicity and salinity patterns of some representative profiles-Bura West area

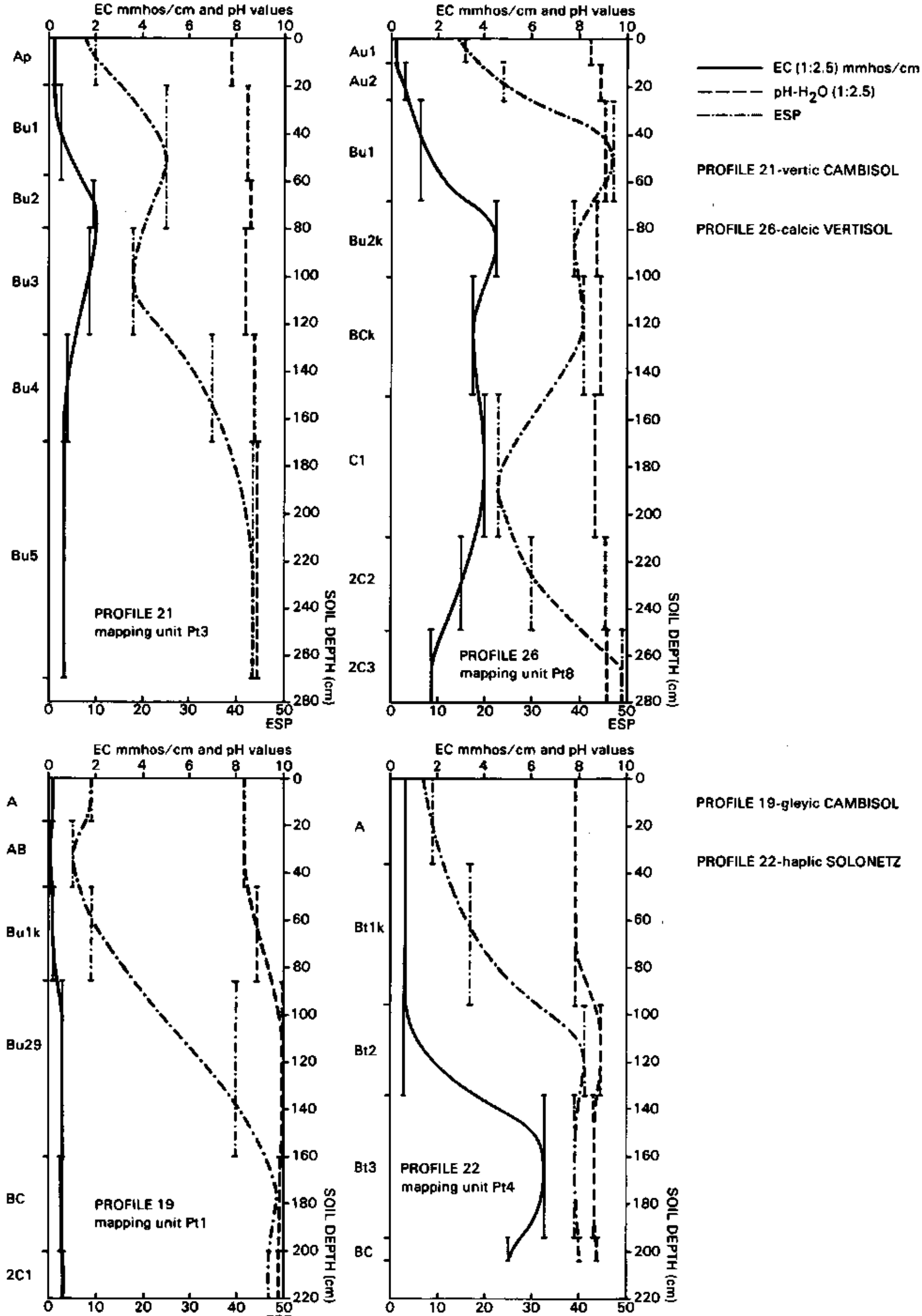


Fig 55 pH, sodicity and salinity patterns of some representative profiles-Hola Irrigation Scheme

Salinity.
Salinity was measured by means of the electrical conductivity of a soil/water ,suspension (EC) or extract (ECe). The following salinity classes were used (cf. Muchena and Van der Pouw, 1981a):

Class	ECe (mmhos/cm)	EC (1:2.5 mmhos/cm)
Non-saline	0 - 4	0 - 0.9
Slightly saline	4 - 8	0.9 - 2.0
Moderately saline	8 - 16	2.0 - 4.0
Strongly saline	> 16	> 4.0

The EC (1:2.5) values corresponding to the above classes of ECe were arrived at after carrying out correlations between measured ECe and EC values for a wide range of soils in the study area (see Muchena and Van der Pouw, 1981a). Details of salinity are given in the individual soil mapping unit descriptions in appendix 2 and in the soil map legends (appendices 5, 6 and 7). Here, only a few remarks of the salinity conditions are made.

In the Bura East area, soils that are non-saline to a depth of at least 100 cm occur in mapping units Ps 2.1. and Ps 2.2. The major part of the area, however, consists of saline soils although to a different degree. The ridges of the slightly high-lying land (mapping units Ps 1.1., Ps 1.2. and Ps 1.3.) are all strongly saline. In the northwestern half of the area, salinity decreases in a direction away from the central ridge of the slightly high-lying land. In the southeastern half of the area, salinity starts at rather shallow depth.

The depth at which salinity starts is related to the extent of soil horizon(s) with high sodicity (ESP greater than 15 and pH-H_2O 9.0-9.5) as follows: When salinity starts at greater depth, an extensive non-saline, sodic zone with high pH-values is observed (see figure 53 profile 3). When salinity starts at shallow depth, only a narrow zone of high sodicity (pH-H_2O greater than 9.0) remains close to the surface (see figure 53 profiles 9, 10 and 12).

In the Bura West area, non-saline conditions prevail in the toplayer in all the soil units at varying depths. Only the soils of units Pf 1.1., Pf 2.1. and A 1. are non-saline to a depth of at least 70 cm. Most of the soils have saline-sodic subsoils apart from soils of mapping unit Pf 2.1. which have a non-saline but sodic deeper subsoil (see figure 54). The salinity tends to increase with depth.

In the Hola Irrigation Scheme, salinity starts near the surface in the bulk of the non-irrigated soils. The irrigated soils are non-saline to greater depths (see figure 55 and appendix 7). The occurrence of salinity at greater depths in the irrigated soils is attributed to leaching of salts. Observations made at the Hola Irrigation Scheme during the period 1967 to 1982 (ILACO, 1976; Anonymous, 1985a) indicated that after prolonged irrigation salinity level had decreased in some of the soils (eg. to a depth of 100 cm in soils of unit Pt 1. and 60 cm in soils of unit Pt 8.). However, the same observations revealed that during some years, particularly 1979, there was a slight increase in salinity and sodicity probably due to underirrigation. The changes in salinity and sodicity during the period 1982-1985 are discussed in chapter 4.

Chemical analytical data of soluble salts concentrations of soils in the Bura East and Bura West areas revealed that the predominant cation in the soil solution is sodium. With increasing sodium concentration the quantity of calcium and magnesium tend to decrease. Soluble potassium occurs in small amounts. Of the anions chloride predominates. Bicarbonate is the second most important anion in the non-saline horizons. At high salinity levels this anion is only a minor constituent of the soil solution. Sulphate ions tend to increase with an increase in salinity and sodicity.

From the composition of the cations and anions, it is apparent that sodium chloride (NaCl) is the dominant salt occurring in these soils.

Sodicity.

Sodicity was determined according to the exchangeable sodium percentage (ESP) on the soils exchange complex. To describe the degree of sodicity of the soils the following key was used (cf. Muchena and Van der Pouw, 1981a):

Class	ESP
Non-sodic	0 - 5 %
Slightly sodic	5 - 10 %
Moderately sodic	10 - 15 %
Strongly sodic	> 15 %

In the Bura East area soils that are non- to slightly sodic to an appreciable depth (about 100 cm) occur mainly in mapping units Ps 2.1. and Ps 2.2. (see appendix 5 and figure 53 profile 3). A close relationship between sodicity, pH and salinity was observed. ESP values of less than 10 were observed to have no or little effect on pH-values. Higher values (ESP > 10) occurring in non-saline soils or soil horizons were found to have a strong effect on the pH-value, which was found to rise to 9.5 and sometimes even higher. Non-saline, moderately to strongly sodic horizons were found above the saline soil horizons. This is clearly demonstrated by higher pH-values (see figure 53 profiles 9, 10 and 12). In most soils, the ESP increases regularly to a certain maximum and remains almost constant in the deeper horizons. The depth over which the maximum ESP values occur, usually coincides with the zone of high salt concentrations (see figure 53 profiles 10 and 12) which has a neutralizing effect on the pH-H_2O.

In the soils of the Bura West area, sodicity starts at varying depths but all the soils have strongly sodic deeper subsoils. As in the case of the Bura East soils sodicity increases regularly with depth and the depth over which the maximum ESP values occur coincides with the zone of maximum salt concentration (see figure 54 profiles 13, 14, 15 and 18).

The pattern of sodicity in the non-irrigated soils of the Hola Irrigation Scheme follow a similar trend as those of the Bura East and Bura West areas. The ESP values increase regularly with depth (see figure 55 profile 22). However, in some of the irrigated soils a different pattern was observed (see figure 55 profiles 21 and 26). The irregular pattern can be attributed to the effect of leaching of salts upon irrigation. The leaching of salts in the surface horizons seems to result in a corresponding increase of pH and ESP values. Subsequent accumulation of salts in the subsoil leads to a decrease in pH and ESP values. Alperovitch and Dan (1972) carrying out studies of sodium affected soils in the Jordan Valley attributed similar patterns of sodicity and salinity as observed at Hola, Bura East and Bura West to varying degrees of leaching intensity under past climatic conditions.

3.3.3.3. Ion exchange characteristics.

Soil ion exchange characteristics that are important in evaluating suitability for irrigation include the cation exchange capacity (CEC) and the nature and balance of exchangeable cations, particularly the exchangeable sodium percentage (ESP).

The CEC and the base saturation of a soil are important because of their influence on chemical and physical soil properties. Soils with a high CEC and high base saturation are potentially fertile soils as they may provide adequate supply of plant nutrients. However, a high CEC is also associated with the occurrence of 2:1 clay minerals such as montmorillonite, illite etc. which shrink and swell upon changing moisture conditions, thereby creating unfavourable physical conditions for plant growth. If such soils are in addition saline and sodic, even more unfavourable conditions are created (FAO, 1979; Szabolcs et.al., 1976). The latter case applies to the majority of the soils in the study areas.

The range of the CEC-soil and the CEC-clay of the various soil mapping units is given in tables 12 to 19 (see chapter 3.2.). The CEC-soil shows a variation which is largely due to differences in clay content. It varies from about 5 to 20 me/100 g in loamy sand to sandy clay loam topsoils to about 50 to 60 me/100 g in very clayey subsoils. The CEC-clay does not show significant differences between the various soil types i.e. SOLONETZ, VERTISOLS, CAMBISOLS, CALCISOLS and LUVISOLS. However, the soils of the Bura East area tend to have slightly higher CEC-clay values than those of the Bura West and Hola irrigation Scheme. This difference may be attributed to differences in clay mineralogy (see chapter

3.3.4.). The CEC-clay of the Bura East soils vary from about 50 to 120 me/100 g while those of the Bura West and the Hola Irrigation Scheme range between 30 and 80 me/100 g.

The degree to which the major exchangeable bases i.e. Ca, Mg, K and Na saturate the exchange complex of the soil is called base saturation. The base saturation of the bulk of the soils in the study areas is 100 percent due to the presence of free carbonates and/or salts. Most of the soils have, at varying depths, an excess of salts (predominantly NaCl) and therefore the exchange complex is proportionally saturated with Na. From the data on exchangeable bases, given for representative profile pits in the annex to this report it can be seen that in the study areas the exchange complex is dominated by Ca, Mg and Na. The exact proportions to which they dominate the exchange complex vary widely. The variations depend on the salt content, type of salt, the degree of calcareousness, presence of gypsum, the type of clay minerals etc. Potassium (K) is always present in relatively small amounts (usually between 0.5 and 4.5 me/100 g).

The soils tend to have high amounts of exchangeable Ca and exchangeable sodium percentage (ESP). This, to some extent can be attributed to incomplete leaching, of soluble salts from the soil samples before determination of the exchangeable bases. Richards (1954) pointed out that analysis of exchangeable cations of saline and sodic soils is subject to difficulties because of presence of alkaline-earth carbonates and relatively high concentration of soluble salts. In particular, occurrence of calcium and magnesium carbonates prevents accurate determination of exchangeable calcium and magnesium. Yaalon (1957) has also pointed out problems associated with soil testing on calcareous soils.

The historical criterion for distinguishing between sodic and non-sodic soil conditions has been an exchangeable sodium percentage (ESP) equal to 15% or more of the CEC. However, because of the numerous potential errors that may crop up in traditional CEC and ESP determinations, the terminology committee of the Soil Science Society of America has recommended that the Sodium Adsorption Ratio (SAR) of the saturation extract should be used for sodic soil characterisations. The sodium-adsorption ratio (SAR) is defined as $Na^{+}/\sqrt{(Ca^{++} + Mg^{++})/2}$ where Na^{+}, Ca^{++} and Mg^{++} refer to the concentration of the designated soluble cations in milliequivalents per litre (Richards, 1954). Although ESP and SAR are not exactly equal numerically, a SAR value of 15 has been maintained for convenience as the dividing line between sodic and non-sodic conditions. In clayey soils SAR values in the general range 10 to 20 should be considered potentially hazardous, and should be examined more closely in the context of anticipated management conditions. Higher SAR and ESP values can be tolerated for soils of low clay content or for soils having low content of swelling clay (smectite) minerals. Lower SAR values can be tolerated for soils with high clay content, particularly if they contain moderate to large amounts of smectite minerals (Bresler et.al., 1982 page 76-77). Chemical analytical data of the soils in the three study areas indicate that most of the soils with high ESP values (greater than 15) have also high SAR values (more than 15) and would still be characterised as sodic according to the above proposed criterion.

The subsoils of the various soil units, particularly in the Bura East and Bura West areas, show both a high ESP, exchangeable magnesium percentage (EMP) and salt content which is a reflection of the marine origin of the sediments from which the soils have been developed. The low ESP and EMP values of the present non-saline, non-sodic upper soil horizons is attributed to soil profile development through leaching. It is generally assumed that the exchangeable sodium is responsible for a decrease in plant growth. However, the exchangeable magnesium also can be responsible especially in coastal sediment situations; Mg would then act as a monovalent cation (Buringh, 1960). In view of the presence of much exchangeable magnesium in these soils, it would be useful to study the influence of exchangeable magnesium in plant growth and soil conditions within the study area. This could, however, not be done in the framework of the present study.

3.3.3.4. Available nutrients.

To get an indication of the chemical fertility of the soils in the study areas, composite soil samples of the 0-30 cm topsoil were taken at the sites where representative profile pits were made. These soil samples were subjected to a "mass analysis" according to the method developed, by Mehlich et.al. (1962) which is used in Kenya for soil fertility evaluation. This analysis was also carried out on topsoil samples (0-30 cm) taken from the sites where soils were collected for soil conditions monitoring at Bura West and Hola Irrigation Schemes. The results of the available nutrients for the representative profiles are given in the annex to this report while the range of these nutrients is given in Table 26.

Table 26: Range of "mass analysis" results.

Area	Available nutrients (Mehlich et.al., 1962)				P-Olsen	C %
	Ca(me/100g)	Mg(me/100g)	K(me/100g)	P(ppm)	(ppm)	
Bura East	10-35	6-10	0.2-1.8	10-25	nd	0.2-0.9
Bura West	10-40	6- 8	0.3-0.9	3-35	2-15	0.1-0.9
Hola	15-40	6-10	0.3-0.7	10-50	2-10	0.4-1.6

nd = not determined

Since these chemical data were not calibrated against crop performance under field conditions, they are discussed here in a general way in as far as they may influence the nutritional status of the crop and affect crop production.

In general, the soils as a whole are well supplied with elements known to be of nutritional value to the crop. Available calcium (Ca) and magnesium (Mg) values are considered to be high or very high. The potassium (K) levels are also considered to be adequate. The phosphorus (P) values range from low to adequate. It should be noted that the P-Mehlich values are consistently higher than P-Olsen values. Under the prevailing alkaline soil conditions P-Olsen is considered to give a better estimation of the available P than that obtained by the Mehlich method which was developed mainly for acid soils. The organic matter content and the nitrogen (N) content of the soils is low. The low values of N and P indicate the need for addition of fertilizers for optimum crop production on these soils under irrigation. However, trials at Hola have shown that cotton responds positively to nitrogen but not to phosphate or potash (Scholte Albers, 1982; Anonymous, 1985b). It is also reported (Anonymous, 1985a and b) that fertilizer trials on groundnuts at Hola showed no response to nitrogen, phosphate and potash. No explanation has been given as to why there is no response to the added nutrients. A logical explanation may be sought from the prevailing chemical properties of these soils.

Given the widespread occurrence of free carbonates and salts in these soils, the inter-relationship between the various cations is important. Nutrient induced deficiencies through ion antagonisms are possible. For example, the high values of Ca and Mg in the exchange complex may render potassium to be unavailable to plants. High pH-values may depress the availability of micronutrients and may also inhibit uptake of phosphates. Acres/ILACO (1967) attributed the iron deficiency symptoms observed with groundnuts on the experimental plots at Hola Irrigation Scheme, to the high pH-values of the soils. Apart from the adverse physical effects of soils due to high salt concentration, the high levels of natrium and chloride ions contained in some of the soils may cause toxicity to the crop and at the same time result in nutritional imbalance. The presence of dissolved sodium salts in the soil solution and/or exchangeable Na^+ ions in the soil absorption complex are said to be directly or indirectly responsible for the low fertility of salt affected soils (Szabolcs, et.al., 1976).

In view of the complex chemical properties of the soils, the nature and extent of fertility problems and ways to overcome them should be investigated in detail for increased crop production in the study areas.

3.3.4. Mineralogical characteristics[5].

3.3.4.1. Mineralogy of the clay fraction.

The kind of clay minerals present in a soil determines many of its physical and chemical characteristics such as cation exchange capacity, nutrient status etc. A general understanding of the nature of the clay is essential for irrigation suitability evaluations. It provides some important clues which can be used to predict the behaviour of soils after irrigation has been introduced. Clay mineralogy is also applied in soil classification at the family level according to the USDA Soil Taxonomy (Soil Survey Staff, 1975).

Clay mineralogical investigations were carried out on clay fractions of soil samples derived from various horizons of representative profile pits. X-ray diffraction techniques were applied in the clay mineralogy analysis (cf. Hinga et.al., 1980 and appendix 1). Solvation[6] and heat[7] treatments were carried out for clay mineralogical identification. Examples of X-ray diffractograms obtained from three soil types:
a Chromi-calcic VERTISOL,
a Chromi-calcaric CAMBISOL and
a Calcari-gleyic SOLONETZ;
are shown in figures 56a to 56c respectively.

Montmorillonite was found to be the dominant clay mineral in the SOLONETZ of the Bura East area (cf. mapping units Ps 1.1., Ps 1.2, Ps 1.3., Ps 2.9., Ps 2.10. and Ps 2.12. to Ps 2.15.). The VERTISOLS of the same area (mapping unit Ps 3.1.) contain predominantly poorly crystallized montmorillonite, with some traces of illite. The Gleyic LUVISOLS (mapping unit Ps 2.1.) and the Chromic LUVISOLS (first component of mapping unit Ps 2.17.) contained illite as the dominant mineral. The bulk of the other

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[5]There was no specific study carried out on the mineralogical composition of the sand and silt fractions. However during the micromorphological studies (see chapter 3.1.2.) it was noted that the composition of the skeleton grains in soils of the Bura West and the Hola Irrigation Scheme was dominated by quartz. Feldspars and ferromagnesian minerals (mainly hornblende) were also present. Acres/ILACO (1967) also reported presence of quartz and feldspars in the silt and sand fractions in soils of the Lower Tana area which includes the Bura West and the Hola Irrigation Scheme.

[6]Mg saturation and ethylene glycol solvation at room temperature.

[7]Heating of K-saturated sample to 550°C.

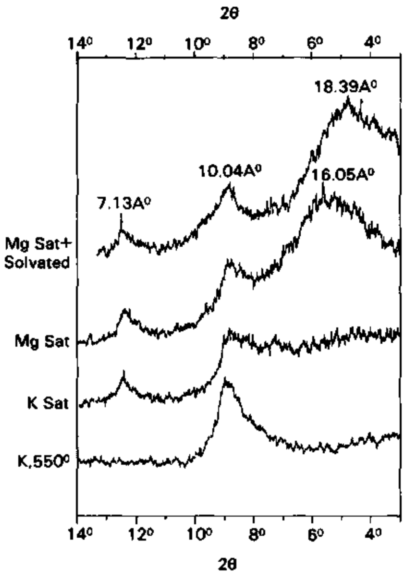

Fig. 56a X-ray diffractograms of the clay fraction (<2μ) from a Chromi-calcic VERTISOL from the Hola Irrigation Scheme

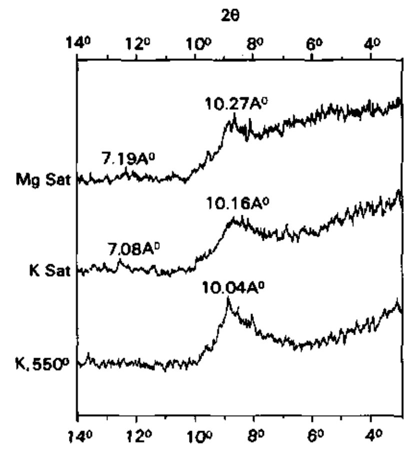

Fig. 56b X-ray diffractograms of the clay fraction (<2μ) from a Chromi-calcaric CAMBISOL from the Bura West area

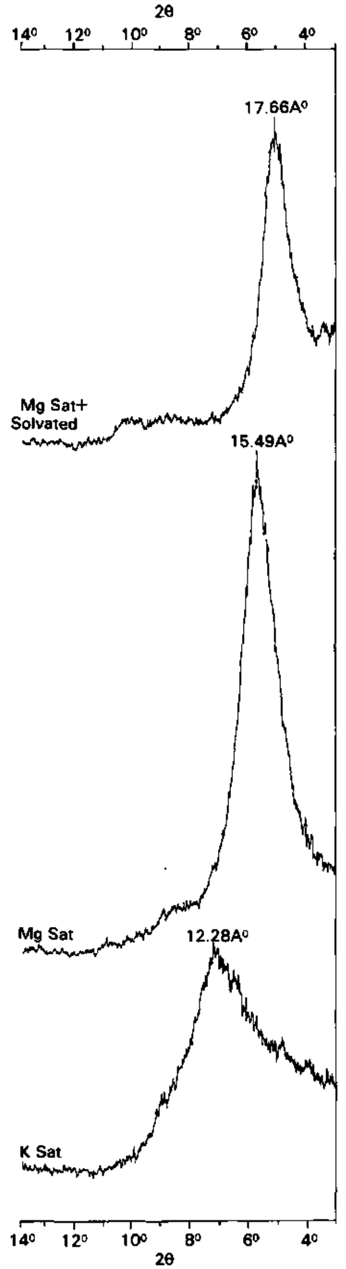

Fig 56c X-ray diffractograms of the clay fraction (<2μ) from a Calcari-gleyic SOLONETZ from the Bura East area

soils (cf. mapping units Ps 2.2. to Ps 2.8.) had topsoils with traces of poorly crystallized illite and subsoils containing mixed-layer or interstratified clay minerals mainly belonging to the illite-montmorillonite type. Upon solvation with ethylene glycol this intergrade grades towards illite.

In all the soil samples examined from the Bura West area, trace amounts of kaolinite was found in addition to illite or an illite-montmorillonite intergrade. The upper layers of soils of unit Pf 2.1 (Chromi-calcaric CAMBISOLS) contained illite as the dominant clay mineral with traces of kaolinite. However, the deeper subsoil contained an illite-montmorillonite intergrade with traces of kaolinite. The SOLONETZ (mapping unit Pf 1.2.) were found to contain kaolinite and illite in the upper layers and traces of kaolinite and an illite-montmorillonite intergrade in the deeper subsoil. The VERTISOLS in this area had mainly a poorly crystallized illite-montmorillonite interstratified clay mineral which grades towards montmorillonite. The clay fraction of soils of mapping unit Pf 2.2. was found to be composed of almost equal proportions of illite and montmorillonite with traces of kaolinite.

All the investigated soils of the Hola Irrigation Scheme were found to contain an illite-montmorillonite interstratified clay mineral which grades towards montmorillonite. All the soils also contained traces of kaolinite. The soils of unit Pt 7. had montmorillonite as the dominant clay mineral.

Two main observations are worth noting with regard to the mineralogy of the clay fraction in the soils of the three study areas. The first is the absence of kaolinite in virtually all the soils of the Bura East area whereas it is found in all the soils of the Bura West and the Hola Irrigation Schemes. The presence of kaolinite in the Bura West and Hola Irrigation Scheme soils is indicative of either better drainage conditions which provided a better environment for more advanced weathering and/or a different source of the sediments on which the soils are developed. Makin et.al. (1969) and Acres/ILACO (1967) reported high quartz to feldspar ratios in the sand fraction of similar soils in the Lower Tana area which they attributed to a more advanced degree of weathering. This is in agreement with the observation of Sombroek et.al. (1982) that soils in the west bank of Tana river, where Bura West and Hola Irrigation Schemes are situated, are developed on partly pre-weathered sediments derived from the adjacent Kitui hinterland. These pre-weathered sediments were deposited under fluviatile conditions and probably created a more favourable environment for weathering leading to formation of kaolinite. On the other hand, the soils on the east bank of Tana river, where Bura East is situated, are developed on marine/lacustrine sediments and have poorer drainage conditions which have probably enhanced the formation of 2:1 type of clay minerals and probably inhibited advanced weathering of soils to kaolinite.

The second interesting observation is the occurrence of an illite-montmorillonite intergrade at least in the deeper subsoils of all the soils in the three study areas. This interstratified 2:1 type of clay mineral exhibits unusual feature of the labile nature of the c-axis spacing of its X-ray diffraction patterns (see an example in figure 56a). Upon Mg-saturation a c-axis spacing was observed which is too large by several A° units for montmorillonite. The observed c-axis spacing ranged between 15.5 and 16.7 A° while the normal one for montmorillonite is expected to be in the region between 12 and 15 A° (Thorez, 1975). Furthermore, upon solvation and upon K-saturation, the expansion and collapse exceeded that of the true montmorillonite. However, in some of the soils this 2:1 type of mineral graded towards montmorillonite whereas in others it graded towards illite. A similar type of 2:1 clay mineral was reported by Acres/ILACO (1967) and Makin et.al. (1969). The occurrence of 2:1 lattice clay minerals in the above deeper subsoils, which in most cases are also saline and sodic, may be associated with the slow hydraulic conductivity of these soils (see chapter 3.3.5.). Because of their swelling nature and sticky consistence, the presence of 2:1 clay minerals may also result in difficulties of tillage and drainage (Dudal, 1965).

The mineral palygorskite, which is commonly associated with soils developed in arid environments, was not found in all the soil samples investigated. This somehow indicates that these soils were probably developed in a more humid climate in the past other than the present day semi-arid to arid conditions. This is in support of the earlier views expressed in chapter 3.1.1.

3.3.4.2. Calcium carbonate content.

The presence of calcium carbonate ($CaCO_3$) may affect both physical and chemical characteristics of a soil. Horizons of massive and hardened carbonate accumulation (petrocalcic horizons) may not restrict water movement severely but may prevent root penetration (FAO, 1979). Discrete particles of carbonate also affect moisture characteristics and tend to create a less fertile environment for plant roots. Carbonate concretions or nodules are less active than similar concentrations in diffused form. High contents of $CaCO_3$ may result in lime-induced chlorosis of crops grown in such soils (Yaalon, 1957). The presence of free carbonates may also reduce the ability of soils to retain moisture especially at high tensions and subsequently result in a need for more frequent irrigation at relatively low moisture tension (Massoud, 1973). Calcium carbonate can have a beneficial effect on physical soil properties by assisting formation of stable aggregates, particularly during the process of leaching of saline and sodic soils. However, surface crusting can be a serious problem probably as a result of low organic matter content in newly irrigated calcareous soils (Massoud, 1973).

Calcium carbonate occurs in the soils of the three study areas in form of concretions, nodules, soft powdery lime or as discrete particles in the clay fraction. Horizons of massive and hardened carbonate accumulation are encountered in soils of unit Pf 2.1. in the Bura West area. Most of the soils react strongly with dilute hydrochloric acid giving an impression that they are moderately to strongly calcareous. However, chemical analytical data reveal that the soils in general have low percentage of $CaCO_3$. The $CaCO_3$ content ranges between 0.1 and 10 percent and tends to increase with depth. Some of the topsoils do not have any $CACO_3$ which is indicative of some degree of decalcification.

3.3.4.3. Gypsum content.

The presence of gypsum may have a long term beneficial effect on physical soil properties. Gypsum, due to its relatively higher solubility than calcium carbonate, is a source of calcium which may, on the long run, after leaching of salts replace sodium on the exchange complex and thereby reduce soil dispersion subsequently preserving soil structure. However, high percentages of gypsum in soil, can cause serious problems in irrigated soils. Van Alphen and Romero (1971) studying characteristics and behaviour of gypsiferous soils concluded that up to 2 percent gypsum in the soil favours crop growth; that between 2 and 25 percent gypsum has little or no adverse effect if in powdery form but more than about 25 percent gypsum can cause substantial reductions in crop yield.

