

Draft

**BURA IRRIGATION SCHEMES, KENYA
SOILS INVESTIGATION REPORT**

R. W. Borden

1990

**Cargill Technical Services
Thame, Oxon
UK**

DRAFT BURA IRRIGATION SCHEME SOILS INVESTIGATION REPORT ¹

R. W. Borden

1.0 INTRODUCTION

This report follows a 10 day visit to the Bura West Irrigation Project and a one day visit to the Hola Irrigation Scheme in October 1990. It is based on field observations and on various background information and documents (see list of reference material) and conversations with various individuals with knowledge of, and interest, in the Bura scheme.

The history of the scheme dates from the mid 1970's but the concept of irrigation of land along the Tana River is at least 40 years old. The British colonial administration established the Hola Irrigation Scheme 40 km south of Bura in the mid 1950's, and this was seen as an indicator of potential success for the Bura West Scheme.

Development of irrigation along the Tana River has been slow for a number of reasons, not the least being the fact that most of the suitable land area has highly saline-sodic soils - soils that are difficult and therefore costly to develop for high yielding and variable cropping. The limitation of the soils was recognized when the Bura West Scheme was initiated - in fact the criteria in the original land suitability classification had to be softened to find sufficient land area to justify the scheme. In spite of this, the financing was agreed and the project initiated.

Phase 1, Stage 1 of the Bura West Project was designed to provide irrigation to a net area of 6650 ha based on 30 ha units divided into 4 subunits. The first settlers arrived in 1981, and to date 2159 farm families have been settled. The first crop - 200 ha of maize - was grown in 1981. The first cotton crop (740 ha) was grown in 1982. The largest area planted to date has been 2500 ha of cotton in 1987 and 1200 ha of maize in 1985. Individual farmers consistently get over 3000 kg/ha seed cotton (Bura field staff- personal communication) but on average yields for cotton (and maize) have been relatively low - Cotton 2000 and Maize 2500 kg/ha (Tables 1 and 2 in Appendix A).

While potential unit and subunit yields could be expected to vary with soil type (and degree of salinity and sodicity within the soil profile), soil suitability would not result in the kind of fluctuations seen in average annual cotton and maize yields. This variability can be largely attributed to variability in management, particularly timing of water availability, land preparation and pest control, and the amount of water applied per irrigation.

2.0 SOILS OF BURA WEST SCHEME

2.1 General Description

An area of just under 15,000 ha (gross) was selected for the Bura West Irrigation Scheme, half of which was developed as Phase I, Stage 1.

The soils, in general, are Na-Mg rich reflecting the calcareous, saline and sodic nature of the parent materials on which they have developed. With few exceptions, this parent material is older alluvium deposited on a gently sloping plain which has a gradient of between 1 and 3 percent west to east and less than one percent north to south. Occasional slight ridges and depressions run west-east. These slight differences in relief are important to soil formation and to irrigation, and thus the soils have been divided into three units: slight high-lying, slightly low-lying and low-