Within the study areas, gypsum is found in the deeper subsoils in form of fine crystals. Most of the soils have very low gypsum contents in the upper parts of the solum. Chemical analytical data (see annex to this report) showed only traces of gypsum. In the bulk of the soils the amount of gypsum measured was in the region between 0.1 and 0.2 percent. Higher values of gypsum, up to 1.7 percent were measured in the deeper subsoil of only a few profiles.

4. SOIL CONDITIONS MONITORING AND FIELD OBSERVATIONS.

4.1. FIELD OBSERVATIONS.

4.1.1. Crop performance in irrigated soils.

Observations on crop performance in irrigated soils at the Bura West and Hola Irrigation Schemes were made during the course of field work during the period 1983 to 1986. The observations made within the two areas are discussed separately below.

A. Bura West Irrigation Scheme.
Cotton crop was observed to be growing satisfactorily over most of the irrigated area. However, some of the irrigation units had a patchy crop with some of the areas showing acute moisture stress and very little growth. In these areas plants along the ridges upstream and down stream of the dry patches were normal indicating that irrigation water had passed down the furrows but had failed to wet the soil. When augered, this soil was completely dry and loose. These observations were made in irrigated areas of mapping units Pf 2.3., Pf 3.2. and parts of unit Pf 2.2. It was also observed, particularly on soils of units Pf 2.2. and Pf 2.3., that on irrigation the soils slaked and formed a surface crust (cf. photograph in figure 45.). This surface crusting was observed to affect seedling emergence. As indicated by micromorphological observations (see chapter 3.1.2.) these soils have a tendancy of forming crusts which may render infiltration of irrigation water to be slow. These adverse physical conditions are brought about by the high amounts exchangeable sodium (sodicity) and presence of salts in these soils.

Before cultivation (including land levelling and planing) these soils had non-saline and non-sodic topsoils ranging in depth between 10 and 40 cm, with the bulk of them having shallower (less than 20 cm) non-saline and non-sodic topsoils. It is believed that during land levelling and subsequent cultivations (including ridging) some of the saline and sodic subsoil was exposed and brought up to form part of the furrows and ridges. Such a presence of the saline and sodic soil on the ridges will be responsible for the non-wetting of the ridges and also for the variations in crop growth observed in these areas. Crop growth, particularly maize which is very sensitive to salinity and sodicity, was very poor. Farmers constructed extra bunds around these patches of poor maize to pond water but they were not very successful in wetting these soils. In places, salt efflorescence was observed on the ridges and polygonal cracks in the furrows due to salinity and water ponding (cf. figure 57 and figure 46 in chapter 3.3.2.2.).

The other factors which were observed as influencing crop performance, particularly with regard to availability of water, are the low infiltration rates and slow hydraulic conductivity of

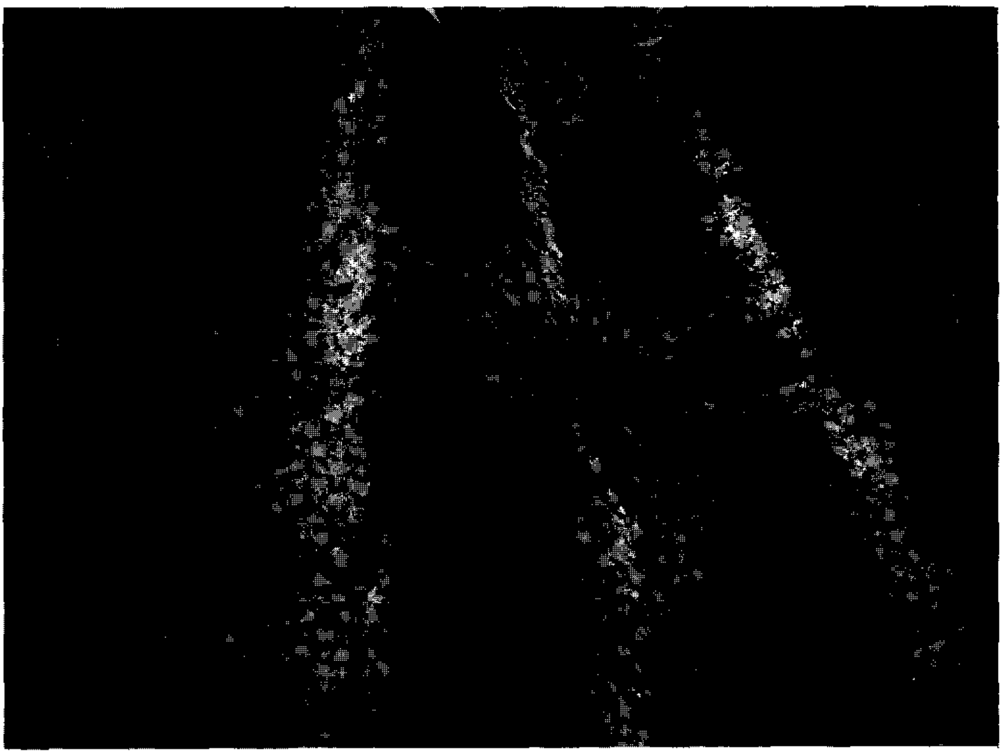

Fig. 57. Salt efflorescence in parts of the irrigated soils - Bura West area.

some of the irrigated soils. The low infiltration rates coupled with somewhat steep furrow slopes (greater than 100 cm per kilometre (Anonymous, 1984b) results in the water moving too rapidly down the furrows. This rapid water movement renders the top of the furrows to be under-irrigated while water ponds and waterlogs the bottom of the furrows.

In places, where the sodic subsoil was exposed (e.g. in drains or unirrigated areas) the soils were strongly eroded by water (see figure 47). In the cultivated areas, it was observed that the exposed loose soil, particularly after ploughing during the dry weather conditions, was very susceptible to wind erosion.

In general, the crop yields in the scheme were very much influenced by moisture management and cultural practices. Under experimental conditions at Bura Research Station yields of maize to the tune of 4.4.tons/ha have been obtained (Anonymous, 1985b) compared with the average yields in the order of 2.0 tons/ha obtained in the farmers fields. These latter maize yields are considered to be very low taking into account the high production and management input levels involved. However, it is anticipated that, despite the prevailing unfavourable soil conditions, under improved water management, use of better suited maize varieties and adoption of better cultural practices, the yield levels could be improved.

B. Hola Irrigation Scheme.
As in the case for the Bura West Irrigation Scheme, cotton was observed to be growing satisfactorily in most of the irrigated area. However, differences in crop performance and yields were observed in the various irrigation units. These differences were attributed to differences in levels of water management and cultural practices by the various farmers. It was also observed that most of the irrigation units were not properly levelled and the fields had uneven slopes. This, coupled with the low infiltration rates of the soils in the scheme, resulted in water ponding in various sections within an irrigation unit. This waterlogging affected crop growth, particularly maize.

It was also observed that the surface soils of most of the soils tended to puddle and form a crust when disturbed by running water in furrows. The formation of the surface crust may affect seedling emergence. In some irrigation units accumulations of salt crystals on the surface were observed (Area I). Stunted plant growth was observed in irrigation units located in mapping units Pt 3., Pt 4., Pt 5. and Pt 8.

4.1.2. Root observations.

Agricultural crops usually need a well developed root system in order to exploit moisture and nutrients stored in different layers of soil at different depths. Root development,however,is to a great extent dependent on the prevailing soil conditions. For example, compacted soil layers and soil layers with high salinity and sodicity may impede root growth. Therefore information on root development can give useful hints on methods of fertilizer application and irrigation techniques.

In this study root observations were carried out to collate the depth of root development with the observed soil characteristics. The information obtained was then used to assess the effective rooting depth of the soils encountered for land evaluation purposes.

Root observations were carried out using the excavation method (cf. Schuurman and Goedewaagen, 1971; Böhm, 1979). Profile pits were dug next to the cotton plants as shown in figure 4 (see chapter 1.4.). Roots were counted in a zone 40 cm wide and at depth intervals of 10 cm. The roots were grouped into four classes according to the diameter viz more than 5 mm, 2-5 mm, 1-2 mm and less than 1 mm (FAO, 1977). The quantity of each class of roots per zone was recorded. Notes on the occurrence of secondary roots and taproots were also taken. The relative rooting intensity was estimated by calculating the surface area occupied by the roots and expressing this as a percentage of the surface area over which the roots were counted. The results are presented in figure 58.

The results of root observations indicate that the cotton plant roots tend to be mainly concentrated on the top 30 cm of the soil. This depth in most cases coincided with the bottom of the ridges on which the cotton was planted. Below this depth only a few roots were observed (see figure 60a, 60b and 60c). It was noted that most of the secondary roots occurred within depths ranging between 20 and 50 cm. In some of the soils (particularly the SOLONETZ) the taproot was also confined to this depth range. However, observations on the variations of rooting depth of cotton plants grown in a Chromi-calcaric CAMBISOL at Bura Research Station, revealed that taproots grew in these soils down to a depth of 105 cm (see figure 59). Pearson and Lund (1968) making direct observations of cotton root growth under field conditions noted that with favourable soil chemical and physical conditions cotton primary roots (or tap roots) can reach depths greater than 170 cm at the period of first boll formation (i.e. 11 weeks after planting). From figure 59 the length of the taproot of the cotton plant at Bura West was only 88 cm after 11 weeks of growth.

4.2. SOIL CONDITIONS MONITORING.

4.2.1. Introduction.

A frequent problem associated with development of semi-arid to arid lands for agricultural production under irrigation is the accumulation of soluble salts. The soluble salts impose a stress on growing crops that can lead to decreased yields and, in some severe cases, complete crop failure. It is reported in literature that approximately one third of the developed agricultural lands

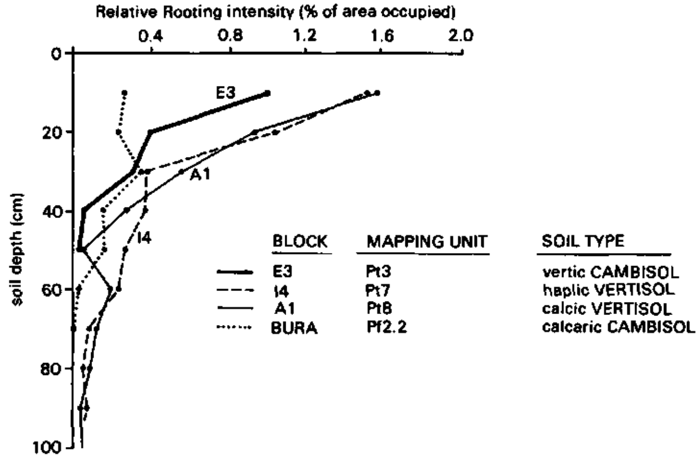

Fig. 58 Variation of rooting intensity of cotton plant (Variety BPA 75) in different soils at Hola and Bura Irrigation Schemes

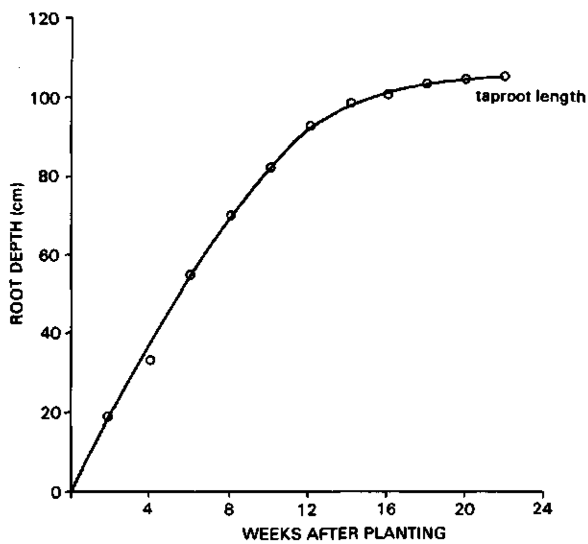

Fig. 59 Variation of rooting depth of cotton (Variety BPA 75) with time in a Chromi-calcaric CAMBISOL at Bura West Irrigation Scheme. (courtessy of S.M. Mwatha. Bura Research Station)

Fig. 60a. Development of roots of cotton grown in Chromi-calcic VERTISOLS at Hola Irrigation Scheme.

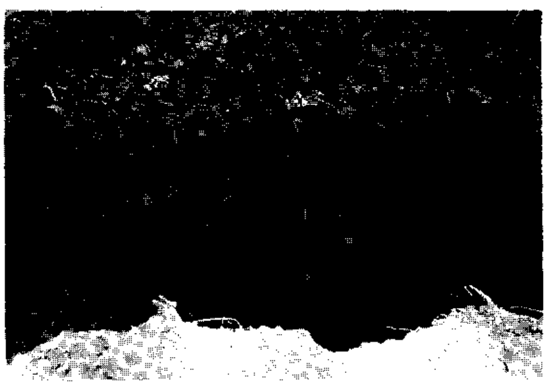

Fig. 60b. Development of roots of cotton grown in Calcari-vertic CAMBISOLS at Hola Irrigation Scheme.

Fig. 60c. Development of roots of cotton grown in Calcari-haplic SOLONETZ at Hola Irrigation Scheme.

in semi-arid and arid regions of the world reflect some degree of salinity accumulation (Allison, 1964; Bresler et.al. 1982). The origin and to some extent the direct source of salts are the primary minerals found in the soils. Salts may also accumulate as a result of irrigation.

In the study areas different concentrations of soluble salts occur in the soils at varying depths (see appendices 5, 6 and 7). Upon irrigation the salt concentration may decrease through leaching or may be concentrated due to evaporation. It is therefore important that for sustained agricultural production under irrigation, the changes that might be taking place in the soils upon irrigation should be monitored. With this in mind, a programme of monitoring the soil conditions and changes under irrigation was started in 1982 at both the Bura West and Hola Irrigation Schemes. This programme is expected to be continued for a period of at least 10 years in order to give conclusive results on what the effect of irrigation would be on the irrigated soils. However, for purposes of this study, the data obtained so far (for 4 years) are statistically analysed to give an indication of what is happening particularly in relation with salinity and alkalinity and also to facilitate development of a model that could be used for predicting the likely changes that may take place in future. This model may also be used for future soil conditions monitoring.

4.2.2. Methodology.

4.2.2.1. Soil Sampling.

Under surface irrigation a change in salt content of a soil profile may be expected especially along the furrows. Due to the variations in water application within a furrow, leaching of salts may be expected during irrigation and the reverse during fallow. To get a sound picture of the possible changes that might take place within an irrigation subunit, the soil samples were collected along the diagonal of the irrigation subunits to ensure that even if the direction of irrigation water flow changed there would not be a loss of continuity of the data being collected. The sampling sites were located at least 20 metres from the edges of the irrigation subunit. In between, the sampling sites were located at fixed distances to ensure that the samples were subsequently collected at the same sites. Schematically the sampling sites were located as shown below.

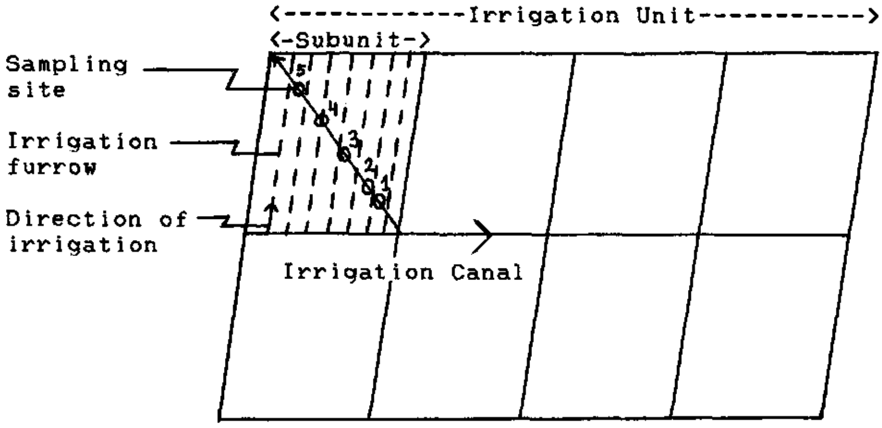

Fig. 61. Schematic presentation of the location of sampling sites within an irrigation subunit.

The irrigation subunits monitored were located on the major soil types that were under irrigation. A stratified random sampling method was used. In each of the selected subunit at least two sites were sampled. For the Bura West area, five sites were sampled in all subunits. For the Hola Irrigation Scheme, only two sites were sampled in each of the selected irrigation subunits. The location of the irrigation subunits sampled is shown in figure 5 and figure 6 (see chapter 1.4.) for Bura West and Hola irrigation schemes respectively. The soil types sampled are shown in Table 27.

At each sampling site, soil samples were collected with the aid of a soil auger. At each site six subsamples were taken and mixed for each depth. The location of the sites where the six subsamples were taken was such that they covered the top of the ridge, the slope of the ridge and the bottom of the furrow. This was done to ensure that the possible effect of leaching of salts along the furrows and accumulation of salts in the ridges were accounted for. It should be noted that when the land is ploughed after harvesting the previous crop, next ridges are made at almost the same position every year.

In case of the Bura West area, the samples were collected at depth intervals of 30 cm down to a depth of 150 cm. However, for the Hola area, the samples were collected at depth intervals of 15 cm down to 60 cm and thereafter at depth intervals of 30 cm down to 150 cm. The different sampling depth at Hola was used to enable utilisation of soils data which had been collected prior to this study. A maximum depth of sampling of 150 cm was selected taking into account the root zone depth of cotton crop as observed at Hola.

The soil samples collected were analysed for electrical conductivity (EC 1:2.5 soil:water ratio), pH (1:2.5), Exchangeable

Cations, Cation Exchange Capacity (CEC), ESP, organic carbon, and P-Olsen. The analyses were carried out at the National Agricultural Laboratories (NAL)-Nairobi. Because of the large number of samples collected, the above analyses were carried out only for the first two years of sampling. Subsequently the analyses which were continued are pH and EC. This was because after the first two years of sampling it was becoming apparent that changes in salinity and sodicity were the most important factors to be monitored.

Soil sampling was carried out after the crops were harvested during the months of January-February. For the Hola area sampling was carried out over a period of four years (1982 to 1985) whereas for the Bura West area it was carried out for three years (1982, 1983 and 1985). The original data of the soils before irrigation started was used as the time zero during the assessment of the likely changes of the soils after irrigation.

Table 27. Soil types and irrigation subunits sampled for soil conditions monitoring.

Mapping unit	Soil classification (FAO, 1987)	Irrigation subunit sampled	No. of sampling sites	Mapping unit	Soil classification (FAO, 1987)	Irrigation subunit sampled	No. of sampling sites
Bura West Irrigation Scheme							
Pf 2.2.	Chromi-calcaric	G1/1	5	Pf 3.2.	Chromi-calcic	E1/4	5
	CAMBISOLS	A4/1	5		VERTISOLS	E4/1	5
	salic-sodic	B3/4	5		salic-sodic	E2/3	5
	phase	J4/1	5		phase		
		J3/3	5				
		J1/4	5				
Hola Irrigation Scheme							
		Area I					
Pt 3.	Calcari-vertic	C1	2	Pt 8.	Chromi-calcic	Area I	
	CAMBISOLS	E3	2		VERTISOLS	A1	2
	salic-sodic	G1	2		salic-sodic	Extension	
	phase	G5	2		phase	E11	2

4.2.2.2. Data analysis.

Statistical methods were used to analyse the soils data collected during the soil conditions monitoring. The methods used were to answer the following questions:

A. Is there a significant change in the soils over the years of irrigation and over different depths?

B. If so, how great are the changes and how will the soils behave in the future?

C. Are the subunits within one irrigation unit really homogeneous?

The above questions were answered by a so-called analysis of covariance, where attention was focussed on main effects, interaction terms and covariate (Draper and Smith, 1981; Snedecor and Cochran, 1982). The data were analysed using a computer. The SPSS statistical package for social sciences (Nie et.al., 1975) and the Showreg Programme (internal programme developed by Ir. A. Stein of the Agricultural University, Wageningen) were used.

The following model was applied to investigate the relationships.

$$Y = \mu + \alpha_i + x_1 + x_2 + (\alpha x_1)_i + (\alpha x_2)_i + \gamma_{k/i}$$

where Y is the response variable ie. pH or EC respectively
μ is the overall mean
α_i, $i = 1, 2$ is an effect due to soil
x_1 is a continuous time effect
x_2 is a continuous depth effect
αx_1 is the interaction between soil and year
αx_2 is the interaction between soil and depth
γ_{ki} is the within soil effect of sites, where k is equal to the number of sites within one soil type.

With this model the answers on most of the questions raised above can be given. For instance: significancy in the term γ_{ki} points to inhomogeneity in sites within one soil unit. The model can also be used to answer the question on whether there exists any trend in the changes of the soil conditions in time.

The model was applied for different soil properties that is for pH, EC and log EC in both Bura West and Hola study areas. In order to have the same number of replicates for both Bura West and Hola, the Bura West data was analysed only for two out of the five sampling sites in each subunit (ie. sites 2 and 4 as shown in figure 61). Because of the large number of observations involved a critical confidence limit region of 0.99 was chosen.

4.2.3. Results and Discussion.

The distribution of electrical conductivity (EC) values of soils from both Bura West and Hola Irrigation schemes are given in appendix 3 figures 3.2. and 3.1. respectively. For both areas the EC values showed a skew distribution. The values are most likely log normal distributed. This is also illustrated by the fairly high skewness values (1.184 for Bura West and 2.133 for Hola) and the differences between median, mean and mode (for Bura West: 1.0, 2.4, and 4.0; for Hola: 0.8, 1.5 and 0.6 respectively). Statistical Analyses, like ANOVA[1], can be sensitive to outliers, which frequently occur in log normal distributed variables (Draper and Smith, 1981; Snedecor and Cochan, 1982). Therefore it was decided to perform a log-transformation on the EC values. The

[1]1. ANOVA - Analysis of Variance

log (EC) values, however, still showed also some characteristics which can influence the outcomes of the statistical analyses. In the Hola-data (see appendix 3 fig. 3.1B) a relatively high skewness is still present (value 0.711), whereas in the Bura West-data (see fig. 3.2B) a two-topped distribution of the log (EC) values seems present-illustrated by a high value of the mode and a start negative value for the kurtosis. However, after investigating both values, EC and log (EC), it was found that log (EC) was far more reliable to analyse and hence the latter was subsequently used in the model.

The output of the data analysis showing relationship between pH and log (EC) with soil depth and time is presented in graphical forms in figures 62 to 77. The significance of the effects of the various variables is given below:

I. BURA WEST IRRIGATION SCHEME

(a) pH

On this variable the following effects were significant:

Source of variation	Degrees of Freedom (DF)	F	Significance of F
Soil x Depth	1	32.7	0.000
Soil x Year	1	17.1	0.000
Field/Soil	7	7.4	0.000

(b) log (EC)

On this variable the following effects were significant:

Source of variation	Degrees of Freedom (DF)	F	Significance of F
Soil	1	31.1	0.000
Depth	1	299.5	0.000
Year	1	15.1	0.000
Field/Soil	7	3.9	0.000

II. HOLA IRRIGATION SCHEME

(a) pH

On this variable the following effects were significant:

Source of variation	Degrees of Freedom (DF)	F	Significance of F
Depth	1	29.9	0.000
Year	1	30.3	0.000
Field/Soil	3	8.7	0.000

(b) log (EC)

The following effects were significant:

Source of variation	Degrees of Freedom (DF)	F	Significance of F
Soil	1	13.8	0.000
Depth	1	173.0	0.000
Year	1	188.6	0.000
Soil x Depth	1	11.2	0.001
Soil x Year	1	16.3	0.000
Field/Soil	3	6.9	0.000

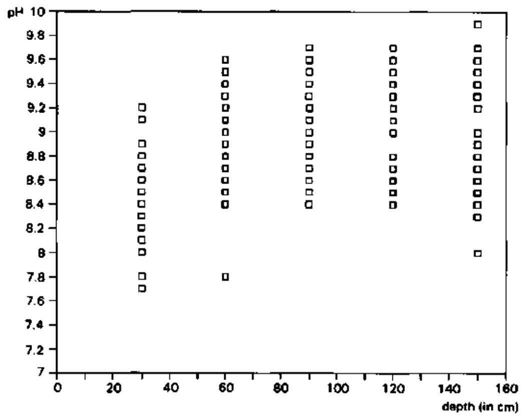

Fig. 62 Relationship between pH and soil depth for Chromi-calcaric CAMBISOLS (unit Pf2.2)-Bura West

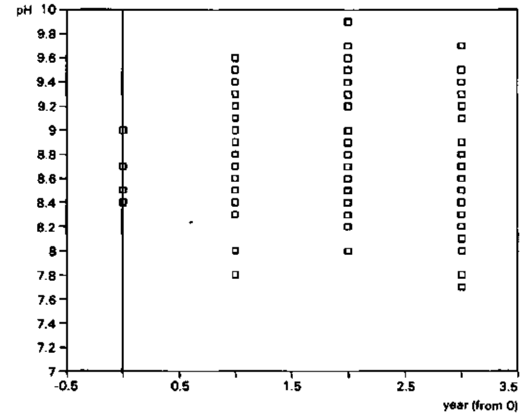

Fig. 63 Relationship between pH and time for Chromi-calcaric CAMBISOLS (unit Pf2.2)-Bura West

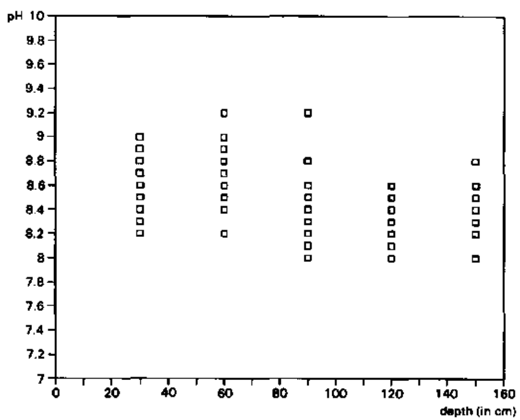

Fig. 64 Relationship between pH and soil depth for Chromi-calcic VERTISOLS (unit Pf3.2)-Bura West

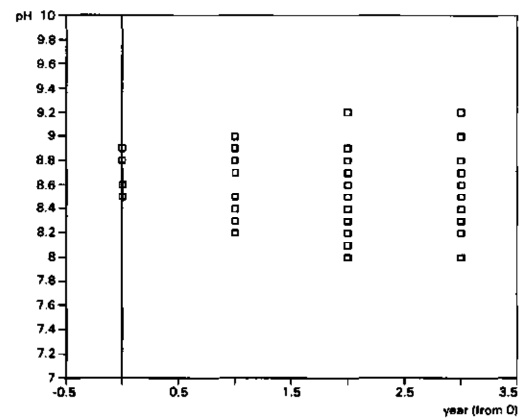

Fig. 65 Relationship between pH and time for Chromi-calcic VERTISOLS (unit Pf3.2)-Bura West

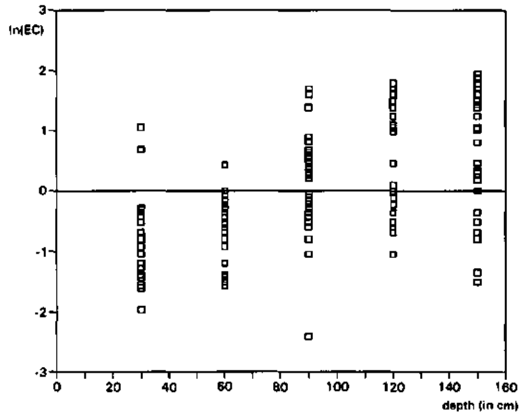

Fig. 66 Relationship between ln(EC) and soil depth for Chromi-calcaric CAMBISOLS (unit Pf2.2)-Bura West

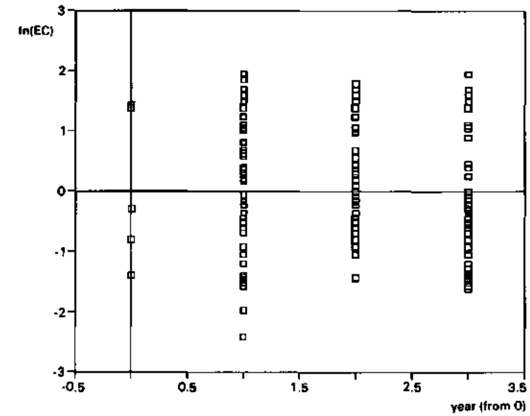

Fig. 67 Relationship between ln(EC) and time for Chromi-calcaric CAMBISOLS (unit Pf2.2)-Bura West

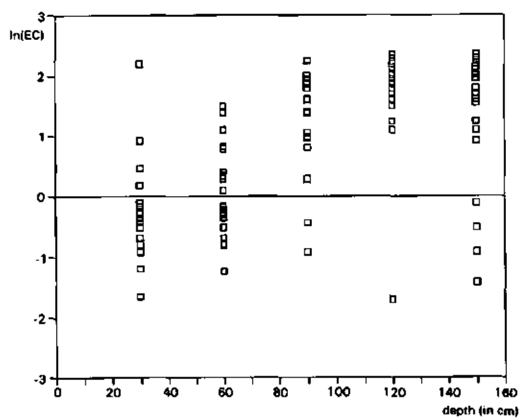

Fig. 68 Relationship between ln(EC) and soil depth for Chromi-calcic VERTISOLS (unit Pf3.2)-Bura West

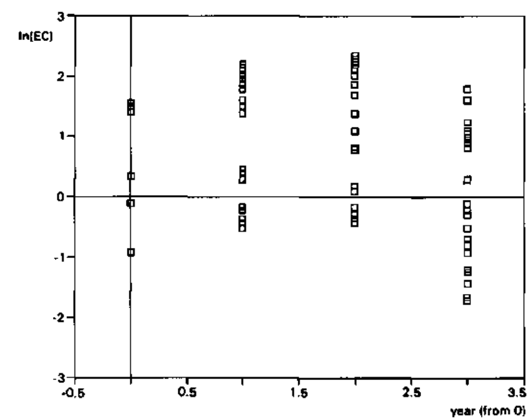

Fig. 69 Relationship between ln(EC) and time for Chromi-calcic VERTISOLS (unit Pf3.2)-Bura West

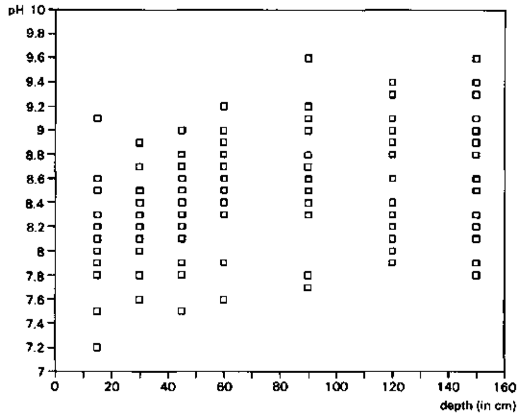

Fig. 70 Relationship between pH and soil depth for Calcari-vertic CAMBISOLS (unit Pt3)-Hola

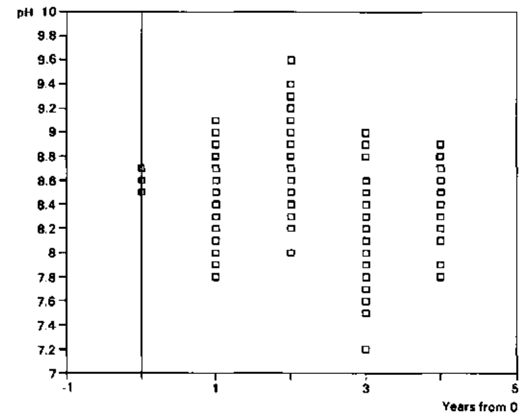

Fig. 71 Relationship between pH and time for Calcari-vertic CAMBISOLS (unit Pt3)-Hola

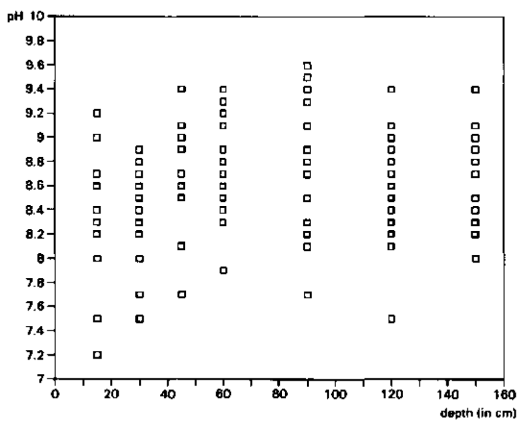

Fig. 72 Relationship between pH and soil depth for Chromi-calcic VERTISOLS (unit Pt8)-Hola

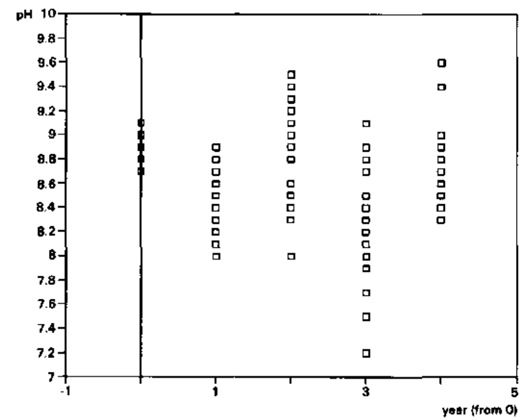

Fig. 73 Relationship between pH and time for Chromi-calcic VERTISOLS (unit Pt8)-Hola

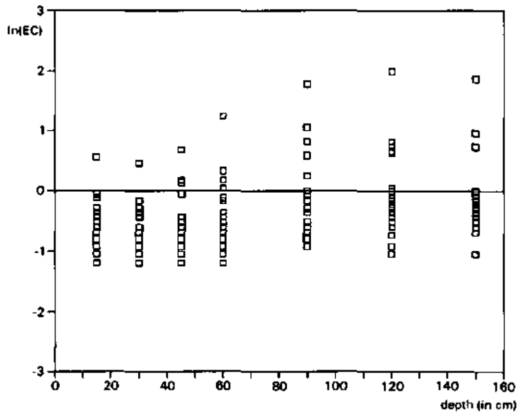

Fig. 74 Relationship between ln(EC) and soil depth for Calcari-vertic CAMBISOLS (unit Pt3)-Hola

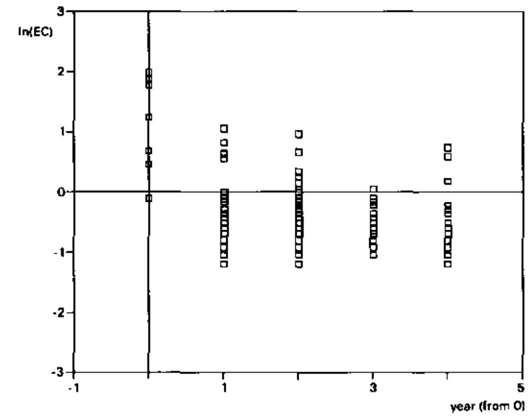

Fig. 75 Relationship between ln(EC) and time for Calcari-vertic CAMBISOLS (unit Pt3)-Hola

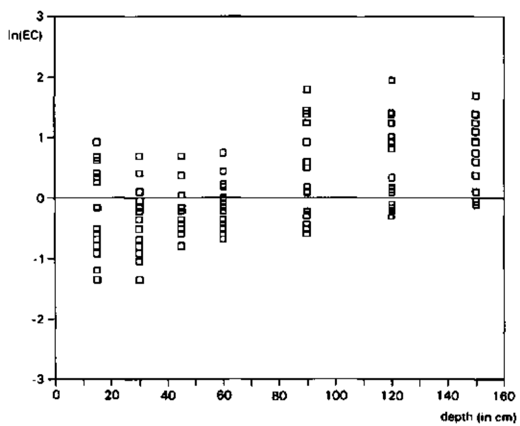

Fig. 76 Relationship between ln(EC) and soil depth for Chromi-calcic VERTISOLS (unit Pt8)-Hola

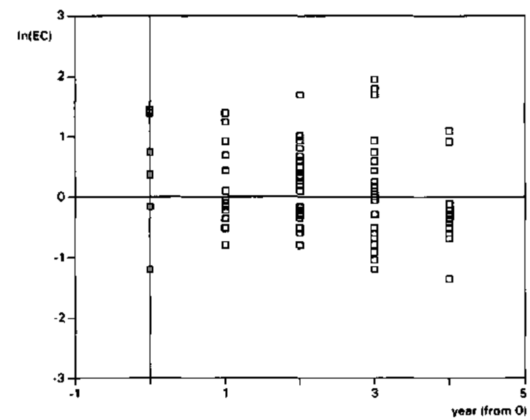

Fig. 77 Relationship between ln(EC) and time for Chromi-calcic VERTISOLS (unit Pt8)-Hola

The results of the various effects of the variables pH and log (EC) are summarised in Table 28. From these results the following

Table 28. Summary of the results of statistical analysis.

area	Variable	Soil	Depth	Year	SoilxDepth	SoilxYear	Field/Soil
Bura West	pH				X	X	X
	log (EC)	X	X	X			X
Hola	pH		X	X			X
	log (EC)	X	X	X	X	X	X

1) Significant entries are marked with a cross
2) Field/Soil refers to the soils within each irrigation subunit sampled.

general conclusions can be made:

1. Except for pH in Bura West, there is a significant distinction in depth and in time for the different variables.
2. There is no reason to state that the irrigation subunits sampled within one soil type are relatively uniform. Significant differences exist between them with regard to pH and electrical conductivity (EC).
3. Leaving aside the within soil variation due to the different subunits sampled, the following interpretations of the effects on the different variables can be made:
   a. pH-Bura West Soils: There are no significant main effects between the soils and depth and soil and time. However, interactions exist between soil and depth and soil and time. With the two soils considered there are different effects with increasing depth and time (cf. figures 62, 63, 64 and 65). The pH of soils of Unit Pf 2.2. (Chromi-calcaric CAMBISOLS) tend to increase with depth over time whereas that of soils of unit Pf 3.2 (Chromi-calcic VERTISOLS) tend to decrease with depth over time.
   b. log (EC)-Bura West Soils: Here there are no interactions. Differences exist between soils, in depth and time. However the effects do not intermix (cf. figures 66, 67, 68 and 69). The results show that the two soils (Chromi-calcaric CAMBISOLS and Chromi-calcic VERTISOLS) behave differently with regard to leaching of salts. In both soils there is a tendency of EC values to decrease with depth and time. However, the rate at which the EC values decrease is less in the Vertisols than in the Cambisols. This can probably be attributed to differences in permeability of the two soils.
   c. pH-Hola Soils: Significant differences exist in depth and in time but not in soils. There are no interactions with soil and depth and soil and time (cf. figures 70, 71, 72 and 73). The results reveal that the soils behave in a similar manner with regard to changes in pH over depth and time. For both soils (Calcari-vertic

CAMBISOLS and Chromi-calcic VERTISOLS) there is a tendancy for the pH to decrease slightly with depth over time.

d. <u>log (EC)-Hola Soils:</u> All the effects are significant (cf. figures 74, 75, 76 and 77). This means that both soils (ie. Chromi-calcic VERTISOLS and Calcari-vertic CAMBISOLS) behave differently with regard to salinity. In both soils salinity varies differently according to depth and time. The EC values decrease in the topsoils but increase in the subsoil. This shows that leaching of salts is taking place in the upper soil layers and accumulating in the deeper subsoil.

4.2.4. Predictive Models.

Models are simplified representations of systems, describing only a limited part of the reality, with well-defined boundaries. Models can be constructed if the structure of the system under consideration is sufficiently well known so that the various processes which play a role in the system can be described in detail (Van Wijngaarden, 1985).

The predictive models developed here are empirical because they have been constructed on the basis of results obtained from data analysis collected at Bura West and Hola Irrigation Schemes (see chapter 4.2.3.). For both areas the predictive models have been constructed for the two soil properties, pH and log (EC). In the preceding chapter sufficient data on the significant effects of the above soil properties was discerned to justify construction of predictive models. It should however be noted that these models can be used to show interrelationships only for the four soil types considered. The objective of constructing the predictive models is to show the possible long term effects of irrigation on the soil reaction (pH) and soil salinity treated in the models as log (EC). The four predictive models are:

A. <u>Bura West</u>

(i) pH = 8.67-0.18*Soil+0.025*Soil*depth+0.07*Soil*Year.

(ii) log (EC) = -0.99-0.41*Soil+0.018*depth-0.13*Year.

Here depth is in centimetres

Year is in integers, from zero onwards (zero = reference level); years 0, 1, 2, 3 are included.

Soil { 1 for Chromi-calcaric CAMBISOLS (unit Pf 2.2.)
{ -1 for Chromi-calcic VERTISOLS (unit Pf 3.2.)

B. <u>Hola</u>

(i) pH = 8.54+0.0026xdepth-0.08*Year

(ii) log (EC) = -0.06+0.18*Soil+0.0088*depth-0.30*Year

Here depth is in centimetres

Year is in integers, from zero onwards (zero = reference level); years 0, 1, 2, 3, 4 are included.

Soil { 1 for Calcari-vertic CAMBISOLS (Unit Pt 3.)
{ -1 for Chromi-calcic VERTISOLS (unit Pt 8.)

Table 29 gives an overview of the 99% confidence limits for the estimates of the different coefficients in the models.

Table 29. 99% confidence limits for the estimates of coefficients used in the model.

Area	Variable	Conf. limit	Const	Depth	Year	Soil	Soil*Year	Soil*depth
		upper	8.71			-0.07	0.11	0.0016
Bura	pH	lower	8.63			-0.28	0.04	0.0034
West		upper	-0.77	0.020	-0.05	-0.32		
	log (EC)	lower	-1.21	0.016	-0.20	-0.49		
		upper	8.63	0.0035	-0.05			
	pH	lower	8.44	0.0017	-0.11			
Hola		upper	0.09	0.010	-0.25	0.33	-0.04	-0.0009
	log (EC)	lower	-0.20	0.007	-0.34	0.04	-0.13	-0.0036

Future observation values can be predicted as follows:

$$t = x'_o.\hat{\beta}$$
$$var(t) = (x'_o(X'X)^{-1}x_o+1).\hat{\sigma}^2$$

where:

$\hat{\beta}$ is an estimation of the parameters of the significant effects in the model

for instance $\hat{\beta} = \begin{bmatrix} 8.67 \\ -0.18 \\ 0.0025 \\ 0.07 \end{bmatrix}$ for pH in Bura West

x_o is a vector with the values in the future observation point i.e. year, soil, depth and interactions as far as these effects are included.

X is the design matrix depending on the variables and observations in the model.

$\hat{\sigma}^2$ is the residual sum of squares.

Predictions are carried out for the two soils of the Bura West (Chromi-calcaric CAMBISOLS and Chromi-calcic VERTISOLS) and for the two soils of the Hola Irrigation Scheme (Calcari-vertic CAMBISOLS and Chromi-calcic VERTISOLS) for both pH and log (EC). Two soil depths are considered i.e. 30 cm and 120 cm. The predictions are made over the next six (6) years. The results are presented in figures 78 to 81 and figures 82 to 85 for the Bura West and Hola soils respectively. In the figures a kind of confidence bound is included, being $t \pm \sqrt{var(t)}$.

Conclusions:
From the above predictions, the following general conclusions can be made:

A. Bura West Soils:

1. The Bura West soils monitored behave differently with respect to pH. The pH of the Chromi-calcaric CAMBISOLS

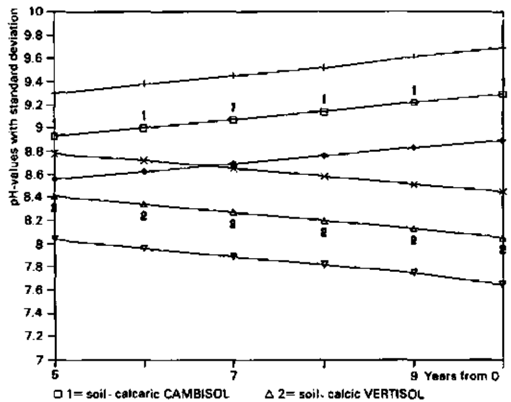

Fig. 78 Predicted pH values, at a depth of 30 cm, for the Chromi-calcaric CAMBISOLS (unit Pf 2.2) and the Chromi-calcic VERTISOLS (unit Pf 3.2)-Bura West.

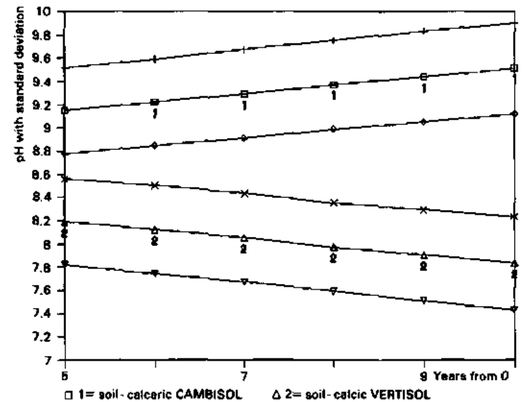

Fig. 79 Predicted pH values, at a depth of 120 cm, for the Chromi-calcaric CAMBISOLS (unit Pf 2.2) and the Chromi-calcic VERTISOLS (unit Pf 3.2)-Bura West.

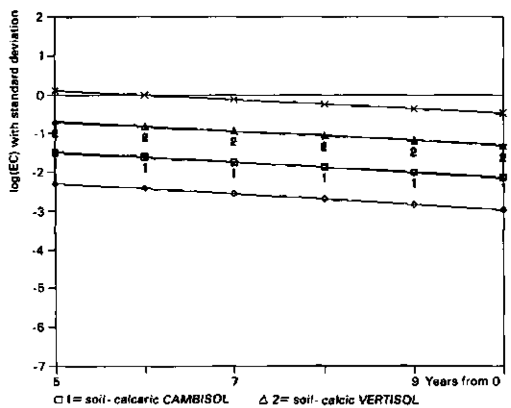

Fig. 80 Predicted log(EC) values, at a depth of 30 cm, for the Chromi-calcaric CAMBISOLS (unit Pf 2.2) and the Chromi- calcic VERTISOLS (unit Pf 3.2)-Bura West.

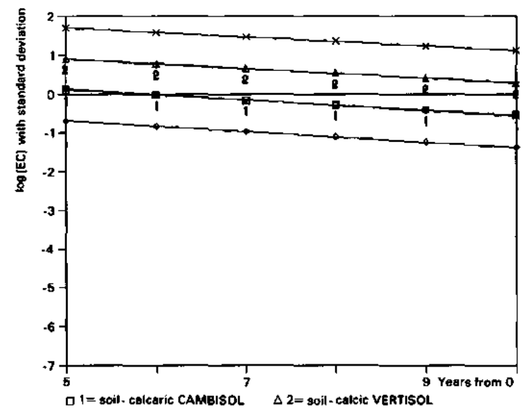

Fig. 81 Predicted log(EC) values, at a depth of 120 cm, for the Chromi-calcaric CAMBISOLS (unit Pf 2.2) and the Chromi-calcic VERTISOLS (unit Pf 3.2)-Bura West.

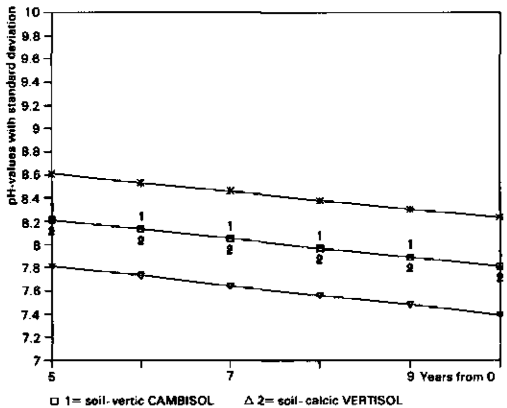

Fig. 82 Predicted pH values, at a depth of 30 cm, for the Calcari-vertic CAMBISOLS (unit Pt 3) and the Chromi-calcic VERTISOLS (unit Pt 8)-Hola.

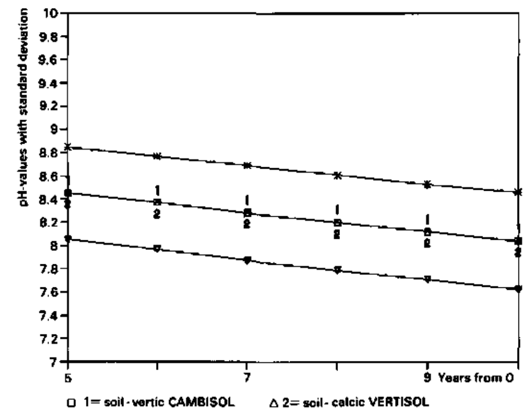

Fig. 83 Predicted pH values, at a depth of 120 cm, for the Calcari-vertic CAMBISOLS (unit Pt 3) and the Chromi-calcic VERTISOLS (unit Pt 8)-Hola.

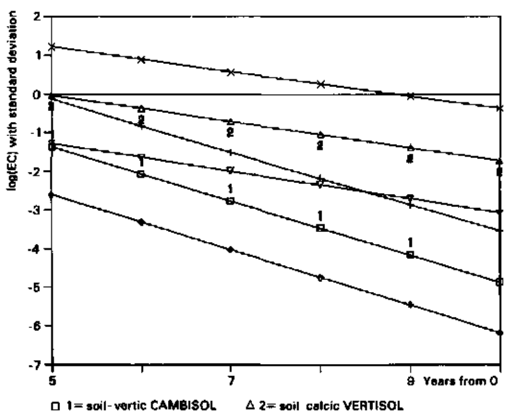

Fig. 84 Predicted log(EC) values, at a depth of 30 cm, for the Calcari-vertic CAMBISOLS (unit Pt 3) and the Chromi-calcic VERTISOLS (unit Pt 8)-Hola.

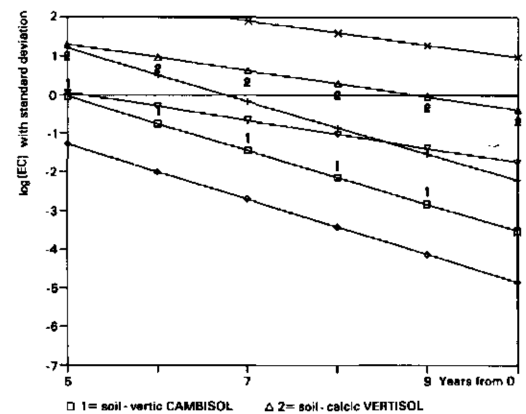

Fig. 85 Predicted log(EC) values, at a depth of 120 cm, for the Calcari-vertic CAMBISOLS (unit Pt 3) and the Chromi-calcic VERTISOLS (unit Pt 8)-Hola.

(unit Pf 2.2.) tends to increase with time at both depths (30 cm and 120 cm respectively) whereas that of the Chromi-calcic VERTISOLS (unit Pf 3.2.) tends to decrease with time. The increase of pH in the irrigated soils of mapping unit Pf 2.2. is probably due to an increase of exchangeable sodium as a result of removal of soluble salts by leaching. This increase in pH may result in adverse soil conditions for irrigation management.

2. The salinity of both soils decreases with time and depth. However, the changes of salinity with time and depth are different in both soils. The above observations indicate that as irrigation continues, leaching of salts will take place in both soils. However as the salts are leached in the Chromi-calcaric CAMBISOLS (unit Pf 2.2.) there would be a subsequent increase in pH probably due to an increase of exchangeable sodium in the soils exchange complex.

B. Hola Soils:

1. The Hola soils monitored behave in a similar manner with respect to pH over depth and time. The prediction results show a slight decrease of pH over time for both soils.
2. The soils behave differently with regard to salinity. There is a decrease in salinity with time and depth for both soils. However, the decrease in salinity at the depth of 30 cm in the Calcari-vertic CAMBISOLS (unit Pt 3) is greater than that of the Chromi-calcic VERTISOLS (unit Pt 8.). The decrease in salinity at 120 cm depth is less than that at 30 cm depth for both soils. This probably indicates that the salts leached from the upper soil layers accumulate in the deeper subsoil layers in the case of both soils.

As a whole it may be concluded that the decreasing salinity effect is more in the Hola soils than in the Bura West soils. This difference can probably be attributed to slightly better drainage conditions at Hola than at Bura West. As indicated earlier in this text, the Hola soils have sand encountered at depths varying from 2.5 to 4 metres which probably enhances subsurface drainage and hence removal of salts. At Bura West occurrence of such sand layers was not observed.

5. LAND EVALUATION.

5.1. INTRODUCTION.

Rapid population growth, particularly in the developing countries exerts a high demand for increased agricultural production, to provide both food and cash income. Considering the adverse impacts of drought in many of these countries, particularly in Africa, irrigation can play a crucial role in increasing and stabilizing agricultural production. However, it should be borne in mind that irrigation developments are expensive and usually require investment and credit facilities and mistakes can be very costly. Therefore, areas that are earmarked for irrigation development should be evaluated to ascertain their suitability for the intended irrigation system.

The first step in assessment of the potential of an area for irrigation and the likely risks that may be involved is soil investigations carried out through a soil survey preferrably combined with topographic studies. Storie (1964, quoted in FAO, 1979) listed the following principal reasons for soil studies in irrigation investigations:

- to ensure selection of soils for irrigation that will be productive;
- to aid in location of canals and other irrigation works;
- to determine irrigation needs of specific soil types for every crop;
- to determine drainage needs of specific soil types for every crop;
- to determine overall land levelling needs;
- to determine erosion control needs;
- to aid in determining crops suitable for particular soils;
- to help in determining the size of farms;
- to aid in appraising land value in order to allocate the costs of development on basis of ability to pay;
- as an aid in devising individual farm management needs, such as use of fertilizers, use of soil ammendments, type of irrigation system etc.

Most of the above requirements can be met by data from soil surveys. A soil survey provides the fundamental information about soil and related land characteristics. This information together with data on other environmental factors such as climate, vegetation, etc can be interpreted to indicate the suitability of various tracts of land for irrigation.

Various systems have been used in the past for interpretation of this data. The land classification system of the Bureau of Reclamation of the U.S. Department of the Interior has been used or adapted widely in many places for irrigation projects. A good general summary of the Bureau of Reclamation's land classification system is given by Maletic and Hutchings (1967). Detailed aspects of the method are given in the Bureau of Reclamation

Manual (USBR, 1953). This classification is quantitative and general principles are applied to fit land classification to the economic, social, physical and legal patterns existing in a project area. Other systems that have been used in land classification are described by Steele (1967), FAO (1974 and 1975), Vink (1975), Beek (1978), Dent and Young (1981) and Sys (1985) among others. However, as Beek (1978) rightly points out, although each system may serve its purpose perfectly well, and although some successful adaptations of such systems to other environments have been realized, none of these systems has been universally accepted. Realizing this, FAO, after a number of Expert Consultation meetings, prepared a manual entitled "A Framework for Land Evaluation" (FAO, 1976). This manual is intended to have a worldwide application.

According to the Framework for Land Evaluation (FAO, 1976, page 67) land evaluation is the process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation. To serve its purpose, land evaluation should answer the following questions:

- How is the land currently managed, and what will happen if present practices remain unchanged?
- What improvements in management practices, within the present use, are possible?
- What other uses of land are physically possible and economically and socially relevant?
- Which of these uses offer possibilities of sustained production or other benefits?
- What adverse effects, physical, economic or social are associated with each use?
- What recurrent inputs are necessary to bring about the desired production and minimize the adverse effects?
- What are the benefits for each form of use?

Incase of irrigation development the following questions should also be answered:

- What changes in the condition of land are feasible and necessary and how can they be brought about?
- What non-recurrent inputs are necessary to implement these changes?

Basic in this approach is that land evaluation is only meaningful for clearly defined use. On the basis of the Framework FAO has further prepared guidelines for Land Evaluation for irrigated agriculture (FAO, 1985). These guidelines are intended to give guidance to land classification teams in the field and also to agencies responsible for investing in irrigation development so that they can make sure that land resources evaluation provides a satisfactory basis for predicting the results of development.

5.2. SYSTEM APPLIED.

The system of Land Evaluation used in Kenya, and therefore in this study closely follows the principles of the FAO Framework for Land Evaluation (FAO, 1976) somewhat modified to suit Kenyan conditions. In this system, the relevant land utilization types (LUTs) i.e. kinds of land use that are physically possible and also socially and economically promising are identified in the early stages of the soil survey. For each survey area a background study is made of the essential attributes that are used to define the relevant LUTs. The most important attributes are produce, capital and labour intensity, farm power, farm size, technical know-how of land users and related management practices (Beek, 1978 and 1980). Each LUT has its own requirement in terms of land characteristics such as slope, available water capacity etc. However, if the land characteristics are employed directly in evaluations, problems arise when these characteristics interact. Therefore the concept of land quality (Beek and Bennema, 1972; FAO, 1976 page 12-14) is used. A land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of land use. Land qualities are sometimes estimated or measured directly but they are frequently established by weighted combinations of several land characteristics. Each land quality is rated for all mapping units identified in the area being evaluated (see Van de Weg and Mbuvi, 1975; Van de Weg and Braun, 1977; Nyandat and Muchena, 1980; Muchena and Van de Weg, 1982 among others). These ratings are "matched" with specifications set in "conversion tables" for each LUT to arrive to a suitability classification. The end results are presented in a Land Evaluation Key.

This system has been applied in Kenya mainly for rainfed agriculture and in a general way for irrigation. However, attempts have also been made to marry the Framework approach with that of the U.S. Bureau of Reclamation in conducting land evaluation for irrigation (Muchena, 1981; Muchena and Van der Pouw, 1981a). In most of these cases only a physical land evaluation has been carried out. Thus the suitability classification has in the past been based primarily on the physical and chemical constraints due to non-availability of certain economic data. In this study, the principles outlined in FAO's Guidelines for Land Evaluation for irrigated agriculture (FAO, 1985) will be adapted. However these Guidelines will be modified where necessary to suit Kenyan conditions.

5.3. APPROACH.

The following stages will be adopted for the land evaluation.

Stage I.
Identification and definition of the relevant Land Utilization Types (LUTs). At this stage an analysis of key attributes will be made.

Stage II.
Compilation of the specifications of the Land requirements (LR) of each LUT. These include ecological requirements, management requirements, conservation requirements and improvement requirements. At this stage too, the land qualities (LQ) that are likely to limit the suitability of each mapping unit, for the defined LUT will be identified and rated.

Stage III.
Formulation of land suitability criteria - preparation of "conversion tables" for each LUT.

Stage IV.
Matching of criteria with land requirements and land qualities to arrive at land suitability classification.

The above approach is illustrated diagrammatically in figure 86.

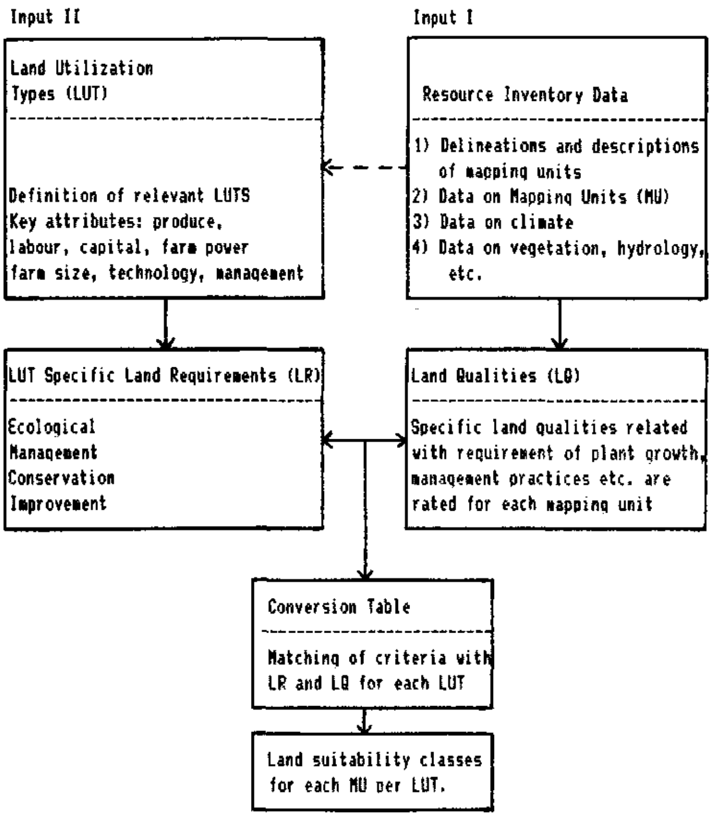

Fig.: 86 Schematic presentation of the land evaluation approach.

A further attempt to arrive at an economic evaluation will be made. Potential crop production will be calculated following the methods outlined by Van Keulen and Wolf (1986). These potential yields will be compared with the actual yields obtained under irrigation at Bura West and Hola with an ultimate goal of assigning a land productivity index to each suitability classification for each LUT.

5.4.LAND UTILIZATION TYPES CONSIDERED.

The selection of the Land Utilization Types (LUTs) to be considered for land evaluation has taken into account the present irrigation land use at the Hola and Bura West Irrigation Schemes. However, it should be noted that some of the LUTs considered, such as sugarcane, and rice, are not currently being practised and are therefore introduced as possible alternative LUTs. The source of irrigation water is Tana river and the water is pumped. A brief description of the LUTs considered is given below.

A. LUT-C: Irrigated cotton; surface irrigation using long furrows; cropping intensities anticipated 100 percent. Smallholder plots of 1.25 ha within a government owned centrally managed settlement scheme. Water supply is to be on rotation at 14-day intervals. Mechanised land preparation (ploughing, hallowing, ridging and levelling) but all other operations by hand apart from aerial sprays. High input levels. Farm inputs (seeds, fertilizers - 80 to 120 Kg N/ha, herbicides and pesticides) available on credit. Produce - seed cotton. Technical know-how of farmers low to moderate, therefore intensive extension services are needed. Labour - mainly family labour, occasionally hired labour at peak periods such as weeding and cotton picking.

B. LUT-M: Irrigated maize[1]; surface irrigation using long furrows; cropping intensity 48 percent. Smallholder plots of 0.625 ha within a government owned centrally managed settlement scheme. Irrigation interval - 14 days. Mechanised land preparation but all other operations by hand. Moderate input levels. Farm inputs (improved seeds, fertilizers - 80 kg N/Ha, pesticides) available on credit. Produce - maize mainly for subsistence. Technical knowledge of the farmers is low to moderate. Supervision and extension services are needed. Labour - mainly family labour. Hired - labour may be necessary during weeding and harvesting periods.

C. LUT-R: Irrigated rice; basin irrigation; two crops per year; large scale commercial production; plot size variable but not

[1]It should be noted that under the current land use practice in the study area, maize is grown after cotton but for purposes of land evaluation in this report, it will be treated as a separate LUT. This also applies to LUT-P-cowpeas and LUT-G-groundnuts. Maize and cowpeas are usually intercropped but because of their different requirements they are treated here as separate LUTs.

less than 1 ha. Mechanised land preparation. Transplanting, weeding and harvesting by hand. High input levels. Farm inputs - improved varieties, fertilizers and pesticides necessary. Produce - rice for commercial purposes. Level of technical know-how - moderate to high. Labour requirements - high during transplanting, weeding and harvesting.

D. LUT-S: Irrigated sugarcane; surface irrigation; cropping intensity anticipated is 100 percent. Large scale commercial production. Plot size variable but not less than 1 ha. Mechanised land preparation. Planting and harvesting by hand labour. High input levels. Farm inputs - improved varieties, fertilizers, herbicides and pesticides. Produce - sugarcane for sugar extraction. Level of technical know-how-moderate to high. Labour requirements - high during planting and harvesting.

E. LUT-P: Irrigated cowpeas; surface irrigation using long furrows; anticipated cropping intensity 50 percent mainly smallholder plots of 0.625 ha within a government owned centrally managed settlement scheme. Mechanised land preparation but all other operations by hand. Input level - low to moderate. Farm inputs (improved seed, fertilizer and pesticides) require credit. Water application to be supervised by the extension staff. Produce - cowpeas grains mainly for subsistence and green leaves as a vegetable. Level of technical know-how - low to moderate. Labour - mainly family labour.

F. LUT-G: Irrigated groundnuts; surface irrigation using long furrows; anticipated cropping intensity about 50 percent. Smallholder plots of about 0.625 ha within a centrally managed settlement scheme. Mechanised land preparation but all other operations by hand. Low to moderate input levels. Farm inputs (seeds, fertilizer if needed, pesticides) require credit. Supervised water application. Produce - nuts for both cash income and subsistence. Level of technical knowledge of the farmers - low to moderate. Labour - mainly family labour.

5.5. CROP REQUIREMENTS.

5.5.1. Cotton (Grossipyum hirsutum).

Cotton cannot be grown successful above 1,500 m in Tropical Africa (Purseglove, 1972; Acland 1971). It requires a frost free growing season of 200 days. Optimum temperature for germination is 34°C while that for growth of seedlings is between 24 and 29°C. For the other growing periods temperatures of about 32°C are preferred. Low temperatures increase the production of vegetative branches and extend the cropping period. High temperatures increase the number of fruiting branches and reduce the cropping period. Acland (1971) has indicated that in East Africa, night temperatures of about 15.5°C lead to production of short staple, poor quality cotton.

Cotton is sun-loving. Reduced light intensity due to prolonged overcast weather, shading from interplanted crops or too dense a stand of cotton, retards flowering and fruiting and increases boll shedding.

Cotton can be grown on a wide range of soils - sandy soils to heavy clay soils. Cotton can tolerate salinity levels of up to ECe of about 8.0 mmhos/cm without a reduction in yield potential. However, at ECe values of about 9.5, 13 and 17 mmhos/cm yield potentials are 90%, 75% and 50% respectively. At ECe values of 27 mmhos/cm crop growth ceases (Ayers and Westcot, 1985). Cotton can tolerate ESP values ranging between 20 and 40. At ESP values of 40-60 stunted crop growth is noted (FAO 1979,Sys, 1985 page 113). Inadequate drainage may restrict growth. A pH less than 5.0-5.5 may also affect growth. Cotton requires fertile soils particularly those with adequate supplies of nitrogen (N), phosphorus (P) and potassium.

5.5.2. Maize (Zea Mays).

Different types of maize are suited to different temperatures at altitudes from sea level to 2,500 metres. However, in some parts of Kenya it is also grown at altitudes between 2,500 and 2,900 metres above sea level. A frost free growing period is required. Optimum temperature for germination is 18-21°C. Below 13°C germination is greatly reduced and at 10°C it fails altogether (Purseglove, 1968; Acland, 1971; Doorenbos and Kassam, 1979). Temperature at tasseling should be 21-30°C for optimum conditions.

Maize needs well drained soils and a good supply of nutrients. It is sensitive to waterlogging. Maize is highly sensitive to salinity - can tolerate ECe values of about 2 mmhos/cm without any effect on yields. At ECe values of about 2.5, 4 and 6 mmhos/cm, the yield potentials are 90%, 75% and 50% respectively. No growth or very little growth takes place at ECe values of 10 mmhos/cm (FAO, 1979; Ayers and Westcot, 1985). Maize is sensitive to sodicity and yield reductions of up to 50 percent may be obtained at ESP values of 15 or less (Sys, 1985; FAO, 1979). Maize grows in soils with a pH between 5.0 and 8.0. The optimum pH is 6.0 to 7.0 (Purseglove, 1968).

Total growing period (in the study area) from emergence to maturity varies from 80 to 110 days for short duration varieties. Maize is day-neutral or short day plant.

In general maize requires well drained, non-saline and non-sodic, fertile soils with a pH-value of about 5 to 8 and air temperatures between 18 and 30°C.

5.5.3. Rice (Oryza Sativa).

Although rice is considered as a tropical crop, it is grown on an extensive area in subtropical climates. It can be cultivated in almost any region having 4 to 6 months with an average temperature of atleast 20 to 25°C and a minimum of 10°C (Sys, 1986) so long as there is an adequate supply of water. It is grown at altitudes varying from sea level to 3,000 metres (Himalayas). Generally it is considered that rice grows successfully when the mean temperature of the growing season varies from 20 to 38°C (Purseglove, 1968). Mean temperatures lower than 10°C and higher than 45°C during the crop development stage are considered unsuitable (Sys, 1986; Doorenbos and Kassam, 1979; Dent and Young, 1981).

Long periods of sunshine are essential for high yields. High relative humidity levels favour crop development while low relative humidity levels are desired at ripening period.

Rice, particularly that grown under basin irrigation requires heavy textured, slowly permeable soils with an adequate supply of nutrients. Optimum pH for rice is 5.5-6.5 (dry soil) and 7.0-7.2 for flooded soils (Purseglove, 1968). However, it can be grown on alkaline soils with a pH value of 8 to 9. It is moderately sensitive to salinity. ECe of less than 2 mmhos/cm is considered optimum. Yield reductions of 90%, 75% and 50% are obtained at ECe values of about 4, 5 and 7 mmhos/cm respectively. At ECe values of 11 mmhos/cm there is no growth (FAO, 1979; Ayers and Westcot, 1985). Rice tolerates high sodicity status. Up to 10-20 percent sodium saturation no yield reductions have been observed. However, ESP values over 30 are considered marginal for rice growth (Sys, 1986).

Growing period from transplanting to maturity varies from 90 to 150 days depending on the variety.

In general rice requires slowly permeable non-saline, fertile soils with a pH of about 7 to 9 under flooded conditions and an air temperature between 20 and 38°C.

5.5.4. Sugarcane (Saccharum Officinarum).

Sugarcane is fairly drought resistant but it needs a steady supply of soil moisture throughout the growing period. Under rainfed conditions, an average rainfall of atleast 1,500 mm evenly distributed throughout the year is required. It requires high temperatures and plenty of sunlight. The optimum temperature for germination of stem cuttings or setts is 32-38°C. Below 21°C growth is slow or fails (Purseglove, 1968).

Sugarcane tolerates a wide variety of soil conditions but only yields well under conditions of good drainage and high natural fertility (Acland, 1971; Purseglove, 1968). It can grow in soils with a pH between 5.0 and 8.0. However, the optimum pH is 6.3 to 6.7. Sugarcane is moderately sensitive to salinity. At ECe values of about 3.5, 6 and 10 mmhos/cm, the yield potential is reduced by 90%, 75% and 50% respectively. At ECe values of 19 mmhos/cm there is no growth or very little growth (Ayers and Westcot, 1985). It is semi-tolerant to exchangeable sodium and can thrive in soils with ESP values between 15 and 40 (FAO, 1979).

A long growing period is required for high yields. The average growing period is 14 to 18 months depending on the variety, with a 12 months ratoon crop.

Generally sugarcane requires well drained, fertile soils with a pH between 5 and 8 and high air temperatures (32-38°C).

5.5.5. Cowpeas (Vigna Unguiculata (sinensis)).

Cowpeas can be grown under a wide range of conditions. However, they need warm conditions and only give good yields of seed below about 1,500 metres above the mean sea level. Cowpeas are sensitive to cold and are killed by frost. They are intolerant of waterlogging and must therefore be grown on soils with good drainage conditions (Acland, 1971; Purseglove, 1972).

Cowpeas are moderately sensitive to salinity - can tolerate ECe values up to 5 mmhos/cm without any yield reductions. However, at ECe values of about 6, 7 and 9 mmhos/cm yield reductions of 90%, 75% and 50% respectively are obtained. At ECe values of 13 mmhos/cm there is virtually no growth (Ayers and Westcot, 1985). They are relatively sensitive to sodicity and are affected by ESP values between 10 and 20 (FAO, 1979).

In general cowpeas require well drained, fertile soils and warm conditions.

5.5.6. Groundnuts (Arachis hypogaea).

Groundnuts require adequate moisture supply throughout the growing period. They need a warm climate. In East Africa, they are mainly grown at altitudes below 1,500 metres (Acland, 1971).

They grow well in soils with a reasonable fertility and with light textured topsoil. Heavy textured soils present problems particularly during harvesting. Groundnuts are moderately sensitive to salinity. At ECe values of about 3.5, 4 and 5 mmhos/cm yield potentials are 90%, 75% and 50% respectively. At ECe values of about 6.5 there is no yield or growth is impaired (Ayers and Westcot, 1985; FAO, 1979). They are sensitive to sodicity and are affected by ESP values between 10 and 20.

In general groundnuts require a warm climate and well drained, fertile soils with a light textured topsoil.

5.6. LAND SUITABILITY EVALUATION.

5.6.1. Land qualities and their ratings.

Land suitability evaluation is the process of assessing the suitability of land for specified kinds of use. Here, the land is evaluated for six different land utilization types (LUTs) under irrigation. As mentioned in chapter 5.2. each LUT has its own requirements in terms of land qualities, that is land qualities related to plant growth and those related to management practices in crop production. The major limiting factors that restrict the use of land for irrigation fall broadly under the following categories: soil deficiencies, drainage including flooding,

Table 30. Land qualities and their land characteristics.

Land Quality	Land characteristic(s)
Capacity for water retention	Soil texture, type of clay, organic matter. Soil depth (effective rootable depth). Calcium carbonate content
Absence of salinity	Electrical conductivity of saturation extract (ECe) in mmhos/cm.
Absence of sodicity	Exchangeable sodium percentage (ESP) (soil reaction-pH).
Availability of oxygen for root growth	Drainage class.
Conditions for germination (seedbed)	Structure of topsoil. Susceptibility to crusting.
Availability of nutrients	Cation Exchange Capacity of soil (CEC). Available nutrients, pH-H_2O.
Availability of foothold for roots	Soil depth to limiting layer.
Workability (ease of tillage)	Dry and moist consistence
Ability for drainage	Natural drainage conditions. Infiltration rates. Presence of impermeable layers. Texture (type of clay minerals).
Ease of land clearing (sparseness of vegetation cover)	Physiognomic vegetation types.
Freedom for layout of field plans	Topography and slope.

topography and density of vegetation cover. These factors are dealt with under the various land qualities in this land evaluation. The land qualities considered are indicated below.

A. Land qualities related to plant growth:
* capacity for water retention
* absence of salinity
* absence of sodicity
* availability of oxygen for root growth
* conditions for germination (seedbed)
* availability of nutrients
* availability of foothold for roots.

B. Land qualities related to management practices in plant production:
* workability (ease of tillage)
* ability for drainage
* ease of land clearing (sparseness of vegetation cover)
* freedom for layout of field plans.

Each of the above land qualities is determined by a specific land characteristic or several land characteristics (see table 30). On the basis of specifications outlined in appendix 4A for the "rating of the land qualities" each land quality was rated for all the land mapping units identified in the three study areas. The ratings were carried out separately for each individual mapping unit. The results of the ratings are given in tables 31a, 31b, 31c for the Bura East, Bura West and Hola Irrigation Scheme respectively.

5.6.2. Specific criteria used.

Since each of the land utilization type (LUT) under consideration has its own requirements in terms of the land qualities, a land suitability evaluation criteria was set for each LUT separately (see tables 32a to f).

In the process of selection of the land qualities to be considered and the specifications of the criteria for land suitability evaluation for each LUT, the following basic assumptions were made:

1. that the quantity and quality of irrigation water is not limiting. The quality of irrigation water is important, particularly when taking into account the management aspects of irrigation. As indicated in chapter 2.3.2.2. the Tana river water is classified as low-salinity/low sodium water (class C1-S1) and is therefore considered suitable for irrigating even the most sensitive crops. However, the water is of such low salinity that it may further reduce the infiltration rate of the soils by causing the surface structure to slake (FAO, 1976; Ayers and Westcot, 1985 p. 59).
2. that the level of irrigation management is high with also high inputs. In view of this the land quality "availability of nutrients" is given less weight in the specifications for the land suitability evaluation criteria for the various LUTs. It is presumed that the low chemical soil fertility of

TABEL 31a. RATING OF THE LAND QUALITIES - BURA EAST AREA.

Mapping Unit	Land Quality										
	Capacity for water retention	Absence of salinity	Absence of sodicity	Availability of oxygen for root growth	Conditions for germination	Availability of nutrients	Availability of foothold for roots	Workability (ease of tillage)	Ability for drainage	Ease of land clearing (sparseness of vegetation cover)	Freedom for layout of field plans
Ps 1.1.	3	4	5	3	4	4	5	4	4	4	1
Ps 1.2.	3	5	5	3	4	4	4	4	4	4	1
Ps 1.3.	3	4	5	3	4	3	4	3	4	4	1
Ps 2.1.	2	1	1	2	2	3	1	3	2	1	1
Ps 2.2.	2	1-2	1	2-3	2	3	1	3	2	2	1
Ps 2.3.	2	1-2	2	3	2	3	1	3	2	2	1
Ps 2.4.	2	1-2	3	2	2	3	2	3	2	2	1
Ps 2.5.	2	1-2	3	2-3	2	3	3	3	2	2	1
Ps 2.6.	2	2	3	3	3	3	3	3	3	2	1
Ps 2.7.	2	2	3	3	3	3	3	3	2	3	1
Ps 2.8.	2	3	3	2-3	3	3	3	3	3	2	1
Ps 2.9.	2	3-4	3	3	3-4	3	4	4	3	2	1
Ps 2.10.	2	3-4	4	3	3-4	3	4	4	3	2	1
Ps 2.11.	2	3-4	4	3-4	3	3	3	3	3	2	1
Ps 2.12.	2	3-4	3	3-4	3	4	3-4	4	3	1-2	1
Ps 2.13.	2	3-4	3-4	3-4	3	3	4	4	3	1-2	2
Ps 2.14.	2	3	4	3-4	3	3	4	4	3	2	2
Ps 2.15.	2	4	4	3-4	3-4	3	4	3	3	2	2
Ps 2.16.	2	2-4	2-5	2-3	3	3	2-3	3	2	2	1
Ps 2.17.	2	2-4	2-5	2-3	3-4	3	3	3-4	2	2	1
Ps 3.1.	3	3-4	3	4	2	3	4	4	3	1	2
Ps 3.2.	3	3-4	3	4-5	2	3	4	4	4	1	2

TABLE 31b. RATING OF THE LAND QUALITIES - BURA WEST AREA.

Mapping Unit	Land Quality										
Pf 1.1.	4	3	3	1-2	4	4	2	2	5	na	na
Pf 1.2.	1-3	4	4	2-3	4	4	4	2	4	na	na
Pf 1.3.	1-3	5	5	2-3	4-5	4	5	3-5	4	na	na
Pf 2.1.	2	1	2	1	2	2-3	1-2	2	2	na	na
Pf 2.2.	2-3	2-4	4	1	3	3	3	3	3	na	na
Pf 2.3.	2	3-4	4	1	3	3	4	3	3	na	na
Pf 2.4.	2	2-4	4-5	1-2	3	3-4	3-4	4	4	na	na
Pf 2.5.	2	2-4	4-5	1-2	4	4	4-5	5	4	na	na
Pf 3.1.	3	3-4	3-4	2-3	3	3	3	3	3	na	na
Pf 3.2.	3	3-4	3	2-3	3	3	3	4	3	na	na
Pf 3.3.	3	3-4	3	3-4	4	4	3	4	3	na	na
Al	3	1-3	3	3	3-4	4	2	4	4	na	na

TABLE 31c. RATING OF LAND QUALITIES - HOLA IRRIGATION SCHEME.

Mapping Unit	Land Quality										
Pt1-I	1	2	3	1-2	2	3	2	3	2	na	na
Pt1-NI	1	3	3-4	1-2	2-3	3	3	3	3	na	na
Pt2-I	1-2	2	4	1-2	2	3-4	2	3	2	na	na
Pt2-NI	1-2	2-4	4	1-2	2-3	3-4	3	3	3	na	na
Pt3-I	2	2-3	3	1-2	2	3-4	2-3	3-4	3	na	na
Pt3-NI	2	4	3-4	1-2	2-3	3-4	3	3-4	3	na	na
Pt4-I	2	1-2	4	2-3	2-3	3	3	3	4	na	na
Pt4-NI	2	1-2	5	2-3	2	3	4	3	4	na	na
Pt5-I	2	3	4	2-3	2	3-4	3	3-4	3	na	na
Pt5-NI	2	4	5	2-3	4	4	4-5	3-4	3	na	na
Pt6-I	2	2	3	2-3	3	3-4	3	3-4	3	na	na
Pt6-NI	2	3-4	3	2-3	3	4	4	3-4	3	na	na
Pt7-I	1-2	2	3	2-3	2	3	2	3-4	3	na	na
Pt7-NI	1-2	4-5	3-5	2-3	3	3	4	3-4	3	na	na
Pt8-I	2	2	3	2-3	1-2	3-4	3	3	2	na	na
Pt8-NI	2	4	4	2-3	3-4	3	4	3	2	na	na
Pt9	3	2-4	4-5	3	3	3	4	3	4	na	na

I - Irrigated
NI - Non-Irrigated
na - not applicable
Note: The range of the ratings given reflects the variations of the land qualities within the mapping unit.

TABLE 32a. LAND SUITABILITY EVALUATION CRITERIA FOR LAND UTILIZATION TYPE C - IRRIGATED COTTON.

Land Suitability Class	Land Quality: Capacity for water retention	Absence of salinity	Absence of sodicity	Availability of oxygen for root growth	Conditions for germination	Availability of nutrients	Availability of foothold for roots	Workability (ease of tillage)	Ability for drainage	Ease of land clear-ing (sparseness of vegetation cover)	Freedom for layout of field plans
S1	1	2	2	2	1	2	1	2	1	1	1
S2	2	3	3	3	2	3	2	3	2	2	2
S3	3	4	4	4	3	4	3	4	3	3	3
NS2	4	5	5	5	4	4	4	5	4	4	4

TABLE 32b. LAND SUITABILITY EVALUATION CRITERIA FOR LAND UTILIZATION TYPE M - IRRIGATED MAIZE.

Land Suitability Class	Land Quality										
S1	1	1	1	1	1	2	2	2	1	1	1
S2	2	2	2	2	2	3	3	3	2	2	2
S3	3	3	3	3	3	4	4	4	3	3	3
NS2	4	4	4	4	4	4	5	5	4	4	4

TABLE 32c. LAND SUITABILITY EVALUATION CRITERIA FOR LAND UTILIZATION TYPE R - BASIN IRRIGATION OF RICE.

Land Suitability Class	Land Quality										
S1	2	1	1	2	na	2	2	2	2	1	1
S2	3	2	2	3	na	3	3	3	3	2	1
S3	4	3	3	4	na	4	4	4	4	3	2
NS2	5	4	4	1,5	na	4	5	5	5	4	3

TABLE 32d. LAND SUITABILITY EVALUATION CRITERIA FOR LAND UTILIZATION TYPE S - IRRIGATED SUGARCANE.

Land Suitability Class	Land Quality										
S1	1	1	1	2	na	2	2	2	1	1	1
S2	2	2	2	3	na	3	3	3	2	2	2
S3	3	3	3	4	na	4	4	4	3	3	3
NS2	4	4	4	5	na	4	5	5	4	4	4

TABLE 32e. LAND SUITABILITY EVALUATION CRITERIA FOR LAND UTILIZATION TYPE P - IRRIGATED COWPEAS.

Land Suitability Class	Land Quality										
S1	1	1	1	1	1	2	2	2	1	1	1
S2	2	2	2	2	2	3	3	3	2	2	2
S3	3	3	3	3	3	4	4	4	3	3	3
NS2	4	4	4	4	4	4	5	5	4	4	4

TABLE 32f. LAND SUITABILITY EVALUATION CRITERIA FOR LAND UTILIZATION TYPE G - IRRIGATED GROUNDNUTS.

Land Suitability Class	Land Quality										
S1	1	1	1	1	1	2	2	1	1	1	1
S2	2	1	2	2	2	3	3	2	2	2	2
S3	3	2	3	3	3	4	4	3	3	3	3
NS2	4	3	4	4	4	4	5	4	4	4	4

S1 - highly suitable
S3 - marginally suitable
S2 - moderately suitable
NS2 - permanently not suitable
na - not applicable

most of the soils in the three study areas can be corrected by addition of appropriate fertilizers.

3. that in the process of planning and implementation of the irrigation schemes, soil conservation measures were taken or will be taken to protect the soils against erosion. In view of this the land quality "resistance to erosion" has not been applied in this land evaluation.
4. that flood control measures form part of the irrigation implementation and thus the land quality "hazard of flooding" was not included as a limitation in this land evaluation. However, flooding hazard is implicit in drainage limitations.

5.6.3. Land suitability classification.

The land suitability classes were established for each of the LUTs by considering the land quality requirements of the various land mapping units. The land qualities of the land mapping units were compared ("matched") with the limits set for each LUT to arrive at the suitability classes. The most limiting land quality of the land mapping unit under consideration determines the final suitability. However, it should be noted that at this stage of the land evaluation procedure personal judgement based on the knowledge of the field conditions plays an important role as well.

Five land suitability classes were distinguished according to the degree of the limitations and their effect on the productivity of the land under irrigation. The suitability classes used have been adopted from FAO (1976) and modified to suit Kenyan conditions (cf. Muchena 1981; Muchena and van der Pouw, 1981a). The effects of the various land qualities on productivity in each LUT have been estimated on the basis of general data on crop requirements and the general information on the envisaged management problems associated with each land quality (see chapter 5.5.).

Individual land suitability classes were assigned "Productivity indices" which decrease proportionally from a maximum of 100 percent for class S1 (highly suitable) to less than 40 percent for class NS2 (not suitable). The "productivity indices" were defined on the basis of calculated "potential production" based on the availability of solar radiation, the temperature of the production environment and the photosynthetic mechanism of the plant (Driessen, 1986; Van Keulen and Wolf, 1986; FAO, 1978).

Class S1 Highly suitable.
Lands having little or no limitation for sustained high yields of most climatically adapted crops under irrigation (basin irrigation of rice and/or basin-furrow irrigation of other crops) with minimum costs of development and management associated with the land. Productivity 100-81 percent of the calculated maximum.

Class S2 Moderately suitable.
Lands having moderate limitations for sustained irri-

gated crop production (basin irrigation of rice and/or basin-furrow irrigation of other crops); the limitations will reduce productivity and will require moderate costs for development and management to the extent that the overall advantage to be gained from irrigated crop production, although still attractive will be appreciably inferior to that expected on class S1 land. Productivity 80-61 percent of the calculated maximum.

Class S3 Marginally suitable.
Lands having severe limitations for sustained irrigated crop production (basin and/or basin-furrow); these lands require high costs for development and management which can be only marginally justified. Productivity 40-60 percent of calculated maximum.

Class NS1 Provisionally not suitable.
Lands which are considered not suitable for sustained irrigated crop production (basin and/or basin-furrow) pending further investigations. The limitations may be surmountable in time but cannot be corrected with existing knowledge at currently acceptable cost. Productivity not determined.

Class NS2 Permanently not suitable.
Lands having excessively severe limitations which preclude any possibilities for sustained irrigated crop production (basin and/or basin-furrow). Productivity less than 40 percent of calculated maximum.

5.6.4. Calculations of potential production.

The "potential production" of five[a] crops (cotton, maize, rice, groundnut and sugarcane) considered in the various LUTs were calculated using the crop production model (WOFOST) developed by the centre for World Food Studies in Wageningen (cf. Van Keulen and Wolf, 1986 and Driessen, 1986). The calculated potential production is the highest that is theoretically possible and is dictated only by the availability of solar radiation, temperature regime during the growing period and the properties of the crop grown. Other land qualities such as availability of moisture, nutrients, diseases and pests etc. are assumed to be optimal. It should however, be noted that the calculated potential production levels are rarely achieved by farmers. Nevertheless they can be used as estimates of the production possibilities of the examined LUT. The temperature and solar radiation data recorded at Hola (KMD, 1984) were used for the climatic inputs in the model. The mean monthly temperatures were used to calculate the temperatures during the various growth decades. It should be noted that the results obtained by use of such average data only give a rough approximation of the average situation since in actual situations conditions are different every year.

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[a]No potential production was calculated for cowpeas due to lack of input data on crop coefficients for the model used.

The estimated potential production possibilities of the five crops considered are given in table 33. Although the crop factors

Table 33. Estimated potential production of the various crops.

Crop	Estimated potential production (in tons/hectare)	Date of planting for highest production
Cotton	5 - 6	Late February to early April
Maize	6.5 - 7.5	August - November
Rice	5 - 6	Early May to late June
Sugarcane	22 - 25	March to April
Groundnuts	3 - 4	Late April to early June

used in the model for the calculation of the potential product ion are for crop varieties which are different from the ones currently being grown at Hola Irrigation Scheme, the calculated figures may probably be taken as a good estimate of the potential production possibilities in the study areas. Below the calculated potential productions for maize and cotton are compared with the observed yields at Bura West and Hola Irrigation Schemes.

Experiments carried out at Bura West Irrigation Scheme to investigate the effect of time of planting on seed cotton production (Anonymous, 1984a) have shown that seed cotton yields tend to increase for the cotton planted during the period early February to early April when a peak is reached. A depression of yields was observed for cotton planted after this period. It is reported also that a similar trend has been observed for seed cotton production at Hola Irrigation Scheme (Acres/ILACO, 1967 and Anonymous, 1984a). The calculated potential production using the model also indicates that the highest yields would be obtained when cotton is planted during the period late February to early April (see appendix 4B). ILACO (1974) reported that cotton grown over the short rains season (October to December) gave some 30 percent lower yields than that planted during the period mid-February to early April. The calculated potential production figures shown in appendix 4B also indicate that cotton grown during the period October to December would have a production potential which is 60-70 percent of that planted during the period late February to early April. This observation together with the previous one mentioned above, show the same trend as the observed situations at Hola and Bura West Irrigation Schemes. In view of this, the estimated potential production possibilities calculated for cotton may be taken as good approximations of the expected maximum yields under the prevailing climatic conditions without any other limiting factors for crop production.

Monitoring of maize cultivation at Hola has shown that yields are unaffected by time of planting. The calculated yield potentials also do not vary much throughout the year (see appendix 4C). This implies too that the calculated potential production for maize may also be taken as a good approximation of the expected maximum yields of the maize variety considered under the prevailing climatic conditions without any other limitations for crop production.

The average cotton yields obtained at Hola and Bura West Irrigation Schemes are in the order of 2.5 to 3.0 tons seed cotton per hectare (see figures 18a and 18b in chapter 2.4.2.). These yields are approximately 40 to 60 percent of the calculated potential yields. Under research conditions yields of 3.8 tons per hectare have been obtained. This is about 60 to 75 percent of the calculated maximum potential production.

The average maize yields at Hola are normally 2 to 3 tons per hectare while those at Bura West Irrigation Scheme are in the order of 2 tons per hectare. These yields correspond to 30-40 percent and 30 percent of the calculated potential production. Under research conditions yields of 3.3 to 4.4 tons and 3.3 tons per hectare have been obtained for Hola and Bura West Irrigation Schemes respectively. These yields are in the order of 50 to 60 percent of the calculated potential production.

5.6.5. Results and conclusions of the land evaluation.

The results of the land suitability classification are presented in tables 34a, 34b and 34c, for the Bura East, Bura West and Hola Irrigation Scheme respectively. The suitability of the soils for the various LUTs considered is discussed briefly below:

LUT-C: Irrigated Cotton

Bura East area	Soils of mapping units Ps 2.1. and Ps 2.4. are moderately suitable whereas those of mapping units Ps 2.2., Ps 2.3. and Ps 2.5. are marginally to moderately suitable. Soils of mapping units Ps 2.6. to Ps 2.8. and Ps 2.11. are marginally suitable whereas the bulk of the other soils are considered as not suitable.
Bura West area	Soils of mapping unit Pf 2.1. are considered as moderately suitable whereas those of mapping units Pf 2.2, Pf 3.1. and Pf 3.2. are marginally suitable. The soils of the other mapping units are considered as not suitable.
Hola Irrigation Scheme	The irrigated soils of mapping units Pt 1 are considered moderately suitable while those of mapping units Pt 3 and pt 8 are marginally to moderately suitable.

Table 34. Land suitability classes for the various LUTs.

Mapping Unit	Area in hectares	Land utilization type C- Irrigated cotton	Land utilization type M- Irrigated maize	Land utilization type R- Basin irrigation of rice	Land utilization type S- Irrigated sugarcane	Land utilization type P- Irrigated cowpeas	Land utilization type G- Irrigated groundnuts
(a) Bura East area							
Ps1.1	7750	NS2	NS2	NS2	NS2	NS2	NS2
Ps1.2	8400	NS2	NS2	NS2	NS2	NS2	NS2
Ps1.3	1500	NS2	NS2	NS2	NS2	NS2	NS2
Ps2.1	930	S2	S2	S2	S2	S2	S2_S3
Ps2.2	1150	S2	S2-S3	S2	S2	S2-S3	S2-S3
Ps2.3	1310	S2	S3-S3	S2	S2	S2-S3	S2-S3
Ps2.4	3000	S2	S2-S3	S2-S3	S2-S3	S2-S3	S3
Ps2.5	2210	S2-S3	S2-S3	S2-S3	S2-S3	S3	S3
Ps2.6	4080	S3	S3	S2-S3	S3	S3	S3
Ps2.7	2200	S3	S3	S2-S3	S3	S3	S3
Ps2.8	2420	S3	S3	S3	S3	S3	NS1
Ps2.9	13700	NS1	NS2	NS1	NS2	NS2	NS2
Ps2.10	3770	NS1	NS2	NS1	NS2	NS2	NS2
Ps2.11	3260	S3	NS2	NS1	NS2	NS2	NS2
Ps2.12	9750	NS1	NS2	NS1	NS2	NS2	NS2
Ps2.13	2700	NS2	NS2	NS1	NS2	NS2	NS2
Ps2.14	1590	NS2	NS2	NS2	NS2	NS2	NS2
Ps2.15	4960	NS2	NS2	NS2	NS2	NS2	NS2
Ps2.16	570	NS2	NS2	NS2	NS2	NS2	NS2
Ps2.17	1280	S3-NS2	S3-NS2	S3-NS2	S3-NS2	NS2	NS2
Ps3.1	4140	NS2	NS2	NS1	NS2	NS2	NS2
Ps3.2	960	NS2	NS2	NS2	NS2	NS2	NS2
Total	81630						
(b). Bura West area							
Pf1.1	20	NS2	NS2	NS2	NS2	NS2	NS2
Pf1.2	3050	NS2	NS2	NS2	NS2	NS2	NS2
Pf1.3	185	NS2	NS2	NS2	NS2	NS2	NS2
Pf2.1	2845	S2	S2	S2	S2	S2	S2
Pf2.2	2620	S3	S3-NS2	S3-NS2	S3-NS2	S3-NS2	NS2
Pf2.3	1730	S3-NS2	NS2	NS2	NS2	NS2	NS2
Pf2.4	1210	NS2	NS2	NS2	NS2	NS2	NS2
Pf2.5	600	NS2	NS2	NS2	NS2	NS2	NS2
Pf3.1	450	S3	S3-NS2	S3-NS2	S3-NS2	S3-NS2	NS2
Pf3.2	1710	S3	S3-NS2	S3-NS2	S3-NS2	S3-NS2	NS2
Pf3.3	35	NS2	NS2	S3-NS2	S3-NS2	NS2	NS2
Ai	435	NS2	NS2	S3 *	NS2	NS2	NS2
Total	14890						
(c). Hola Irrigation Scheme.							
Pt1-I		S2	S3	S2-S3	S3	S3	S3
Pt1-NI	270	S3	S3-NS2	S3-NS2	S3-NS2	S3-NS2	NS2
Pt2-I		S3	S3-NS2	S3-NS2	S3-NS2	S3-NS2	NS2
Pt2-NI	175	S3	NS2	NS2	NS2	NS2	NS2
Pt3-I		S2-S3	S3	S3	S3	S3	S3
Pt3-NI	495	S3	S3-NS2	NS2	NS2	NS2	NS2
Pt4-I		NS2	NS2	NS2	NS2	NS2	NS2
Pt4-NI	50	NS2	NS2	NS2	NS2	NS2	NS2
Pt5-I		S3	S3-NS2	S3-NS2	S3-NS2	S3-NS2	NS2
Pt5-NI	175	NS2	NS2	NS2	NS2	NS2	NS2
Pt6-I		S3	S3	S3	S3	S3	S3
Pt6-NI	40	NS2	NS2	NS2	NS2	NS2	NS2
Pt7-I		S3	S3	S3	S3	S3	S3
Pt7-NI	45	NS2	NS2	NS2	NS2	NS2	NS2
Pt8-I		S2-S3	S3	S3	S3	S3	S3
Pt8-NI	135	S3-NS2	NS2	NS2	NS2	NS2	NS2
Pt9-NI	335	NS2	NS2	NS2	NS2	NS2	NS2
Total	1720						

* If the risk of inundation is taken into account this unit would classify as NS2.

I - Irrigated
NI - Non-irrigated

The soils of the other mapping units are either marginally suitable or not suitable.

LUT-M: Irrigated maize:

Bura East area	Soils of mapping units Ps 2.1. to Ps 2.8. are considered to be marginally to moderately suitable. The bulk of the other soils are not suitable.
Bura West area	Soils of mapping unit Pf 2.1. are moderately suitable while soils of mapping units Pf 2.2., Pf 3.1. and Pf 3.2. are considered as marginally suitable to not suitable. The soils of the other mapping units are considered as not suitable.
Hola Irrigation Scheme	The soils of the irrigated parts of mapping units Pt 1., Pt 3., Pt 6., Pt 7. and Pt 8. are classified as marginally suitable. The soils of the other mapping units are either marginally suitable to not suitable or not suitable.

LUT-R: Basin Irrigation of rice:

Bura East area	Soils of mapping units Ps 2.1. to Ps 2.3. are moderately suitable, those of mapping units Ps 2.4. to Ps 2.7. marginally to moderately suitable while those of mapping unit Ps 2.8. are marginally suitable. Soils of mapping units Ps 2.9. to Ps 2.13. and Ps 3.1. are considered provisionally not suitable for basin irrigation of rice pending further investigations particularly with respect of possibilities of leaching the salts. The soils of the other mapping units are considered as not suitable.
Bura West area	Soils of mapping unit Pf 2.1. are moderately suitable while those of mapping units Pf 3.1., Pf 3.2. and Pf 3.3. are considered as marginally suitable to not suitable. Soils of mapping unit A1 are considered as marginally suitable for irrigated rice but if the risk of inundation by Laga Hiraman is considered, these soils too would be classified as not suitable. The soils of the other mapping units are considered as not suitable.
Hola Irrigation Scheme	The bulk of the irrigated soils are considered to be marginally suitable.

LUT-S: Irrigated Sugar cane

Bura East area	Soils of mapping units Ps 2.1. to Ps 2.3. are moderately suitable while those

	of mapping units Ps 2.4. and Ps 2.5. are marginally to moderately suitable. Soils of mapping units Ps 2.6. to Ps 2.8. are marginally suitable. The bulk of the other soils are considered as not suitable.
Bura West area	Soils of mapping unit Pf 2.1. are moderately suitable whereas those of mapping units Pf 3.1. to Pf 3.3. are marginally suitable to not suitable. The soils of the other mapping units are considered as not suitable.
Hola Irrigation Scheme	Irrigated soils of mapping units Pt 1., Pt 3., Pt 6., Pt 7. and Pt 8. are marginally suitable whereas those of irrigated parts of mapping units Pt 2., Pt 5. and the non-irrigated parts of unit Pt 1 are considered to be marginally suitable to not suitable.

LUT-P: Irrigated cowpeas

Bura East area	Soils of mapping unit Ps 2.1. are moderately suitable; those of mapping units Ps 2.2. and Ps 2.3. are marginally to moderately suitable whereas those of mapping units Ps 2.4. to Ps 2.8. are marginally suitable. The other soils are considered as not suitable.
Bura West area	Soils of mapping unit Pf 2.1. are moderately suitable, those of mapping units Pf 3.1. and Pf 3.2. are marginally suitable to not suitable whereas the other soils are considered as not suitable.
Hola Irrigation Scheme	Irrigated soils of mapping units Pt 1., Pt 3., Pt 6., Pt 7. and Pt 8. are marginally suitable whereas the irrigated soils of mapping units Pt 5. and Pt 2. plus the non-irrigated soils of mapping unit Pt 1. are considered as marginally suitable to not suitable. The other soils are considered as not suitable.

LUT-G: Irrigated Groundnuts

Bura East area	Soils of mapping unit Ps 2.1. are marginally to moderately suitable whereas those of mapping units Ps 2.2. to Ps 2.7. are marginally suitable. Soils of mapping unit Ps 2.8. are classified as provisionally not suitable whereas those of the other mapping units are considered as not suitable.
Bura West area	Only soils of mapping unit Pf 2.1. are

	considered as moderately suitable. The other soils are considered to be not suitable.
Hola Irrigation Scheme	Irrigated soils of mapping units Pt 1., Pt 3., Pt 6., Pt 7. and Pt 8 are classified as marginally suitable whereas the other soils are considered to be not suitable.

The soils classified as provisionally not suitable (class NS1) require further investigations to determine their final suitability. Those soils classified as permanently not suitable (class NS2) are the soils in which the production of the envisaged crops is considered uneconomical under the prevailing soil conditions and management.

It is worthwhile to mention here that a land suitability evaluation like this one should be accompanied by a socio-economic study. This aspect is beyond the scope of the present study. However, it should be noted that some economic considerations are implicit in the definition of the various LUTs and the "productivity indices" used in partitioning the suitability classes. Fortunately for the Bura West and Hola Irrigation Schemes socio-economic and agro-economic studies have been carried out which also point out the marginality of these soils for irrigated-agriculture. For a comprehensive socio-economic analysis of the Bura West Irrigation Scheme reference is made to the work of De Leeuw (1985) while for an agro-economic analysis of production costs at Hola Irrigation Scheme reference is made to the study of Houtman (1981).

From the results of the land suitability classification presented above, the bulk of the soils in the three study areas are considered to be marginally suitable to not suitable, for irrigated agriculture. This is the case particularly for commonly grown crops such as maize, cowpeas, groundnuts etc. which are sensitive to salinity and sodicity. The yields of maize obtained at Hola and Bura West Irrigation Schemes are about 30 to 40 percent of the estimated potential yields. These yields are considered to be very low. The low maize yields are attributed to the limiting soil conditions - particularly salinity and sodicity considering that the maize varieties grown are sensitive to salinity and sodicity.

For cotton, which is more tolerant to higher levels of salinity and sodicity (see chapter 5.5.) than the other crops considered in this evaluation, the yields obtained at both Hola and Bura West Irrigation Schemes are slightly better. The yields are in the order of 40 to 75 percent and 40 to 60 percent of the estimated potential production for the Hola and Bura West irrigation Schemes respectively.

The major limiting factors in order of severity are:
* salinity

* sodicity
* drainability
* effective rooting depth
* availability of oxygen for root growth
* workability of the soils
* capacity for water retention
* availability of nutrients
* conditions for germination
* ease of land clearing
* freedom for layout of field plans

The first six factors are considered to be the most limiting in the three study areas.

6. CONCLUSIONS.

A number of conclusions have been reached in the course of discussions under the various topics treated in this study. However, a summary of the most salient ones is given below.

6.1. CLIMATIC CONDITIONS.

The study areas are located in a semi-arid to arid part of Kenya where on average potential evaporation exceeds the rainfall by a factor of two or more throughout the year and therefore the chances of a successful rainfed crop production in the area is very small.

6.2. SOILS.

The soil investigations reveal twenty two (22) soil units in the Bura East area, twelve (12) soil units in the Bura West area and nine (9) soil units in the Hola Irrigation Scheme. The soils fall into six major soil groupings (FLUVISOLS, VERTISOLS, CAMBISOLS, CALCISOLS, SOLONETZ and LUVISOLS) according to the FAO-Fourth Draft Revised Legend (FAO, 1987) or fall into six Great Groups (Natrargids, Haplargids, Paleargids, Camborthids Torrerts and Torrifluvents) according to the USDA, Soil Taxonomy (Soil Survey Staff, 1975).

The soils vary widely in both physical and chemical properties. More notable is the degree of variation in salinity and sodicity in the various soils. The soil drainage classes vary from well drained to poorly drained. However, the possibilities for deep subsurface drainage vary in the three study areas.

The bulk of the soils have clayey textures and have in general low to moderate infiltration rates and slow hydraulic conductivity particularly in the subsoil.

6.3. SOIL CONDITIONS MONITORING.

The results of the monitoring of soil conditions and changes under irrigation at Hola and Bura West Irrigation Schemes have revealed the following:

A. that the two soils monitored at Hola (Chromi-calcic VERTISOLS and Calcari-vertic CAMBISOLS) and the two soils monitored at Bura West (Chromi-calcic VERTISOLS and Chromi-calcaric CAMBISOLS) behave differently under the same irrigation practices and management;

B. that the soils within the various irrigation subunits monitored are not homogeneous with respect to salinity and alkalinity;

C. that there were variations in crop performance in the different irrigation subunits due to variations in soil conditions such as salinity, sodicity, water infiltration rates, surface crusting etc.

The predictive models constructed on the basis of the results of four years soil conditions monitoring at Hola and Bura West Irrigation Schemes show that salinity will decrease in time in all the four soils monitored. However in some of the soils a decrease in salinity is accompanied by an increase in pH which may probably lead to unfavourable soil properties and hence present problems in irrigation management of these soils. In view of this, it is recommended that the soil conditions monitoring be continued in order to validate the predictions of the model and at the same time arrive at firm conclusions as to what the long term effects of irrigation would be on these soils. Trial investigations on salt movement and possible corrective measures have also to be carried out.

6.4. IRRIGATION SUITABILITY.

The results of the land suitability evaluation for the various LUTs considered reveal that the bulk of the soils in the three study areas are marginally suitable to not suitable for irrigated agriculture.

The major limiting factors are: salinity, sodicity, drainability, effective rooting depth and workability of the soils. Low yields of maize at both Hola and Bura West Irrigation Schemes are attributed to the high levels of salinity and sodicity.
The yields of cotton, which is more tolerant to higher levels of salinity and sodicity, are slightly better. This indicates that irrigated agriculture in the study areas should be accompanied by a careful selection of crops and varieties that are tolerant to high levels of salinity and sodicity. However, the final decision on whether to implement irrigation schemes under such limiting soil conditions should be made after comprehensive socio-economic studies have been carried out.

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APPENDIX 1.
METHODS OF INVESTIGATION

1.1. SURVEY METHODS.

1.1.1. Office methods.

As a first step in the reconnaissance soil survey of the Bura East area the available aerial photographs, topographic and geological maps together with all the existing reports and other relevant literature about the area were collected and studied. Aerial photographs (scale 1:40.000) and photo laydowns (scale 1:100,000) were available.

Prior to the fieldwork all photographs covering the study area were studied stereoscopically and a preliminary photo interpretation map and legend was made. Landforms and the vegetation cover initially formed the basis for delineating areas that were thought to have similar soils. Making use of the 1:40,000 aerial photographs taken in 1979 a draft base map was prepared onto which all field observations and soil boundaries were transferred. After completion of the fieldwork the final soil boundaries and symbols were transferred to a topographical base map at scale 1:100,000.

For the Bura West and Hola study areas, existing soil maps by Acres/ILACO (1967) and ILACO (1968) were studied together with aerial photographs (scale 1:20,000) prior to selection of sites where additional profile pits were made.

1.1.2. Field methods.

Soils were studied in the field in soil pits and materials brought up by soil auger. Augerholes were made to a depth of 300 cm, soil conditions permitting. For each augerhole soil samples were taken from natural horizons for screening tests (EC, pH and gypsum) in the field laboratory. At each observation site a shallow pit (about 50 cm deep) was made to study the boundary between the top horizon and the next. In most soil mapping units, representative sites were selected where 150-200 cm deep profile pits were dug. The pits were subsequently augered up to a depth of 3 metres. Soil descriptions were based on the FAO Guidelines for Soil Profile Description (FAO, 1977) and the Soil Survey Manual (USDA, Soil Survey Staff, 1951). Munsell Colour charts were used for the colour identification. In profile pits, each soil horizon was sampled for physical and chemical analysis at the National Agricultural Laboratories (NAL), Nairobi. In addition composite samples of the topsoil (usually 0-30 cm) were taken for fertility evaluation.

In all the three study areas field observations followed a fixed grid pattern. In the Bura East area 268 shallow pits and augerings and 71 profile pits were made and described. Fifteen of the profile pits were dug up to a depth of 5-6 metres and augered up to 10 metres. In the Bura West area 6 profile pits were made in addition to those previously made by Acres/ILACO (1967) and ILACO (1975) and Kenya Soil Survey (Mugai and Van der Pouw, 1978). In the Hola area, 17 additional profile pits were made. In the Bura West and Hola areas additional soil data was obtained from the augerholes made for soil conditions monitoring.

1.2. LABORATORY METHODS.

A detailed account of the physical and chemical methods of soil analyses used at N.A.L. is given in Hinga et.al. (1980). For the purposes of this study only a summary of the methods is given below.

1.2.1. Sample preparation.

Breaking up of aggregates by careful pounding with pestle and mortar, sieving through a 2 mm sieve. The fine earth fraction (smaller than 2 mm) is used for further analyses.

1.2.2. Particle size analysis (Texture).

The determinations were carried out on the fine earth of all samples using the hydrometer method. No chemical treatments were used to remove cementing agents. Samples were shaken overnight with sodium hexametaphosphate/sodium carbonate in an end-over-end shaker at 40 r.p.m. Measurements of silt + clay (0-2 μ) were carried out with a hydrometer ASTM 152 H after 40 seconds and 2 hours respectively. The sand fraction (50-200 μ) was obtained by difference (Day, 1956).

1.2.3. Determination of the pH-water, pH-KCl and Electrical Conductivity (EC).

The pH and EC were measured in suspensions with a soil:water ratio of 1:2.5. Suspensions were prepared by scooping up one volume of fine earth and adding it to 2.5 volumes of water[1]. pH-H_2O readings were done in the suspension with a pH meter with glass electrode. EC readings were done with an Electrical Conductivity meter. pH-KCl measurements were carried out in a suspension with a 1:2.5 ratio of soil:1N KCl.

For samples with an EC greater than 0.8 mmhos/cm a saturation extract was prepared for additional pH and ECe determinations. Soluble salts in the extracts were also measured.

1.2.4. Free Calcium Carbonate determination.

The fine earth fraction was subjected to treatment with 25% HCl and the soil was then shaken for half an hour in a "Scheibler" apparatus. The volume of evolved carbon dioxide (CO_2) was measured. Results are given as % $CaCO_3$ equivalent (Richards, 1954).

1.2.5. Gypsum determination.

Determination of gypsum was based on the low solubility in an aqueous solution of acetone. The separated and washed gypsum precipitate was determined quantitatively using a reference graph showing relationship between the concentration and electrical conductivity of gypsum solutions.

1.2.6. Organic Carbon determination.

The organic carbon was determined according to the Walkley and Black method (Black, 1965, pp. 1372/6). The soil organic matter was oxidized with potassium dichromate and sulphuric acid without application of external heat. The amount of potassium dichromate used was determined by titration with ferrous sulphate using diphenylamine as indicator.

1.2.7. Cation Exchange Capacity determination.

The Cation Exchange Capacity (CEC) was determined by successive leachings of the soil (mixed with purified quartz sand) with 1N sodium acetate of pH 8.2, 95% ethyl alcohol and 1N ammonium acetate of pH 7.0. Na (corresponding to CEC) was determined in the last leachate with EEL flamephotometer. The results in me/100 g of oven dry soil give the CEC value at the equilibrium pH of 8.2.

1.2.8. Exchangeable Cations determination.

The soil mixed with purified quartz sand was leached with 1N ammonium acetate of pH 7.0. Na, K and Ca in the leachate were determined with an EEL flamephotometer with addition of lanthanum chloride for the last element. Mg was determined with an atomic absorption spectrophotometer. The results are expressed in me/100 g soil.

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[1]Loose fine earth prepared for analysis is estimated to have a bulk density of 1.2 g/cm^3. By scooping up one volume of this fine earth and adding it to 2.5 volumes water, the weight/weight ratio of the soil:water suspension is about 1:2.

1.2.9. "Mass Analysis" for available nutrients.

This analysis was carried out for topsoils or composite topsoil samples. The soil was extracted with a mixture of 0.1N HCl and 0.025N H_2SO_4 at a 1:5 ratio. Ca, K and Na were determined with an EEL flamephotometer. Mg was determined colorimetrically with Thiazol yellow reagent (Mehlich et.al. 1962). Mn was also determined colorimetrically using phosphoric acid-potassium periodate for colour development (Mehlich et.al., 1962). For P, the vanado-molybdophosphoric yellow method was followed. The results of Ca, Na, K, Mg and Mn are expressed in me/100 g soil while those for P are given in ppm.

1.2.10. Phosphorus determination.

Phosphorus was determined using the method outlined by Olsen et.al. (1954). The soil was shaken with 0.5 M $NaHCO_3$ for 30 minutes in a 1:20 soil:water ratio. The suspension was filtered and P in the extract was determined colorimetrically using molybdenum blue/ascorbic acid. The results are given in ppm.

1.2.11. Bulk density.

Bulk density values were obtained by determining the oven dry (105°C) weight of a soil core of known volume (Richards, 1954). The results are expressed in g/cm^3.

1.2.12. Determination of available moisture - pF curve.

Undisturbed ring samples and disturbed samples were taken at 26 sites in Bura East, 9 sites in Bura West and 8 sites in Hola area to determine the moisture retention characteristics in the laboratory. The undisturbed samples were used for the determination of the water content of pF0, 2,0, 2.3, 2.5, 2.7 and 3.0 and the bulk density while the disturbed samples were used for the determination of the water content of pF 3.7 and 4.2. The moisture content at the corresponding pressures of 0, 0.1, 0.2, 0.33, 0.5, 1.0, 5.0 and 15 atmospheres respectively was determined using standard moisture extraction equipment as provided by Soil Moisture Company, Santa Barbara, California, U.S.A.

1.2.13. Determination of water soluble salts and ions in a saturation extract.

Water was added to the soil till a saturated paste was obtained. An extract was obtained by filtration applying suction. In the extract ECe was measured with a conductivity meter and results expressed in mmhos/cm at 25°C. Ca^{++}, Mg^{++}, Na^+, K^+, HCO_3^-, Cl^- and $So_4^=$ were determined according to the methods described in USDA Handbook No. 60 (Richards, 1954). The results are expressed in me/litre.

1.2.14. Clay mineralogy.

The fraction 0-2µ was separated after pretreatments with hydrogen peroxide, hydrochloric acid and sodium dithionite (the latter two only if necessary) and dispersion with sodium hexametaphosphate/sodium carbonate. X-ray diffraction analyses were carried out on samples saturated with Mg and K using standard clay minerals for semi-quantitative estimation. Peak area ratios rather than peak height ratios were considered. Techniques involving solvation with ethylene glycol and heating to 550°C. were employed as well.

1.2.15. Preparation of thin sections.

The procedures for the preparation of thin sections follow the outlines by Jongerius and Heintzberger (1964). Samples were impregnated, sawn and polished to a thickness of about 30 micron. 15 thin sections were studied using a petrographic microscope.

A P P E N D I X 2

DESCRIPTION OF SOIL MAPPING UNITS

The Analytical Data and Representative Soil Profile Descriptions are published separately in Annex I., which is available at request from:

* Kenya Soil Survey; P.O. Box 14733; Nairobi - Kenya
* Netherlands Soil Survey Institute STIBOKA; P.O. Box 98; 6700 AB Wageningen, The Netherlands.

2.1. SOILS OF THE BURA EAST AREA.

2.1.1. Soils of the slightly high-lying land.

Mapping Unit Ps 1.1.

FAO-UNESCO Soil Units (FAO, 1974):
Gleyic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic SOLONETZ, Salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, fine loamy over clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained, very deep, greyish brown, to dark greyish brown sandy clay to clay soils with a clear hardpan at the top of the B-horizon. The topsoil is of varying thickness, but mainly 10-15 cm with textures of sandy clay loam to sandy clay. Colours are in hue 10YR.

They have columnar or prismatic structure starting close to the surface, with ped faces characteristically covered by a thin layer of bleached sandy material. The upper part of the columnar structure forms a hardpan. With increasing depth the structure changes to angular or subangular blocky. Clayskins are present in the B-horizon. They are hard to very hard when dry, firm when moist, sticky and plastic when wet. In places hard surface crusts (2-5 cm thick) are found.

The upper 10-15 cm of the soil is non-calcareous while the rest of the solum is strongly calcareous. In the deeper subsoil free lime may occur as concretions or soft powdery lime. Salinity starts at depths varying from 10 to 15 cm. In the deeper subsoil nests of salt crystals and accumulations of gypsum can be found. They are sodic from the surface. Soil reaction is alkaline, with pH-H_2O ranging from 7.5 to 8.6, although the upper part of the B-horizon may have pH-values of 9.0 or higher. pH-KCl is about 7.7 but some topsoils may have a value of less than 7.0.

Analytical data shows that the soils have low organic matter content-organic carbon is less than 0.4%; CEC-soil ranges between 20 and 40 me/100g except for the sandy clay loam or sandy clay horizons, which have a CEC of less than 20 me/100g. The clay mineralogy is predominantly montmorillonite.

Water infiltration rate is low: 3 mm/hour (topsoil). The hydraulic conductivity of the subsoil is slow, about 0.15 m/day. Slower values may be obtained particularly when the soil is wet because of the tendancy to slake due to high amounts of sodium in the exchange complex.

In places, inclusions of soils that are non-saline to a depth of about 50 cm may be found.

A representative profile pit is given as profile description no. 1.

Mapping Unit Ps 1.2.

FAO-UNESCO Soil Units (FAO, 1974):
Gleyic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, fine loamy over clayey, montmorillonitic, isohyperthermic.

These soils are similar to those of Unit Ps 1.1 except for the depth at which calcareousness, salinity and sodicity starts. Also in addition to prismatic and columnar structure, these soils may have moderately coherent massive structure of low porosity.

The soils are non-to slightly calcareous from the surface up to a depth ranging between 10 and 40 cm. The rest of the solum is strongly calcareous. Salinity starts at depths ranging between 10 and 40 cm from the surface. Sodicity starts from the surface, the top 10 to 40 cm being slightly to moderately sodic while the rest of the solum is moderately to strongly sodic. The soil reaction is alkaline, with pH-H_2O increasing with depth from 7.2 to 8.5 at 150 cm. The CEC-soil ranges between 17 and 40 me/100g while that of clay varies from 58 to 95 me/100g.

For a representative profile description with analytical data see Muchena and Van der Pouw (1981a).

Mapping Unit Ps 1.3.

FAO-UNESCO Soil Units (FAO, 1974):
Gleyic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, fine loamy over clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained, very deep, brown to dark greyish brown, sandy clay to clay soils with a thin topsoil of sandy clay loam to sandy clay. A clear hardpan occurs at the top of the B-horizon. Colours are in hue 10 YR.

The topsoil has subangular blocky structure while the subsoil has prismatic structure which changes into angular or subangular blocky in the deeper subsoil. Horizon transitions vary from abrupt and wavy in the topsoil to gradual and smooth in the deeper subsoil. Clay cutans are common in the B-horizon. In some soils slickensides are found. The topsoil is slightly hard when dry, friable when moist, and slightly sticky and slightly plastic when wet. The subsoil is hard to very hard when dry, firm when moist and sticky and plastic when wet.

The soils are slightly calcareous to a depth varying from 10 to 30 cm and strongly calcareous throughout the rest of the solum. The upper 10 to 30 cm of the soil is non- to slightly saline while the rest is moderately to strongly saline. In places nests of salt crystals are found. Sodicity starts from the surface increasing with depth. Soil reaction is alkaline with pH-H_2O varying from 7.8 to 8.6. However, in the upper parts of the B-horizon pH-H_2O values of 9.0 or higher may occur. pH-KCl is about 7.7.

Chemical analysis give organic carbon content of less than 0.4% and a CEC-soil ranging between 20 and 40 me/100 g. CEC-clay varies from 70 to 78 me/100 g in the topsoil and 49 to 54 me/100 g in the subsoil.

Infiltration rates and hydraulic conductivity were not measured in these soils but they are expected to be similar to those of unit Ps 1.1.

2.1.2. Soils of the slightly low-lying land.

Mapping unit Ps 2.1.

FAO-UNESCO Soil Units (FAO, 1974):
Luvic XEROSOLS
FAO-Revised Legend (FAO, 1987):
Gleyic LUVISOLS

USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic HAPLARGIDS, fine to very fine clayey, illitic, isohyperthermic.

These are moderately well drained, very deep, greyish brown to dark greyish brown, friable clay soils. Colours are in hue 10 YR. The structure is massive or weak subangular blocky in both topsoil and subsoil. In places patchy, thin clayskins and/or weak slickensides are found. Horizon transitions vary from clear to diffuse. The soils are slightly hard to hard when dry, friable when moist and sticky and plastic when wet.

These soils are non-calcareous throughout and are only slightly saline from 100/150 cm depth onwards. Sodicity starts at about 100 cm and increases with depth. Soil reaction is slightly acid to alkaline with pH-H_2O ranging between 6.5 in the topsoil and 8.6 in the deeper subsoil. pH-KCl varies from 5.5 to 7.0 over the same distance.

Analytical data indicates that the organic matter content is low (organic C% is less than 0.4). CEC-soil ranges between 30 and 45 me/100 g. CEC-clay varies from 49 to 93 me/100 g; base saturation increases from about 60% in the topsoil to 100% in the deeper subsoil.

Water infiltration rate is low: about 10 mm/hour. Hydraulic conductivity is also slow: varies from 0.05 to 0.09 m/day.

A representative profile pit is given as profile description no. 2.

Mapping Unit Ps 2.2.

FAO-UNESCO Soil Units (FAO, 1974):
Luvic XEROSOLS
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic LUVISOLS
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic HAPLARGIDS, fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, greyish brown to dark greyish brown, friable to firm clay soils, sometimes with a 20-40 cm thick topsoil of sandy clay. Colours are in hue 10 YR. The structure is weakly developed. It varies from massive to weak subangular blocky in the topsoil and from massive to weak angular blocky in the subsoil. In places a weak prismatic macrostructure is found. Broken, moderately thick clay cutans are found in the Bt-horizon. Horizon transitions vary from clear in the upper parts of the solum to diffuse in the lower parts. They are slightly hard to hard when dry, friable to firm when moist and sticky and plastic when wet.

These soils are slightly to strongly calcareous from a depth of 10 to 15 cm onwards. Soft powdery lime is found in the subsoil. Salinity starts at depths varying from 70 to 100 cm from the surface. They are slightly to moderately sodic from 70 to 100 cm onwards. Soil reaction is alkaline with pH-H_2O increasing from 8.0 in the topsoil to 9.5 in the deeper subsoil.

Chemical analysis reveal that organic carbon is less than 0.4%. CEC-soil ranges between 24 and 33 me/100 g while CEC-clay varies from 53 to 63 me/100 g.

In places there are inclusions of soils similar to those of unit Ps 2.1.

A representative profile pit is given as profile description no. 3.

Mapping Unit Ps 2.3.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, sodic phase
FAO-Revised Legend (FAO, 1987):
Calcari-vertic and Calcari-gleyic CAMBISOLS, sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Natric CAMBORTHIDS, fine clayey, mixed, isohyperthermic.

These are imperfectly drained, very deep, greyish brown to dark greyish brown, friable to firm, clay soils. Colours are in hue 10 YR. The structure varies from porous massive to weak subangular blocky in the topsoil to weak or moderate angular or subangular blocky in the subsoil. The upper part of the B-horizon may have a weak prismatic macrostructure. Patchy, thin clayskins and/or some pressure faces are found in the B-horizon. Cracks less than 1 cm wide occur between 20 and 70 cm depth. Horizon transitions are clear in the upper parts of the solum and gradual at greater depth. Consistency is slightly hard to hard when dry, friable to firm when moist and sticky and plastic when wet.

These soils are usually moderately to strongly calcareous throughout. Salinity starts at depths varying from 80 to 120 cm from the surface. The upper part of the solum (80 to 120 cm) is non- to slightly sodic while the rest is moderately to strongly sodic. The soil reaction depends very much on the pattern of salinity and sodicity. pH-H_2O varies from 8.0 in the topsoil to about 9.5 at 100 to 150 cm depth.

CEC-soil varies from 30 to 50 me/100 g while CEC-clay varies from 54 to 78 me/100 g.

Infiltration rates are medium: 18 mm/hour (topsoil), while hydraulic conductivity is slow: 0.03 m/day (subsoil).

In places inclusions of soils of unit Ps 2.5 are found.

A representative profile pit is given as profile description no. 4.

Mapping Unit Ps 2.4.

FAO-UNESCO Soil Units (FAO, 1974:
Haplic XEROSOLS, sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcaric and Calcari-vertic CAMBISOLS, sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Natric CAMBORTHIDS, fine to very fine clayey, mixed, isohyperthermic.

These are moderately well drained, very deep, reddish brown to dark brown, friable to firm, clay soils. The colour of the A- and B-horizons is in hue 5 YR, while that of the C-horizons is in hue 10 YR. The structure of the topsoil varies from fine crumbs to fine subangular blocky. That of the subsoil is predominantly angular blocky but varies from weak to moderate and from fine to coarse. Weak prismatic macrostructures may be observed. Some slickensides and/or pressure faces can usually be found in the B-horizon. Horizon transitions vary from clear in the topsoil to gradual in the subsoil. The soil is slightly hard when dry, friable to firm when moist and sticky and plastic when wet.

They are moderately to strongly calcareous throughout. In places pockets of soft powdery lime occur in the B-horizon. In the deeper subsoil hard calcium carbonate concretions are found. Salinity starts at depths varying from 70 to 100 cm and it increases with depth. They are slightly to moderately sodic from the surface up to a depth of 30 to 70 cm and thereafter strongly sodic. Soil reaction is alkaline - pH-H_2O varies from 7.8 to 8.5 in the topsoil and increases to 9.0 to 9.6 in the subsoil. Over the same distance, pH-KCl increases from about 7.0 to 8.0

Organic carbon content decreases from about 0.5% in the topsoil to 0.1% in the deeper subsoil. CEC-soil varies from 34 to 46 me/100 g while the CEC-clay varies from 52 to 72 me/100 g.

Water infiltration rate is low to medium: 14 to 25 mm/hour (topsoil), while hydraulic conductivity is slow to moderately slow: 0.03 to 0.14 m/day (subsoil).

In places there are inclusions of soils of Unit Ps 2.7.

A representative profile pit is given as profile description no. 5.

Mapping Unit Ps 2.5.

FAO-UNESCO Soil Units (FAO, 1974):

Haplic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Luvi-haplic and Verti-haplic CALCISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Natric CAMBORTHIDS, fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, grey to greyish brown, friable to firm, clay soils with a 10-20 cm thick topsoil of sandy clay. Colours are in hue 10 YR. The topsoil structure varies from massive to weak angular blocky. The subsoil structure is predominantly subangular blocky but varying from weak to moderate and from fine to coarse. Sometimes a prismatic macrostructure is found. Patchy thin clay cutans/pressure faces or slickensides occur in most soils. Cracks less then 1 cm wide may sometimes be found between 20 and 70 cm depth. Horizon transitions vary from clear in the topsoil to gradual in the subsoil. Soil consistence is slightly hard to hard when dry friable to firm when moist and sticky and plastic when wet.

The soils are moderately to strongly calcareous throughout. Accumulations of soft powdery lime may be found in the deeper subsoil. Salinity starts at depths varying from 60 to 80 cm and increases downwards. Accumulations of gypsum crystals are present in some of the subsoils. The top 30 cm is non-to slightly sodic while the rest of the solum is moderately to strongly sodic. Soil reaction is alkaline, with pH-H_2O ranging between 8.0 in the topsoil and 9.0 or in places 10.0 in the subsoil. Over the same distance the pH-KCl increases from about 7.0 to 8.0. Organic carbon decreases from about 0.7 percent in the topsoil to 0.1 percent in the deeper subsoil. CEC-soil ranges between 20 and 50 me/100 g while CEC-clay varies from 42 to 75 me/100 g. Clay mineralogy is illite-montmorillonite intergrade with traces of illite.

Water infiltration rate is low to medium: 10-38 mm/hour (topsoil) while the hydraulic conductivity of the subsoil is moderately slow: 0.09 to 0.12 m/day.

In places there are inclusions of soils of unit Ps 2.3.

A representative profile pit is given as profile description no. 6.

Mapping Unit Ps 2.6.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Verti-haplic and Luvi-haplic CALCISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Natric CAMBORTHIDS, fine clayey, mixed, isohyperthermic.

This unit consists of imperfectly drained to poorly drained, very deep, dark brown to dark grey, friable to firm clay soils. The texture of the topsoil is predominantly clay but in places textures of sandy clay may be found. Colours are in hue 10 YR. The topsoil structure varies from massive to weak, fine to coarse subangular blocky. In places crumb structures are encountered. The subsoil has either a complex structure consisting of a prismatic macrostructure breaking into angular peds or has an angular blocky structure throughout. Thin patchy clay cutans or pressure faces are found in the B-horizon. Horizon transitions vary from clear in the topsoil to gradual or diffuse at greater depth. The soils are slightly hard when dry, friable to firm when moist and sticky and plastic when wet.

They are non- to slightly calcareous from the surface down to a depth ranging between 10 and 20 cm and moderately to strongly calcareous thereafter. Accumulations of soft powdery lime are found in the B-horizons while hard calcium carbonate concretions are found in the C-horizons. Salinity starts at a depth of 60 to 80 cm from the surface and increases downwards. Accumulations of gypsum may be found in the deeper subsoil. The soils are non to slightly sodic from 30/60 cm onwards. The soil reaction is alkaline with pH-H_2O ranging between 8.0 and 8.6. Higher values of pH-H_2O are found in some upper parts of the B-horizon. The pH-KCl varies from 7.0 to 7.8.

The organic matter content in the topsoil ranges between 0.5 and 0.7 percent.

The CEC-soil ranges between 32 and 43 me/100 g while that of clay ranges between 48 and 77 me/100 g. Clay mineralogy analysis indicate presence of traces of illite and montmorillonite.

Infiltration rates are low to medium: 8-17 mm/hour (topsoil) while the hydraulic conductivity of the subsoil is moderately slow: 0.17-0.25 m/day.

Inclusions of soils of Unit Ps 2.1. may be found.

A representative profile pit is given as profile description no. 7.

Mapping Unit Ps 2.7.

FAO-UNESCO Soil Units (FAO, 1974):
Luvic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic LUVISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic HAPLARGIDS, fine clayey, mixed, isohyperthermic.

These are imperfectly drained, very deep, dark brown to dark greyish brown, friable to firm clay soils with, in places, a topsoil of sandy clay loam to sandy clay. The colours of the A- and B-horizons are in hue 7.5 YR while that of the C-horizons leave as original in hue 10 YR. The structure of the topsoil varies from subangular blocky to crumb. The subsoil has a complex structure consisting of a coarse prismatic macrostructure breaking into angular elements. At greater depths this structure changes into angular blocky only. Clay cutans are present in the B-horizon. Horizon transitions are clear or gradual. The soils are slightly hard to very hard when dry, friable to firm when moist and sticky and plastic when wet.

They are strongly calcareous apart from the upper 10 cm which is non- to slightly calcareous. Accumulations of soft powdery lime are found in the subsoil. Salinity starts at depths varying from 80 to 100 cm and increases with depth. Accumulations of gypsum crystals are found in the deeper subsoil. Sodicity starts almost at the surface, with the upper 30 cm being non- to slightly sodic. The soil reaction is alkaline with pH-H_2O values between 7.8 and 8.8. However, the upper part of the B-horizon may have pH-H_2O values of up to 9.5. The pH-KCl values are about 7.7 except in the topsoil where they may be as low as 6.2.

The organic carbon content decreases with depth from 0.5% in the topsoil to about 0.2% in the subsoil. The CEC-soil ranges between 29 and 51 me/100 g while that of clay ranges between 54 and 95 me/100 g. Clay mineralogy analysis indicates presence of moderately crystallized illite and montmorillonite. The water infiltration rate is low: 10 mm/hour (topsoil) while the hydraulic conductivity is moderately slow: 0.22 m/day.
A representative profile pit is given as profile description no. 8.

Mapping Unit Ps 2.8.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Verti-haplic CALCISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Natric CAMBORTHIDS, fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, dark brown to dark greyish brown, friable to firm clay soils. Colours are in hue 10 YR. The structure of the topsoil is massive or fine subangular blocky. That of the subsoil varies from medium to coarse prismatic structure breaking into angular blocky elements to angular blocky only. Some clay cutans or pressure faces are found in the B-horizon. Horizon transitions are clear in the upper parts of the solum and gradual or diffuse in the lower parts. Soil consistence is slightly hard to hard when dry, friable to firm when moist and sticky and plastic when wet.

The bulk of the soil is strongly calcareous except the top 5 to 15 cm which may be non-to slightly calcareous. Accumulations of soft powdery lime are found in the subsoil. Salinity starts at depths varying from 35 to 60 cm and increases downwards. Gypsum crystals are found below the horizons with calcium carbonate accumulations. The soils are non- to slightly sodic from the surface to a depth of 35 to 60 cm and moderately to strongly sodic thereafter. Soil reaction is alkaline with pH-H_2O varying from 8.1 to 9.1 in the upper 150 cm. Usually the upper parts of the B-horizon have the highest pH.

The CEC-soil ranges between 35 and 66 me/100 g while the CEC-clay varies from 68 to 117 me/100 g. Clay mineralogy analysis indicate presence of traces of illite and montmorillonite.

No infiltration tests and hydraulic conductivity measurements were carried out in these soils.

A representative profile pit is given as profile description no. 9.

Mapping Unit Ps 2.9.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, fine loamy over clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained, very deep, brown to dark greyish brown, firm clay soils usually with a topsoil of sandy clay and sometimes sandy clay loam. Colours are in hue 10 YR. The structure of these soils shows typical features of a Solonetz, viz a moderate or strong coarse columnar or prismatic structure, often with a thin sandy cover on the ped faces. The columnar or prismatic structure usually breaks into smaller angular blocky peds. Only a thin horizon with a massive to fine subangular blocky structures overlies the columns or prisms. Broken, moderately thick cutans are found in the natric B-horizon. Horizon transitions are clear in the topsoil and gradual or diffuse in the deeper subsoil. Cracks about 1 cm wide may be found extending from the surface to the upper parts of the B-horizon. the soils are hard to very hard when dry, firm when moist and sticky and plastic when wet.

The soils are moderately to strongly calcareous throughout, soft powdery lime or lime pseudo-mycelium may be found in the B-horizon. Salinity starts at a depth of 40 to 60 cm and increases downwards. Salt crystals and accumulations of gypsum are common in the deeper parts of the solum. These soils are non- to slightly sodic from the surface to a depth of 30 to 60 cm and strongly sodic onwards. The soil reaction is alkaline with pH-H_2O varying from 7.7 to 8.5. However, the upper parts of the natric B-horizon have pH-H_2O values ranging between 8.6 and 9.3.

The organic carbon content is about 0.8 percent in the topsoil and decreases with depth. The CEC-soil varies from 18 me/100 g in the topsoil to 60 me/100 g in the subsoil. The CEC-clay ranges between 55 and 77 me/100 g and 52 and 89 me/100 g in the topsoil and subsoil respectively. Clay mineralogy analysis indicates presence of montmorillonite (about 85%) and moderately crystallized illite (about 15%).

Water infiltration rate is low to medium: 11-24 mm/hour (topsoil). The hydraulic conductivity is slow: 0.03-0.06 m/day.

A representative profile pit is given as profile description no. 10.

Mapping Unit Ps 2.10.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic and Gleyic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic and Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):

Typic NATRARGIDS, fine clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained, very deep, greyish brown to dark greyish brown, firm clay soils, often with a sandy clay topsoil. The colours are in hue 10 YR. The structure of the topsoil is either crumb or fine subangular blocky. The upper part of the subsoil (B-horizon) has a moderate, coarse to very coarse, prismatic structure. The structure changes to angular or subangular blocky at greater depth. Clay cutans and some slickensides are found in the B-horizon. Cracks, about 1-2 cm wide, extend from the surface to the Bt-horizon. These cracks are partly filled with sandy material from the topsoil. The soils are hard to very hard when dry, firm when moist and sticky and plastic when wet.

They are strongly calcareous apart from the upper 5 to 15 cm which is non- to slightly calcareous. Soft powdery lime or pseudo-mycelium is found in the subsoil. The soils are non-saline down to a depth of 40 to 60 cm and are strongly saline thereafter. Salt crystals and gypsum crystals are found in some of the subsoils. These soils are moderately to strongly sodic apart from the upper 10 cm which is non- to slightly sodic. The soil reaction is alkaline with pH-H_2O varying from 8.2 to 8.5 except for the upper parts of the B-horizon where it ranges between 9.0 and 9.5.

Analytical data gives a CEC-soil varying from 32 to 53 me/100 g and a CEC-clay ranging between 62 and 94 me/100 g. Clay mineralogy analysis indicates presence of predominantly montmorillonite with traces of illite.
Water infiltration rate is low to medium: 11-47 mm/hour (topsoil) while the hydraulic conductivity of the subsoil is moderately slow; 0.15-0.3 m/day.

Mapping Unit Ps 2.11.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic and Luvic XEROSOLS, saline sodic phase
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic CAMBISOLS and Calcari-gleyic LUVISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Natric CAMBORTHIDS; fine clayey, mixed, isohyperthermic.

These are imperfectly drained to poorly drained, very deep, greyish brown to dark greyish brown, friable to firm clay soils usually with a topsoil of sandy clay. The colours are in hue 10 YR. The topsoil has a massive or weak subangular blocky structure. The subsoil (B-horizon) has a weak to moderate, medium to coarse prismatic structure which breaks into angular blocky elements. Pressure faces are common in the B-horizon. Horizon transitions vary from abrupt or clear in the upper parts of the solum to gradual in the deeper parts. The soil consistence is hard when dry, friable to firm when moist and sticky and plastic when wet.

These soils are dominantly strongly calcareous throughout. The upper 30 to 60 cm is non-saline while the rest of the soil is moderately to strongly saline. Gypsum crystals are encountered in the subsoil. The upper part of the solum is non- to slightly sodic up to a depth of 30 to 60 cm and moderate to strongly sodic thereafter. The soil reaction is alkaline with pH-H_2O of the upper part of the solum varying from 8.3 to 9.0 while that of the lower parts is usually between 8.0 and 8.4. The pH-KCl fluctuates from 7.1 to 8.4.

Chemical analysis data show that the CEC-soil ranges between 27 and 54 me/100 g while the CEC-clay ranges between 46 and 83 me/100 g. Clay mineralogy analysis shows presence of both illite and montmorillonite.
The water infiltration rate is medium: 25-35 mm/hour (topsoil) while the subsoil hydraulic conductivity is moderately slow: 0.07-0.22 m/day.
Inclusions of soils with lower salinity and sodicity levels occur in this unit.

Mapping Unit Ps 2.12.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, saline-sodic phase; Orthic and Gleyic SOLONETZ saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-gleyic CAMBISOLS, salic-sodic phase; Calcari-haplic and Calcari-gleyic SOLONETZ, salic phase

USDA Soil Taxonomy (Soil Survey Staff, 1975):
Natric CAMBORTHIDS; Typic and Aquic NATRARGIDS, fine-clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained to poorly drained, very deep, dark brown to dark greyish brown, firm clay soils. The colours are in hue 10 YR. The structure of the topsoil is crumb or subangular blocky. The upper part of the B-horizon has a moderate, coarse to very coarse prismatic structure which breaks into coarse angular blocky peds. The deeper parts of the solum have weak to moderate, medium to coarse angular blocky structures. Clay skins and slickensides are present in some of the soils. The horizon transitions are clear in the upper parts of the solum and gradual or diffuse in the lower parts. In most of the soils there are cracks extending from the surface to a depth of 50 cm. the topsoils are slightly hard when dry while the subsoil is hard to very hard when dry, firm when moist and sticky and plastic when wet.

The soils are moderately to strongly calcareous apart from the upper 10 cm which is non-to slightly calcareous. Accumulations of soft powdery lime and sometimes hard calcium carbonate concretions are found in the B-horizons. Salinity starts at depths varying from 30 to 50 cm and increases with depth. Electrical conductivity of saturation extract (ECe) ranges between 0.4 and 1.3 mmhos/cm in the topsoil and between 0.4 and 21 mmhos/cm in the subsoil. Salt crystals are common in the B-horizon. Gypsum crystals are found between the horizons with calcium carbonate and the ones with salt crystals. Within the transitions of these horizons each of the component may be found. The soils are sodic throughout. The soil reaction is alkaline with pH-H_2O varying from 7.5 to 8.9 except in the upper parts of the B-horizon where values between 9.0 and 9.5 were recorded.

Chemical analysis data show that the CEC-soil varies from 28 to 40 me/100 g while that of clay ranges between 46 and 80 me/100 g. Clay mineralogy analysis was not carried out on these soils but the presence of cracks and slickensides suggest presence of 2:1 type of clay minerals.

Water infiltration rate is low to medium: 8-16 mm/hour (topsoil), while the subsoil hydraulic conductivity is moderately slow: 0.07-0.22 m/day.

Inclusions of soils of unit Ps 2.9 and Ps 2.15 are found.

Mapping Unit Ps 2.13.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic and Gleyic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic and Calcari-gleyic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Aquic NATRARGIDS, fine clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained to poorly drained, very deep, dark brown to dark greyish brown, clay soils. The colours are in hue 10 YR. The structure of the topsoil varies from crumb to coarse subangular blocky. The upper part of the subsoil is characterised by a coarse prismatic structure, usually composed of angular or subangular elements, changing into a coarse angular blocky structure at greater depth. Clayskins are present in the B-horizon. The horizon transitions are clear between the top horizons but become gradual with depth. Some slickensides and cracks, 2.5 cm wide, extending to at least 50 cm depth are frequently found. These soils are hard when dry, firm when moist, and sticky and plastic when wet.

The soils are strongly calcareous throughout. A concentration of soft powdery lime usually occurs in parts of the B-horizons. The soils are non- to slightly saline from the surface to depths ranging between 30 and 40 cm and are moderately to strongly saline at greater depth. Accumulations of salt crystals are found in the deeper subsoil. A zone of secondary gypsum accumulation occurs between the zones of lime and salt accumulation. The soils are slightly sodic from the surface to a depth of 30/40 cm and are moderately to strongly sodic at greater depth. The soil reaction is alkaline with pH-H_2O ranging between 8.0 and 9.0.

Laboratory analysis data indicate that CEC-soil varies from 30 to 55 me/100 g while the CEC-clay ranges between 57 and 86 me/100 g.

Infiltration tests and hydraulic conductivity measurements were not carried out on these soils but are expected to be similar to those of soils of unit Ps 2.12.

Inclusions of soils with different salinity and sodicity levels at various depths other than the ones described above are found.

Mapping Unit Ps 2.14.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic and Gleyic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic and Calcari-gleyic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Aquic NATRARGIDS, fine clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained to poorly drained, dark greyish brown clay soils. The colours are in hue 10 YR. With regard to their structure, consistence, calcareousness, soil reaction (pH) and CEC, these soils are very much comparable to those of unit Ps 2.13. However, generally the soils of units Ps 2.14 are saline and sodic almost throughout.

Mapping Unit Ps 2.15.

FAO-UNESCO Soil Units (FAO, 1975):
Haplic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Verti-haplic CALCISOLS and Calcari-vertic CAMBISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Natric CAMBORTHIDS, fine clayey, montmorillonitic, isohyperthermic.

These are imperfectly drained to poorly drained, very deep, greyish brown to dark greyish brown, clay soils, often with a topsoil of sandy clay. The colours are in hue 10 YR. The structure of the topsoil varies from massive to crumb and subangular blocky. The upper part of the B-horizon has a weak to moderate, medium to coarse, angular blocky structure. Few to common clayskins and slickensides are found in the B-horizon. The horizon transitions are usually clear and smooth but sometimes gradual transitions are encountered. Cracks are found in most places. They usually extend to a depth of 50 cm or more. The topsoil is slightly hard when dry. The subsoil is hard to very hard when dry, firm when moist and sticky and plastic when wet.

The soils are moderately to strongly calcareous throughout. In some soils an accumulation of soft powdery lime occurs. The soils are non- to slightly saline from the surface to a depth varying from 20 to 30 cm and are moderately to strongly saline (ECe 4-20 mmhos/cm) from that depth onwards. They are non- to slightly sodic from 10/40 cm and moderately to strongly sodic (ESP 14-57) from that depth onwards. The soil reaction is alkaline with pH-H_2O ranging between 7.9 and 9.0. The pH shows an irregular pattern. Some soils have a fairly constant pH-level, with slightly higher values in the topsoil, while others have a pH pattern rising to the highest level in the deeper subsoil.

The CEC-soil ranges between 30 and 50 me/100 g while that of clay ranges between 50 and 70 me/100 g. The organic carbon content is low, varying from 0.4 to 0.8 percent in the topsoil and decreasing with depth. Clay mineralogy analysis indicate presence of mainly montmorillonite of good crystallization and traces of illite.

Water infiltration rate varies from low to very high: 3-160 mm/hour, wet run (topsoil), while the hydraulic conductivity of the subsoil is slow to moderately slow: 0.02-0.12 m/day. The infiltration rates and hydraulic conductivity would probably be lower than indicated when these soils are wet.

Inclusions of soils of unit Ps 3.1. are found.

Mapping Unit Ps 2.16.

FAO-UNESCO Soil Units (FAO, 1974)
Haplic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Luvi-haplic CALCISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic CAMBORTHIDS, fine clayey, mixed, isohyperthermic.

It should be noted that the above soil classification refers only to the first component of the soil association described below.

This mapping unit comprises an association of moderately well drained, very deep, dark brown, clay soils and moderately well drained to imperfectly drained, very deep, dark reddish brown to dark brown, sandy clay to clay soils. The colours are dominantly in hue 7.5 YR. The topsoil has a crumb and/or a fine subangular blocky structure. The subsoil has a coarse prismatic structure which breaks into angular blocky peds. Horizon transitions are clear or gradual. The soils of the first component are hard when dry, friable to firm when moist and sticky and plastic when wet, except for the topsoil which is soft to slightly hard when dry and very friable when moist. The consistence of the soils of the second component is about the same, with an exception of the topsoil which is non-sticky to slightly sticky and non-plastic to slightly plastic when wet.

The first component is almost strongly calcareous throughout. It has secondary lime accumulations in the form of soft powdery lime and/or soft lime concretions. The second component is non-calcareous from the surface to a depth of 20/30 cm and moderately to strongly calcareous at greater depth. Salinity starts at a depth of 60 cm and 20/30 cm in the first and second component respectively. Salt crystals are observed in the deeper subsoils of both components. The first component is non to slightly sodic from 0-40/60 cm and moderately to strongly sodic at greater depth. The second component is non-sodic from 0-20/30 cm and slightly to moderately sodic at greater depth.

The soils of the first component have an alkaline reaction with pH-H_2O ranging between 7.6 and 9.0. The CEC-soil ranges between 24 and 30 me/100 g while that of clay varies from 46 to 56 me/100 g. Clay mineralogy analysis indicates presence of an illite montmorillonite intergrade with traces of illite. No complete analytical data are available for the second component.

Mapping Unit Ps 2.17.

FAO-UNESCO Soil Units (FAO, 1974):
a)Luvic XEROSOLS, saline-sodic phase and
b)Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
a) Calcari-chromic LUVISOLS, salic-sodic phase and
b) Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
a) Typic PALEARGIDS, coarse loamy over clayey, illitic, isohyperthermic, and
b) Typic NATRARGIDS, fine clayey, mixed, isohyperthermic.

This unit comprises an association of a) moderately well drained, very deep, reddish brown clay soils with a topsoil of sandy loam to sandy clay and b) moderately well drained to imperfectly drained, reddish brown to dark greyish brown clay soils. The soils of component a) are found on slightly higher terrain than those of component b).

Component a) has topsoils with a massive structure and subsoils with a weak to moderate, coarse prismatic structure gradually changing into a subangular blocky structure at greater depth. Clayskins are common. Horizon transitions are abrupt between the top two horizons and clear between the lower horizons.

The component b) has topsoils with a crumb and/or fine subangular blocky structure and subsoils with a moderate, coarse prismatic structure. Clayskins are very well developed. The horizon transitions are clear.

The soils of the first component are hard when dry, friable to firm when moist and slightly sticky and slightly plastic when wet. The soils of the second component are also hard when dry and friable to firm when moist, but sticky and plastic when wet.

Calcareousness starts at depths of 60/70 cm and 15 cm from the surface for the components a) and b) respectively. Salinity starts at depths varying from 35 to 60 cm and 60 to 80 cm for the first and second component respectively. The soils of the component a) are non- or slightly sodic to a depth of 10 to 30 cm and moderately to strongly sodic at greater depth. The soils of component b) are non to slightly sodic from the surface to a depth of 40/70 cm and are moderately to strongly sodic from that depth onwards.

The soil reaction of component a) ranges between neutral (pH 7.0) to strongly alkaline (pH 8.5) while that of component b) varies from mildly alkaline (pH 7.8) to very strongly alkaline (pH 9.3). Organic carbon content varies from 0.2 to 0.5 percent in the topsoils and decreases with depth. Chemical analysis show that the CEC-soil of the first component is about 25 me/100 g (excluding the topsoil which has a CEC of 8 me/100 g) and that of the second component is about 30 me/100 g. The CEC-clay ranges between 47 and 63 me/100 g.

A representative profile pit of component a) is given as profile description no. 11.

2.1.3. Soils of the low-lying land.

Mapping Unit Ps 3.1.

FAO-UNESCO Soil Units (FAO, 1974):
Chromic VERTISOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcic VERTISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic TORRERTS, very fine clayey, montmorillonitic, isohyperthermic.

These are poorly drained, very deep, dark grey to very dark greyish brown, cracking clay soils. The colours are in hue 10 YR. The topsoil has a crumb and/or subangular blocky structure. The subsoil has coarse prismatic structure. Deep cracks and slickensides are common. Gilgai microrelief is observed. The soils are slightly hard to hard in the topsoil and very hard in the subsoil when dry; firm to very firm when moist and sticky and plastic when wet.

These soils are moderately to strongly calcareous throughout. In places accumulations of soft powdery lime are found in the deeper subsoil. The soils are non-to slightly saline from the surface to a depth of about 30/40 cm and moderately to strongly saline from that depth onwards. Some soils show a secondary accumulation of gypsum and salt crystals in the deeper subsoil. They are non-to slightly sodic from the surface to a depth of about 30/40 cm and moderately to strongly sodic thereafter. The soil reaction is alkaline with pH-H_2O ranging between 8.1 and 8.6 in the topsoil and between 8.1 and 9.0 in the subsoil. The pH-KCl fluctuates between 7.1 and 7.6

Chemical analysis data show that the organic matter content is low (organic carbon of the topsoil is about 0.6% and decreases rapidly with depth). The CEC-soil varies from 37 to 55 me/100 g while the CEC-clay ranges between 52 and 78 me/100 g.

This unit includes soils that can be classified as pellic VERTISOLS (FAO, 1974) or Pelli-calcic VERTISOLS (FAO, 1987).

A representative profile pit is given as profile description no. 12.

Mapping Unit Ps 3.2.

These are poorly drained to very poorly drained, very deep, grey to dark grey, cracking clay soils. They are characterised by crumb structure in the topsoil and angular blocky to prismatic structure in the subsoil. Deep cracks are common. The topsoils are slightly hard when dry while the subsoils are very hard when dry. When moist these soils are firm and they are sticky and plastic when wet. Gilgai microrelief is observed.

The soils are moderately to strongly calcareous throughout. Salinity starts at depths varying from 30 to 40 cm from the surface. They are moderately to strongly sodic throughout.

No detailed description of a representative profile and analytical data is available for this unit but from the field observations it may be inferred that the soils would classify as Calcic VERTISOLS, salic-sodic phase (FAO, 1987).

2.2. SOILS OF THE BURA WEST AREA.

2.2.1. Soils of the slightly high-lying land.

Mapping Unit Pf 1.1.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, partly saline phase
FAO-Revised Legend (FAO 1987):
Haplic SOLONETZ, partly salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, sandy over loamy, mixed, isohyperthermic.

These are well drained to moderately well drained, very deep, brown to dark brown, firm, sandy clay loam to clay soils with a clear hardpan at the top of the B-horizon. The upper parts of the solum, usually 50 to 90 cm thick, are coarse textured: sand, loamy sand or sandy loam (clay content ranges between 7 and 17 percent). This layer has a massive or single grain structure. It overlies a natric B-horizon which has moderately to strongly developed columnar or prismatic structures. The upper part of the natric B-horizon is often capped by a bleached and cemented layer which is extremely hard when dry. Clayskins are present in the B-horizon. The lower part of the solum (B-horizon) is slightly to moderately calcareous, slightly to moderately saline and moderately to strongly sodic. Common salt crystals occur in the deeper subsoil.

The soil reaction of the topsoil varies from slightly acid (pH-H_2O 6.4) to mildly alkaline (pH-H_2O 7.7) while that of the subsoil varies from mildly alkaline (pH-H_2O 7.7) to strongly alkaline (pH-H_2O 8.9).

Analytical data shows that the soils have low organic matter content (organic C less than 0.2%). The CEC-soil varies from 4 to 9 me/100 g in the topsoil and from 14 to 22 me/100 g in the subsoil. The CEC-clay ranges between 40 and 72 me/100 g.

No infiltration tests were carried out on these soils but it is expected that the coarse textured topsoil will have rapid water percolation which will slow down as the cemented layer is approached. The cemented upper parts of the B-horizon are somewhat impervious.

These soils occupy only a small portion of the study area.

Mapping Unit Pf 1.2.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, sandy or coarse loamy over fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, dark reddish brown to dark brown, firm, sandy clay to clay soils. The topsoil, usually 15-40 cm thick is dark red to reddish brown and has textures ranging between loose sand and sandy clay (clay content varying mainly from about 14 to

43 percent). The clay content of the subsoil (B-horizon) ranges between 29 and 58 percent. The colours are mainly in hue 5 YR and 2.5 YR. The structure of the topsoil varies from massive (single grain) or crumb or fine subangular blocky. The subsoil (B-horizon) has moderately to strongly developed columnar or coarse prismatic structures. This B-horizon is often capped by a bleached layer which is very hard to extremely hard when dry. Clayskins are present in the B-horizon. The horizon transitions are clear or abrupt in the upper parts of the solum and gradual in the lower parts. The topsoils are loose to slightly hard when dry while the subsoils are very hard when dry, firm when moist and sticky and plastic when wet.

The soils are moderately to strongly calcareous from a depth ranging between 15 and 40 cm from the surface. Salinity starts at depths varying from 15 to 40 cm from the surface. The soils are non- to slightly sodic to a depth of about 15 to 40 cm from the surface but moderately to strongly sodic from that depth onwards. Accumulations of soft powdery lime, calcium carbonate concretions and salt crystals are found in the deeper subsoil. The soil reaction is neutral (pH-H_2O 7.0) to mildly alkaline (pH-H_2O 7.8) in the topsoil while in the subsoil it varies from moderately alkaline (pH-H_2O 7.9) to strongly alkaline (pH-H_2O 8.9).

Chemical analysis data indicate that the organic matter content is low (organic C less then 0.4%). The CEC-soil varies from about 16 to 32 me/100 g, except for the coarser textured topsoil which may have lower values. The CEC-clay ranges between 42 and 73 me/100 g. Clay mineralogy analysis indicate mainly the presence of illite and kaolinite in the upper horizons with traces of montmorillonite in the lower parts.

A representative profile pit is given as profile description no. 13.

Mapping Unit Pf 1.3.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, sandy to loamy over clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, dark brown to dark greyish brown, firm, sandy clay to clay soils. The texture of the topsoil, usually 2 to 15 cm thick, varies from loamy sand to sandy clay loam and sometimes finer when erosion has taken place. These soils are found in the strongly eroded parts of the slightly high-lying land. The soils are characterised by a thin surface crust. The structure of the topsoil is either crumb or subangular blocky, with occasionally weak, platy structures. The structure of the subsoil is mainly subangular or angular blocky with a weakly expressed prismatic super structure. Horizon transitions are abrupt or clear in the upper parts of the solum and mainly gradual in the lower parts.

The soils are non-calcareous, non-saline and non- to slightly sodic from the surface to a depth of about 10 to 15 cm. From this depth onwards they are strongly calcareous, strongly saline and strongly sodic. Accumulations of salt crystals, secondary lime in form of soft powdery lime and calcium-carbonate concretions are found in these soils. Gypsum crystals are also found in the subsoil.

The soil reaction varies from neutral (pH-H_2O 6.9) in the topsoil to strongly alkaline (pH-H_2O 9.0) in the subsoil. The organic matter content is low (organic C less then 0.5% and decreases with depth). The CEC-soil ranges between 12 and 20 me/100 g in the topsoil and between 16 and 34 me/100 g in the subsoil. The CEC-clay varies from 42 to 77 me/100 g.

For a description of a representative profile pit with analytical data the reader is referred to Acres/ILACO (1967) unit N3 or to the Kenya Soil Survey.

2.2.2. Soils of the slightly low-lying land

Mapping Unit Pf 2.1.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, partly sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcaric CAMBISOLS, partly sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic CAMBORTHIDS, fine clayey, illitic, isohyperthermic.

These are well drained, very deep, dark reddish brown to dark brown, friable sandy clay to clay soils. The texture of the topsoil (usually 10-30 cm thick) varies from sandy clay loam to sandy clay (clay content ranging between 26 and 48 percent) while that of the subsoil is predominantly sandy clay to clay (clay content varies from 35 to 61 percent). The colours are mainly in hue 2.5 YR or 5 YR. The structure of the topsoil is mainly weak subangular blocky while that of the subsoil is moderately to strongly developed subangular blocky. The horizon transitions are clear and smooth in the upper parts of the solum while in the lower parts they are mainly gradual and smooth. Abrupt transitions are found with the petrocalcic layer. The soils are slightly hard to hard when dry, friable when moist, and sticky and plastic when wet.

The soils are non calcareous from the surface to depths ranging between 15 and 50 cm and slightly to moderately calcareous from that depth onwards. They are non-saline down to a depth of 100/125 cm. Sodicity starts at depths varying from 60 to 125 cm. Accumulations of calcium carbonate occur in the deeper subsoil. These soils have either a weakly cemented layer of calcium carbonate concretions or a strongly cemented layer (petrocalcic horizon) at varying depths but usually deeper than 125 cm.

The soil reaction varies from slightly acid (pH 6.4) to moderately alkaline (pH 8.0) in the topsoil while in the subsoil it varies from moderately alkaline (pH 7.9) to strongly alkaline (pH 9.0). The CEC-soil ranges between 13 and 26 me/100 g in the topsoil and between 23 and 29 me/100 g in the subsoil. The CEC-clay varies from 36 to 56 me/100 g in the topsoil and from 40 to 73 me/100 g in the subsoil. The organic matter content is low (organic C is 0.6 percent in the topsoil and decreases with depth). Clay mineralogy analysis indicates presence of illite in the upper parts of the solum with traces of both kaolinite and montmorillonite in the deeper parts of the solum.

Water infiltration rate is medium: about 25.2 mm/hour (topsoil). The hydraulic conductivity varies from 0.59 to 0.87 m/day in the topsoil and from 0.14 to 0.16 m/day in the subsoil.

Inclusions of soils of unit Pf 1.2. and Pf 2.2. may be found in this unit. A representative profile pit is given as profile description no. 14.

Mapping Unit Pf 2.2.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1984):
Chromi-calcaric CAMBISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff,1975):
Typic and Natric CAMBORTHIDS, fine clayey, mixed, isohyperthermic.

These are well drained, very deep, dark red to dark reddish brown, friable to firm, sandy clay to clay soils. The texture of the topsoil (usually 10-30 cm thick) varies from sandy clay loam to clay (clay content 41-56 percent) while that of the subsoil is predominantly sandy clay to clay (clay content 50-70 percent). The structure of the topsoil is either crumb or subangular blocky while that of the subsoil varies from subangular blocky to prismatic. Slickensides and/or pressure faces are common in the deeper subsoil. Cracks, 1-2 cm wide extend from the lower parts of the A-horizon into the B-horizon. Horizon transitions are clear and smooth in the upper parts of the solum and clear or gradual in the lower parts. The topsoils are soft when dry while the subsoils are slightly hard to hard when dry, friable to firm when moist and sticky and plastic when wet.

The soils are calcareous throughout. They are non-saline from the surface to depths varying from 20 to 40 cm and are moderately to strongly saline thereafter. The soils are non-to slightly sodic (ESP 2-5%) from the surface to depths varying from 20 to 40 cm and are moderately to strongly sodic from that depth onwards (ESP 13-48%). Accumulations of secondary lime in the form of soft powdery lime spots, or calcium carbonate concretions are found in the subsoil. Common salt crystals are also encountered in the subsoil. The soil reaction varies from neutral (pH 7.2) in the topsoil to very strongly alkaline (pH 9.3) in the subsoil.

Chemical analysis data reveals that the soils have low organic matter content (organic C is less than 0.7%). The CEC-soil varies from 24 to 35 me/100 g in the topsoil and from 33 to 48 me/100 g in the subsoil. The CEC-clay ranges between 53 and 74 me/100 g. Clay mineralogy analysis indicate presence of traces of illite and kaolinite.

The hydraulic conductivity varies from 0.05 to 0.17 m/day in the topsoil and from 0.02 to 0.07 m/day in the subsoil.

Inclusions of soils of units Pf 1.2. and Pf 2.4. may be found in this unit.

A representative profile pit is given as profile description no. 15.

Mapping Unit Pf 2.3.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcaric CAMBISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic and Natric CAMBORTHIDS, fine clayey, mixed, isohyperthermic.

These soils are similar to those of mapping unit Pf 2.2. except for the depth at which salinity and sodicity occurs. The soils are non-saline from the surface to depths varying from 10 to 20 cm and are moderately to strongly saline thereafter (ECe 5.1-22 mmhos/cm). They are non- to slightly sodic (ESP 2-5) from the surface to a depth of 10 to 20 cm and moderately to strongly sodic (ESP 13-48) from that depth onwards.

Inclusions of soils of unit Pf 2.5. may be found in this unit.

Mapping unit Pf 2.4.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, fine clayey, mixed, isohyperthermic.

These are well drained to moderately well drained, very deep, dark reddish brown, firm clay soils. The texture of the topsoil varies from sandy clay loam to sandy clay (clay content 42-47 percent) while that of the subsoil is predominantly clay (clay content 53-62 percent). The colours are in hue 5 YR. The structure of the topsoil is crumb or subangular blocky while that of the subsoil (B-horizon) is coarse prismatic grading into angular blocky in the deeper parts of the solum. Clayskins and slickensides are present in the B-horizon. Cracks also occur in the B-horizon. Horizon transitions are clear in the upper parts of the solum and mainly gradual in the lower parts. The topsoil is soft to slightly hard when dry while the subsoil is hard to extremely hard when dry, firm when moist and sticky and plastic when wet.

The soils are non- to slightly calcareous to a depth of 15 to 30 cm and are moderately to strongly calcareous thereafter. Salinity starts at depths usually ranging between 60 and 70 cm. The soils are non-sodic from the surface to a depth of 15 to 30 cm and are strongly sodic (ESP 25-46) from this depth onwards. Common, fine to very fine calcium carbonate concretions, often stained with manganese,, are found in the subsoil. Also few soft powdery lime pockets are found in the subsoil. The soil reaction varies from mildly alkaline (pH 7.5) in the topsoil to very strongly alkaline (pH 9.9) in the subsoil. The highest pH-values are found in the upper parts of the B-horizon.

Chemical analytical data indicates that the soils have low organic matter content (organic C varies from 0.5 to 0.8 percent in the topsoil). The CEC-soil ranges between 25 and 27 me/100 g in the topsoil and between 28 and 38 me/100 g in the subsoil. The CEC-clay varies from 52 to 67 me/100 g.

Inclusions of soils of unit Pf 2.3. may be found in this unit.

A representative profile pit is given as profile description no. 16.

Mapping Unit Pf 2.5.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, fine clayey, mixed, isohyperthermic.

These are well drained to moderately well drained, very deep, reddish brown to dark reddish brown, firm clay soils. The texture of the topsoil varies from sandy clay loam to sandy clay (clay content 34-44 percent), while that of the subsoil is predominantly clay (clay content 46-60 percent). The colours are in hue 5 YR. These soils have similar morphological and chemical characteristics such as structure, horizon transitions, pH, etc. as those of mapping unit Pf 2.4. The main difference between them is the depth at which calcareousness, salinity and sodicity starts.

The soils are non- to slightly calcareous down to a depth of 10 to 15 cm and moderately to strongly calcareous thereafter. They are non-saline from the surface to a depth varying from 40 to 50 cm and are moderately to strongly saline below this depth. The soils are strongly sodic from a depth of 10 to 15 cm from the surface onwards.

For a representative profile pit see Acres/ILACO (1967, Table 13 annex C-II) and Mugai and Van der Pouw (1978, page 12).

2.2.3. Soils of the low-lying land.

Mapping Unit Pf 3.1.

FAO-UNESCO Soil Units (FAO, 1974):
Chromic VERTISOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcic VERTISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic TORRERTS, fine to very fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, dark reddish brown to dark brown, firm, cracking clay soils. The texture of the topsoil ranges between sandy clay to clay (clay content 53-55 percent) while that of the subsoil is predominantly clay (clay content 56-65 percent). The colours are in hue 5 YR, occasionally in hue 7.5 YR. The structure of the topsoil is crumb or subangular blocky while that of the subsoil is coarse prismatic grading into coarse angular blocky in the deeper subsoil. When dry, these soils have cracks, 2-4 cm wide, extending from the surface into the subsoil (B-horizons) at depths ranging between 50 and 110 cm. Slickensides are common in the subsoil.

The soils are strongly calcareous throughout. They are non-saline to depths ranging between 20 and 60 cm and are moderately to strongly saline thereafter. Sodicity starts at depths varying from 20 to 30 cm. Accumulations of secondary calcium carbonate in the form of concretions or soft powdery lime are found in the subsoil. Common salt crystals are also found in the lower parts of the solum.

The soil reaction varies from strongly alkaline (pH 8.5) to very strongly alkaline (pH 9.5). The CEC-soil ranges between 30 and 40 me/100 g in the topsoil and between 35 and 42 me/100 g in the subsoil. The CEC-clay ranges between 55 and 65 me/100 g. Clay mineralogy analysis indicates presence of illite, montmorillonite and traces of kaolinite.

The hydraulic conductivity of these soils is very slow: 0.001 to 0.01 m/day.

A representative profile pit is given as profile description no. 17.

Mapping Unit Pf 3.2.

FAO-UNESCO Soil Units (FAO, 1974):
Chromic VERTISOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-haplic and Chromi-calcic VERTISOLS, salic-sodic phases
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic TORRERTS, fine to very fine clayey, mixed, isohyperthermic.

These soils are similar in many respects to those of mapping unit Pf 3.1. except for the depth at which salinity and sodicity starts. The soils are non-saline from the surface to depths varying from 15 to 30 cm and are moderately to strongly saline from this depth onwards. They are non-sodic up to a depth of 10 to 15 cm and moderately to strongly sodic thereafter.

These soils occur at slightly lower positions than those of unit Pf 3.1. In places, these soils do not have secondary accumulations of calcium carbonate in the form of soft powdery lime within a depth of one metre, hence their classification as Calcari-haplic VERTISOLS.

A representative profile description is given as profile description no. 18.

Mapping Unit Pf 3.3.

FAO-UNESCO Soil Units (FAO, 1974):
Chromic VERTISOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcic VERTISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic TORRERTS, fine to very fine clayey, mixed, isohyperthermic.

These are imperfectly drained to poorly drained, very deep, dark brown to dark greyish brown, firm to very firm cracking clay soils. The colours are in hue 10 YR. The clay content ranges between 52 and 59 percent in the topsoil and between 56 and 69 percent in the subsoil. The soils are characterised by weak subangular blocky or crumb structure in the topsoil; strong coarse prismatic structure in the upper parts of the B-horizon and coarse angular blocky structure in the lower parts of the solum. Horizon transitions are gradual and smooth. The topsoil is soft when dry while the subsoil is very hard to extremely hard when dry, firm to very firm when moist and sticky and plastic when wet. Slickensides are common in the subsoil. Cracks, greater than 1 cm wide, occur from the surface into the subsoil to depths greater than 50 cm. The soils are calcareous throughout. They are moderately to strongly saline (ECe 11 to 14 mmhos/cm) from depths varying from 50 to 70 cm. The soils are strongly sodic (ESP 24-36) from a depth of 15 to 25 cm onwards. Accumulations of secondary calcium carbonate in the form of concretions and soft powdery lime spots are found in the deeper subsoil.

The soil reaction varies from mildly alkaline (pH 7.8) to very strongly alkaline (pH 9.3). The CEC-soil ranges between 33 and 48 me/100 g while the CEC-clay varies from 58 to 70 me/100 g. Clay mineralogy analysis was not carried out but from the cracking nature of the soils one would expect presence of 2:1 clay minerals.

These soils occur in depressions in the low-lying areas and are susceptible to waterlogging. This mapping unit occupies only a small portion of the study area north of the Bura Branch Irrigation area.

For a representative profile pit see Acres/ILACO (1967, Table 18 annex C-1).

2.2.4. Soils of the Floodplain

Mapping Unit A1.

FAO-UNESCO Soil Units (FAO, 1974):
Calcaric FLUVISOLS, sodic phase
FAO-Revised Legend (FAO, 1987):
Verti-calcaric FLUVISOLS, sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Vertic TORRIFLUVENTS, very fine clayey, mixed, isohyperthermic.

These are imperfectly drained, very deep, dark brown to brown, firm to very firm, stratified clay soils. The texture is predominantly clay with a clay content ranging between 54 and 72 percent. The structure of the topsoil varies from massive to subangular blocky while that of the subsoil is either prismatic or angular blocky. The soils crack intensively during the dry season. Horizon transitions vary from abrupt and smooth to gradual and smooth. The soils are very hard when dry, firm to very firm when moist and sticky and plastic when wet.

The topsoil (20-30 cm) is non- to slightly calcareous while the subsoil is slightly to moderately calcareous. The soils are non-saline to depths varying from 70 to 100 cm from the surface (ECe 0.5-2.4 mmhos/cm). The topsoil (20-30 cm thick) is non- to slightly sodic (ESP varies from 6 to 10) while the subsoil is moderately to strongly sodic (ESP varies from 14 to 30). Accumulations of secondary carbonate occurs in the deeper subsoil in the form of pockets of soft powdery lime.

The soil reaction varies from moderately alkaline (pH 8.4) to strongly alkaline (pH 8.9) in the topsoil whereas that of the subsoil varies from moderately alkaline (pH 8.4) to very strongly alkaline (pH 9.2). The CEC-soil ranges between 33 and 47 me/100 g in the topsoil and between 36 and 54 me/100 g in the subsoil. The CEC-clay varies from 71 to 72 me/100 g in the topsoil and from 72 to 75 me/100 g in the subsoil. The organic matter content is low (organic C is less than 0.4 percent). In places these soils may have thin layers of sand. The soils occur along the streambed of Laga Hiraman and are periodically inundated. Gullies are common.

2.3. SOILS OF THE HOLA IRRIGATION SCHEME

Mapping Unit Pt 1.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, saline*-sodic phase; in places Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcaric and Calcari-gleyic CAMBISOLS, salic*-sodic phase; in places Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Natric CAMBORTHIDS; in places Typic NATRARGIDS, fine clayey, mixed, isohyperthermic.

These are well drained to moderately well drained, very deep, dark reddish brown, friable to firm, sandy clay to clay soils. The texture of the topsoil is mainly sandy clay (clay content 39-53 percent) while that of the subsoil varies from sandy clay to clay (clay content 43-71 percent). The colours are in hue 5 YR and 7.5 YR. The soils are characterised by topsoils with porous massive or subangular blocky structure. The upper parts of the B-horizon have prismatic

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*Note: The saline or salic phase here applies mainly to the non-irrigated soils.

structures which break into angular or subangular peds while the deeper parts of the solum may have only angular or subangular blocky structure. The horizon transitions are clear in the upper parts of the solum and gradual in the lower parts. The topsoil is slightly hard when dry while the subsoil is hard when dry, friable to firm when moist and sticky and plastic when wet. Cracks, often less than 1 cm wide, may reach down to a depth of 70 cm.

The soils are calcareous throughout. The irrigated parts of these soils are non-saline to depths ranging between 70 and 100 cm from the surface (EC 0.2-0.6 mmhos/cm). Below this depth they are slightly to strongly saline (EC 0.1-3.0 mmhos/cm). In the non-irrigated parts of these soils, salinity starts at depths varying from 15 to 45 cm from the surface. The soils are non-sodic to depths ranging between 40 and 50 cm and between 15 and 25 cm in the irrigated and non-irrigated areas respectively. From these depths onwards they are moderately to strongly sodic (ESP 19-63). Accumulations of secondary carbonate in the form of soft powdery lime and/or calcium carbonate concretions are found in the subsoil. Salt crystals are also found in the deeper subsoil.

The soil reaction is moderately alkaline (pH 8.0-8.4) in the topsoil whereas it is moderately alkaline (pH 8.1) to very strongly alkaline (pH 10.1) in the subsoil. The upper parts of the B-horizon usually have the highest pH-values. The CEC-soil ranges between 21 and 30 me/100 g in the topsoil and between 19 and 25 me/100 g in the subsoil. The CEC-clay varies from 34 to 77 me/100 g and from 35 to 58 me/100 g in the topsoil and subsoil respectively. The organic carbon content varies from 0.4 to 1.6 percent, the highest values being obtained in the irrigated soils. Clay mineralogy analysis reveals that the soils have traces of illite and kaolinite in the upper horizons, with montmorillonite appearing in the lower horizons.

Water infiltration rates are low to medium: 5-15 mm/hour in the topsoil. Hydraulic conductivity of the subsoil was not determined but it is expected to be very slow particularly when the soils are wet. Presence of mottles in profile description no. 19 is indicative of poor drainage condition in the deeper subsoil. The Cambisols occupy about 70 percent of the unit while the Solonetz occupy about 30 percent.
Representative profile pits are given as profile description nos. 19 and 20.

Mapping Unit Pt 2.

The soils of this mapping unit are similar to those of unit Pt 1 except for the depth at which salinity and sodicity starts. In non-irrigated areas the soils are non-saline to depths varying from 10 to 15 cm. At depths greater than this, they are slightly to strongly saline. In irrigated areas salinity starts at depths ranging between 70 and 100 cm. The soils are non-sodic from the surface to a depth of 10 to 20 cm and 10 to 15 cm in irrigated and non-irrigated areas respectively. Below these depths the soils are strongly sodic.

Mapping Unit Pt 3.

FAO-UNESCO Soil Units (FAO, 1974):
Haplic XEROSOLS, saline-sodic phase; in places Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-vertic CAMBISOLS, salic-sodic phase; in places Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Natric and Vertic CAMBORTHIDS; in places Ustollic NATRARGIDS, fine-clayey, mixed, isohyperthermic.

These are well drained to moderately well drained, very deep, dark reddish brown to dark brown, friable to firm clay soils. The clay content ranges between 49 and 73 percent. The colours are in hue 5 YR to 10 YR. The structure of the topsoil varies from porous massive to subangular blocky whereas that of the subsoil (B-horizon) varies from prismatic to angular and subangular blocky. Horizon transitions vary from clear in the upper parts of the solum to gradual and/or diffuse in the lower parts. Moist consistence varies from friable to firm while wet consistence is mainly sticky and plastic. In places there are cracks extending from the A-horizon to a depth of about 70 cm. Slickensides and/or pressure faces are found in the subsoil. In places the soils have thin clay cutans.

The soils are moderately to strongly calcareous throughout. In the irrigated areas the soils are non-saline to a depth ranging between 50 and 100 cm, whereas in the non-irrigated areas they are only non-saline to a depth between 10 and 20 cm. Below this depth the soils are moderately to strongly saline. It should be noted however, in some irrigated areas (next to pit no. 6) salinity was observed from the surface. The soils are non- to slightly sodic to depths ranging between 20 and 30 cm and 10 and 20 cm in irrigated and non-irrigated areas respectively. Below this, they are moderately to strongly sodic (ESP 15-62).

The soil reaction varies from mildly alkaline (pH 7.8) to moderately alkaline (pH 8.3) in the topsoil whereas in the subsoil it varies from moderately alkaline (pH 8.4) to very strongly alkaline (pH 9.8). The CEC-soil varies from 27 to 40 me/100 g in the topsoil and from 22 to 43 me/100 g in the subsoil. The CEC-clay ranges between 52 and 65 me/100 g in the topsoil and between 36 and 57 me/100 g in the subsoil. The organic matter content is higher in the irrigated areas than in the non-irrigated areas (organic C varies from 0.4 percent in non-irrigated soils to 1.6 percent in the irrigated soils). Clay mineralogy analysis indicates presence of traces of montmorillonite, illite and kaolinite.

The Cambisols occupy about 80 percent of the unit whereas the Solonetz occupy about 20 percent. Inclusions of soils of unit Pt 8 and unit Pt 2 may be found in this unit.

A representative profile pit is given as profile description no. 21.

Mapping Unit Pt 4.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS, loamy over fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, reddish brown to dark brown, friable to firm, sandy clay to clay soils. The texture of the topsoil, usually 5 to 35 cm thick, varies from loamy sand to sandy clay (clay content 15-44 percent). Colours are in hue 7.5 YR. The topsoil has porous massive, crumb or subangular blocky structure while the subsoil has prismatic structure which grades into angular to subangular blocky in the deeper parts of the solum. Thin clayskins and/or slickensides are present in the B-horizon. The soils are hard when dry, friable to firm when moist and sticky and plastic when wet.

The upper 5 to 35 cm of the soil is decalcified while the rest is moderately to strongly calcareous. Salinity starts at depths varying from 10 to 15 cm and increases downwards. Sodicity starts at the surface and increases with depth (ESP 16-50 in the subsoil). Accumulations of soft powdery lime are found in the subsoil.

The soil reaction is alkaline with pH-H_2O ranging between 7.7 and 9.5. The CEC-soil varies from 10 to 32 me/100 g in the topsoil and from 22 to 40 me/100 g in the subsoil. The CEC-clay ranges between 45 and 73 me/100 g. Organic carbon content ranges between 1.1 and 1.5 percent in the topsoil and decreases rapidly with depth. Clay mineralogy analysis indicates the presence of traces of illite, montmorillonite and kaolinite.

A representative profile pit is given as profile description no. 22.

Mapping Unit Pt 5.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend (FAO, 1987):
Calcari-haplic SOLONETZ, salic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):

Typic NATRARGIDS, fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, dark reddish brown to dark greyish brown, firm clay soils. The colours are in hues 5 YR to 10 YR. The topsoils are characterised by porous massive, crumb or subangular blocky structure. The upper part of the subsoil (B-horizon) has coarse prismatic structure which breaks into subangular and angular blocky peds. The lower part of the solum has angular or subangular blocky structure. Cracks, usually less than 1 cm wide, start at a depth of about 20 to 30 cm and extend to about 60 to 70 cm, and occasionally up to a depth of 1 metre or more. Few, thin slickensides and/or pressure faces or clayskins are found in the B-horizon. Horizon transitions are clear and wavy in the upper parts of the solum and gradual or diffuse and smooth in the lower parts. The topsoil is slightly hard when dry, loose to friable when moist, sticky and plastic when wet. The subsoil is in turn hard to very hard when dry, firm when moist, sticky and plastic when wet. The upper 20 to 30 cm of these soils is non-to slightly calcareous while the rest of the soil is moderately to strongly calcareous.

In the non-irrigated areas, the soils are non-saline to depths varying from 20 to 40 cm and are moderately to strongly saline thereafter. In the irrigated areas, these soils are non-saline to depths ranging between 40 and 70 cm. Sodicity starts at depths varying from 15 to 30 cm. Accumulations of secondary carbonates occur in the subsoil in the form of either soft powdery lime or carbonate nodules.

The soil reaction is alkaline with pH-H_2O ranging between 8.0 and 9.9. The CEC-soil ranges between 20 and 26 me/100 g in the topsoil and between 18 and 22 me/100 g in the subsoil. The CEC-clay varies from 60 to 66 me/100 g in the topsoil and from 33 to 40 me/100 g in the subsoil. The organic carbon content ranges between 1.0 and 1.3 percent in the topsoil and between 0.1 and 0.6 percent in the subsoil. Clay mineralogy analysis indicates presence of traces of illite and kaolinite.

Inclusions of soils of unit Pt 9 and Pt 1 may be found in this unit. A representative profile pit is given as profile description no. 23.

Mapping Unit Pt 6.

FAO-UNESCO Soil Units (FAO, 1974):
Orthic SOLONETZ, saline phase
FAO-Revised Legend(FAO, 1987):
Calcari-haplic SOLONETZ, salic phase (non-irrigated)
Calcari-mollic SOLONETZ, salic phase (irrigated)
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic NATRARGIDS (non-irrigated), Ustollic NATRARGIDS (irrigated), fine clayey, mixed, isohyperthermic.

These are moderately well drained to imperfectly drained, very deep, dark brown, firm clay soils. These soils have similar morphological and physical characteristics as those of mapping unit Pt 5. The main difference between them is the depth at which salinity and sodicity occurs in both the irrigated and non-irrigated areas.

In the non-irrigated areas the soils are non-saline from the surface to depths varying from 10 to 20 cm and are slightly to strongly saline thereafter. In the irrigated areas salinity starts at depths ranging between 60 and 100 cm from the surface. Sodicity starts at depths ranging between 25 and 50 cm, and 10 and 20 cm in the irrigated and non-irrigated areas respectively.

A representative profile pit is given as profile description no. 24.

Mapping Unit Pt 7.

FAO-UNESCO Soil Units (FAO, 1974):
Chromic VERTISOLS, saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-haplic VERTISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):

Typic TORRERTS, fine clayey, montmorillonitic, isohyperthermic.

These are moderately well drained to imperfectly drained, dark reddish brown to dark brown, firm to very firm, cracking clay soils. Colours are in hue 5 YR to 10 YR. The topsoil is characterised by a crumb or subangular blocky structure. The structure of the upper parts of the subsoil (B-horizon) is prismatic breaking into angular blocky peds. The lower part of the solum has angular blocky structure. Slickensides are common in the subsoil. When dry these soils have cracks, 1-3 cm wide, occurring from the surface to depths varying from 60 to 100 cm. Horizon transitions vary from clear and smooth to gradual or diffuse and smooth or wavy. The topsoil is slightly hard when dry, friable when moist and sticky and plastic when wet. The subsoil is hard to very hard when dry, firm to very firm when moist and sticky and plastic when wet.

The soils are strongly calcareous throughout. Salinity starts at depths varying from 45 to 70 cm in the irrigated areas whereas in the non-irrigated parts of these soils it starts at depths ranging between 20 and 30 cm. Similarly sodicity starts at depths ranging between 20 and 60 cm and between 15 and 30 cm in the irrigated and non-irrigated areas respectively. Accumulations of secondary lime in the form of calcium carbonate nodules/concretions are found in the subsoil. Salt crystals are also found in the subsoil.

The soil reaction is alkaline, with pH-H_2O ranging between 8.3 and 9.8. The CEC-soil ranges between 30 and 36 me/100 g whereas the CEC-clay varies from 45 to 70 me/100 g. The organic carbon content ranges between 1.5 percent in the topsoil and 0.1 percent in the subsoil. Clay mineralogy analysis reveals presence of traces of illite and kaolinite in the topsoil (A-horizon) and montmorillonite as the dominant mineral in the subsoil.

A representative profile pit is given as profile description no. 25.

Mapping Unit Pt 8.

FAO-UNESCO Soil Units (FAO, 1974):
Chromic VERTISOLS,saline-sodic phase
FAO-Revised Legend (FAO, 1987):
Chromi-calcic and Chromi-haplic VERTISOLS, salic-sodic phase
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic TORRERTS, fine clayey, mixed, isohyperthermic.

These soils have similar morphological and physical characteristics as those of unit Pt 7. However, they have in places soft powdery lime in the subsoil within a depth of 75 cm and hence are classified as Calcic VERTISOLS. They differ from the soils of unit Pt 7 mainly by the depth at which salinity and sodicity starts.

In the irrigated areas these soils are non-saline to depths ranging between 40 and 50 cm while in the non-irrigated areas salinity starts at depths varying from 10 to 25 cm. The soils are non-sodic up to a depth of 15 to 30 cm in the irrigated areas whereas in the non-irrigated area sodicity starts at about 10 cm. However, in places the soils are sodic from the surface.

A representative profile pit is given as profile description no. 26. A layer of loamy sand to sandy loam was encountered at a depth of 250 cm.

Mapping Unit Pt 9.

FAO-UNESCO Soil Units (FAO, 1974):
Chromic VERTISOLS; in places: Haplic XEROSOLS, saline-sodic phases
FAO-Revised Legend (FAO, 1987):
Chromi-calcic and Chromi-haplic VERTISOLS; in places Calcari-vertic CAMBISOLS, salic-sodic phases
USDA Soil Taxonomy (Soil Survey Staff, 1975):
Typic TORRERTS, fine clayey, mixed, isohyperthermic; in places Natric CAMBORTHIDS.

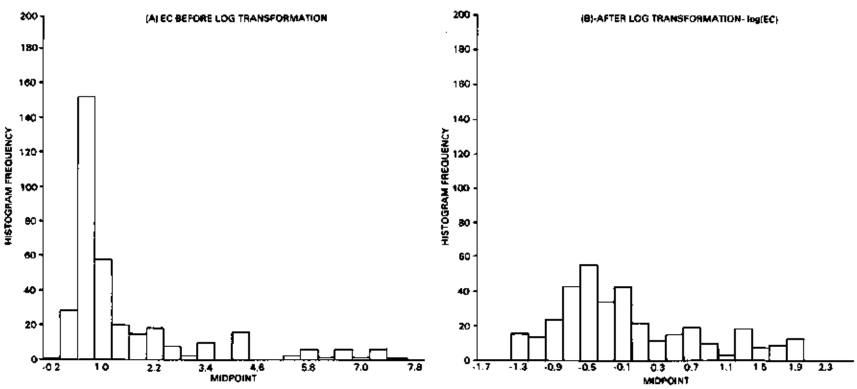
These are imperfectly drained, very deep, brown to dark brown, firm cracking clay soils. The texture of the topsoil varies from sandy clay to clay (clay content 47-53 percent) whereas that of the subsoil is predominantly clay (clay content 50-70 percent). The topsoil is characterised by a crumb or subangular blocky structure while the subsoil has a prismatic structure which grades into angular blocky in the deeper parts of the solum. Cracks, 1-3 cm wide, extend from the surface to depths ranging between 60 and 100 cm. In places these cracks do not reach the surface but are found in the subsoil. Locally where these cracks are wider than 3 cm, the surface material falls into them, forming small micro-depressions (sink holes). The soils are very hard when dry, firm to very firm when moist and sticky and plastic when wet.

These soils are calcareous throughout except for a thin surface layer (5-10 cm thick) which may sometimes be non-calcareous. Accumulations of secondary lime in the form of carbonate nodules/concretions or soft powdery lime are found in the subsoil. The soils are slightly to strongly saline from depths ranging between 50 and 90 cm. They are strongly sodic at depths varying from 15 to 25 cm. However, in places the soils are non-to slightly sodic up to 90 cm.

The soil reaction is alkaline with pH-H_2O ranging between 8.1 and 10.0. The CEC-soil ranges between 26 and 40 me/100 g while the CEC-clay varies from 42 to 73 me/100 g. Clay mineralogy analysis indicates presence of illite and traces of kaolinite and montmorillonite.

A description of a representative profile pit with analytical data can be obtained from the Kenya Soil Survey.

APPENDIX 3 RESULTS OF SOIL CONDITIONS MONITORING- FREQUENCY DISTRIBUTION OF ELECTRICAL CONDUCTIVITY (EC) VALUES



(A)

MEAN	1.457	STD ERR	0.087	MEDIAN	0.800
MODE	0.600	STD DEV	1.619	VARIANCE	2.623
KURTOSIS	3.907	SE KURT	0.260	SKEWNESS	2.133
SE SKEW	0.130	RANGE	7.040	MINIMUM	0.260
MAXIMUM	7.300	SUM	509.900		

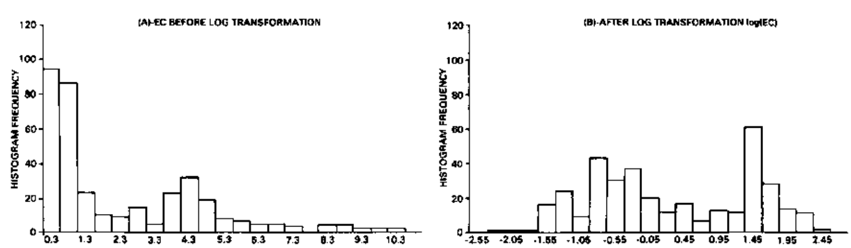
n= 350

(B)

MEAN	-0.039	STD ERR	0.046	MEDIAN	-0.223
MODE	-0.511	STD DEV	0.843	VARIANCE	0.711
KURTOSIS	-0.247	SE KURT	0.260	SKEWNESS	0.616
SE SKEW	0.130	RANGE	3.336	MINIMUM	-1.347
MAXIMUM	1.988	SUM	-13.693		

n= 350

Fig. 3.1 Distribution of Electrical Conductivity (EC) Values in Hola Soils: (A)- before and (B)-after log transformation



(A)

MEAN	2.393	STD ERR	0.128	MEDIAN	1.000
MODE	4.000	STD DEV	2.428	VARIANCE	5.893
KURTOSIS	0.708	SE KURT	0.256	SKEWNESS	1.184
SE SKEW	0.129	RANGE	10.410	MINIMUM	0.090
MAXIMUM	10.500	SUM	861.510		

(B)

MEAN	0.278	STD ERR	0.061	MEDIAN	0.000
MODE	1.386	STD DEV	1.154	VARIANCE	1.333
KURTOSIS	-1.310	SE KURT	0.256	SKEWNESS	0.046
SE SKEW	0.129	RANGE	4.759	MINIMUM	-2.408
MAXIMUM	2.351	SUM	100.037		

Fig. 3.2 Distribution of Electrical Conductivity (EC) Values in Bura Soils: (A)- before and (B)-after log transformation

APPENDIX 4A.
SPECIFICATIONS FOR RATING OF THE LAND QUALITIES.

The rating system applied here follows closely that which is used by the Kenya Soil Survey (cf. Van de Weg and Braun, 1977; Nyandat and Muchena, 1980; Weeda, 1987 among others). However, the system is modified where necessary to suit the present study.

4.1. CAPACITY FOR WATER RETENTION.

The capacity for water retention of a soil depends on the texture of the soil, type of clay, organic matter, soil depth, and the calcium carbonate status.

The water held by the various soil horizons within a soil profile is important. However, for purposes of this evaluation, the amount of available water in the rooting zone will be used. In the rating system, the effect of soil depth is integrated together with waterholding capacity of the soil horizons within the rooting zone. The effective rooting depth is taken as one metre or depth to an impermeable or limiting layer if shallower. The available water is determined between field capacity (pF 2.0) and wilting point (pF 4.2).

Rating	cm of available water that can be stored from the surface to 100 cm or to limiting layer
1	morere than 16.0
2	12.1 - 16.0
3	8.1 - 12.0
4	4.0 - 8.0
5	less than 4.0

The final rating is adjusted taking into account hindrance to root development. For example if a natric horizon occurs close to the surface, the rating is downgraded by two classes.

4.2. ABSENCE OF SALINITY.

Two depths are considered: 0-30 cm (zone of best development of root systems for the crops under consideration) and 30-100 cm. The most limiting factor is used to determine the final rating. For example if the rating of salinity within 0-30 cm is 1 and within 30-100 cm is 2, then the final rating of absence of salinity would be 2.

Rating	Highest ECe (mmhos/cm) value within the depth of: 0 - 30 cm	30 - 100 cm
1	< 2.0	< 4.0
2	2.0 - 4.0	4.0 - 8.0
3	4.1 - 8.0	8.1 - 15.0
4	8.1 - 15.0	15.1 - 30.0
5	> 15.0	> 30.0

4.3. ABSENCE OF SODICITY.

As in the case of salinity, the ratings are carried out for two depths: 0-30 cm and 30-100 cm. Within each depth the highest values of ESP are rated and the most limiting rating gives the final figure.

Rating	Highest ESP values within the depth of: 0 - 30 cm	30 - 100 cm
1	< 6.0	< 6.0
2	6.0 - 10.0	6.0 - 15.0
3	10.1 - 15.0	15.1 - 40.0
4	15.1 - 40.0	> 40.0
5	> 40.0	> 40.0

4.4. AVAILABILITY OF OXYGEN FOR ROOT GROWTH.

The soil drainage classes as outlined in the Soil Survey Manual (Soil Survey Staff, 1951) are used as land characteristics for oxygen availability.

Rating	Soil drainage class
1. very high	well drained to excessively drained
2. high	moderately well drained
3. moderate	imperfectly drained
4. low	poorly drained
5. very low	very poorly drained

4.5. CONDITIONS FOR GERMINATION (SEEDBED).

The conditions for germination depend on: soil moisture storage capacity of the topsoil, structure and consistence of the topsoil and susceptibility to crusting of the topsoil. The soil moisture storage capacity is treated as a separate land quality (see 4.1.). Therefore in this rating system only the topsoil structure and the "susceptibility to crusting" are used. The rating of the susceptibility to crusting is based on laboratory tests i.e. organic matter content, bulk density and silt/clay ratio. This is augmented with field observations.

Rating	Topsoil structure	Susceptibility to crusting
1. very high	single grain, crumb, granular	3 - 4
2. high	medium subangular blocky	5
3. moderate	coarse subangular blocky	6
4. low	massive	7 - 8
5. very low	platy	9 - 10

The rating is determined by any one of the listed characteristics, singly or in combinations with the other.

4.6. AVAILABILITY OF NUTRIENTS.

The ratings are based on CEC-soil, available nutrients determined according to the "mass analysis" method (Mehlich et.al., 1962), organic carbon percentage and pH-H_2O and P-Olsen. The negative effect of salinity and sodicity on the fertility are taken into account in the ratings for absence of salinity and sodicity respectively. The organic carbon content is supposed to have a positive relationship with available nitrogen.

			Available nutrients					
Rating	CEC me/100g	Organic C %	P ppm Mehlich	P ppm Olsen	K me/100g	Ca me/100g	Mg me/100g	pH-H_2O (1:1.5)
1. high	> 16	> 2.0	> 60	> 20	> 0.5	> 6.0	> 3.0	5.6-6.8
2. moderate	6-16	1.1-2.0	21-60	11-20	0.21-0.5	3.0-6.0	1.1-3.0	6.9-7.5
3. low	3- 5.9	0.5-1.0	10-20	5-10	0.10-0.20	1.0-2.9	0.5-1.0	7.6-8.7
4. very low	< 3	< 0.5	< 10	< 5	< 0.10	< 1.0	< 0.5	< 8.7

The most limiting factor determines the final rating.

4.7. AVAILABILITY OF FOOTHOLD FOR ROOTS.

Rating	Rootable depth	Depth class
1. very high	> 120 cm	very deep
2. high	80 - 120 cm	deep
3. moderate	50 - 80 cm	moderately deep
4. low	25 - 50 cm	shallow
5. very low	less than 25 cm	very shallow

4.8. WORKABILITY (EASE OF TILLAGE).

The rating is based on the dry and moist consistence of the topsoil (0-30 cm).

Subrating (r1)	dry consistence	Subrating (r2)	moist consistence
1	loose	1	loose
2	soft	2	very friable
3	slightly hard	3	friable
4	hard	4	firm
5	very hard/ extremely hard	5	very firm/ extremely firm

Rating of workability	Sum of Subrating (r1 + r2)
1	2 - 3
2	4 - 5
3	6 - 7
4	8 - 9
5	10

4.9. ABILITY FOR DRAINAGE.

The land quality ability for drainage is related to natural drainage conditions, texture, presence of impermeable layers, type of clay minerals and calcium carbonate status. These factors are reflected in the infiltration rate of the soils. Hence the factor infiltration rate will be used to rate this land quality.

Rating	Infiltration rate
1	0.8 - 3.5 cm/hour
2	0.5 - 0.8 or 3.5 - 7.0 cm/hour
3	0.2 - 0.5 or 7.1 - 11.0 cm/hour
4	0.1 - 0.2 or 11 - 12.5 cm/hour
5	< 0.1 or > 12.5 cm/hour

The presence of impermeable substrata may influence the ability for drainage. When this is present the rating of this land quality is downgraded in accordance with the depth at which the impermeable substratum occurs. For example if the depth of the impermeable substratum is less than 50 cm, the final rating is 5 irrespective of the infiltration rate of the upperlayers.

4.10. EASE OF LAND CLEARING (SPARSENESS OF VEGETATION COVER).

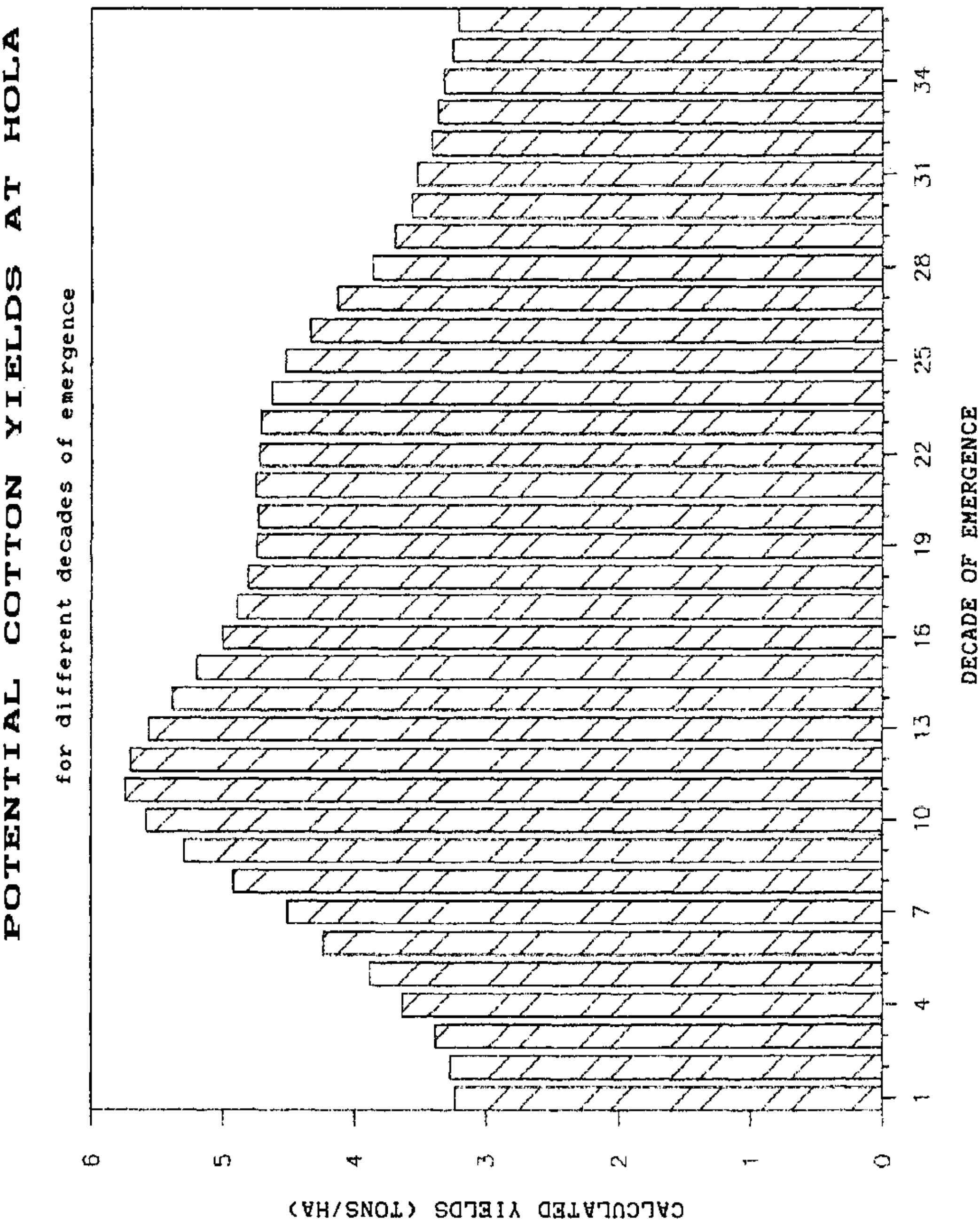
The ease of land clearing is determined by the amount of vegetation cover. Hence the ratings are based on the physiognomic vegetation type.

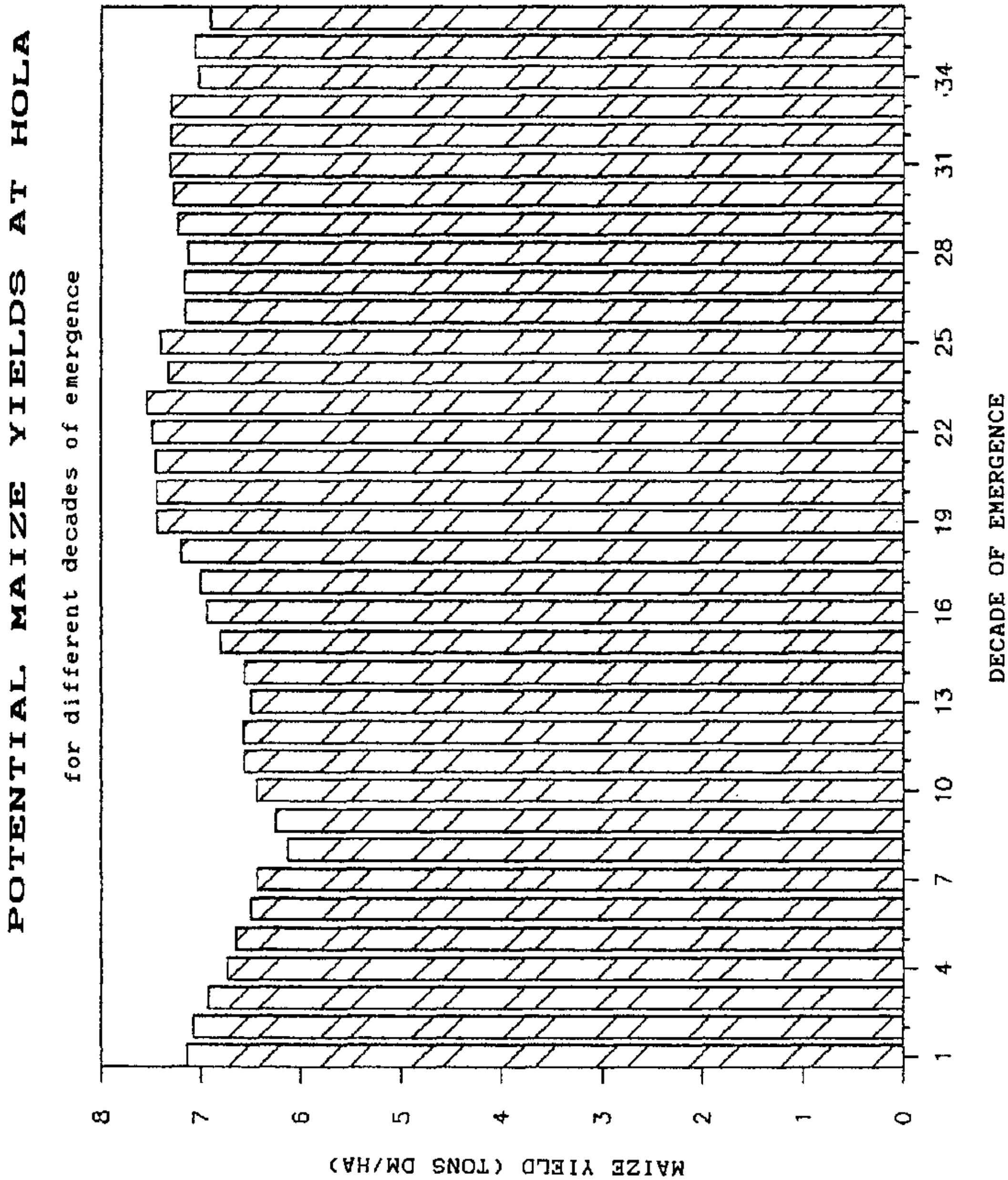
Rating	Physiognomic vegetation type
1. very high	grassland (G) bushed wooded grassland (BWG) wooded grassland (WG)
2. high	bushed grassland (BG) wooded bushed grassland (WBG)
3. moderate	bushland (B) wooded bushland (WB) bushed woodland (BW) woodland (W)
4. low	dense bushland (Bd) dense wooded bushland (WBd) dense bushed woodland (BWd) dense woodland (Wd)
5. very low	bushland thicket (Bt) wooded bushland thicket (WBt)

4.11. FREEDOM FOR LAYOUT OF FIELD PLANS.

This land quality is mainly related to levelling and grading works necessary for gravity fed surface irrigation. The most important factors are topography and slope.

Rating	Slope (%)	Microrelief
1. very high	< 2	none to slight
2. high	< 5	slight
3. moderate	< 8	moderate
4. low	< 16	strong
5. very low	> 16	strong


POTENTIAL COTTON YIELDS AT HOLA
for different decades of emergence
CALCULATED YIELDS (TONS/HA)
0
1
2
3
4
5
6
DECADE OF EMERGENCE
1
4
7
10
13
16
19
22
25
28
31
34


POTENTIAL MAIZE YIELDS AT HOLA
for different decades of emergence
MAIZE YIELD (TONS DM/HA)
0
1
2
3
4
5
6
7
8
DECADE OF EMERGENCE
1
4
7
10
13
16
19
22
25
28
31
34

CURRICULUM VITAE

The author obtained his Cambridge School Certificate in Kenya at Meru School in 1964 and his Higher Cambridge School Certificate at Kangaru School in 1966.
After working for a short period as a teacher, he proceeded to the Nairobi University where he obtained a Bsc degree in Chemistry and Geology in 1971. In 1973 he went to The Netherlands where he attended the Msc course in Soil Science and Water Management at the Agricultural University, Wageningen. In 1975 he obtained a Msc degree with distinction, in soil science with a specialisation in Soil Survey and Land Evaluation.

From June 1971 the author was employed as an Agricultural Research Officer in the Ministry of Agriculture and posted to the National Agricultural Laboratories. During the period 1971 to 1972 he carried out investigations on the sand mineralogy of Kenyan soils before he joined the Kenya Soil Survey. From the period 1975 to 1978, he was the Technical Coordinator of all the technical programmes of the Kenya Soil Survey. He rose to the position of the Head, Kenya Soil Survey in May 1978, a post he holds till the present day.

He has carried out a number of soil surveys varying from reconnaissance, semi-detailed, detailed and site evaluations. He has attended many international and national workshops, conferences and siminars during which he has contributed papers.
He has also published several papers in international journals.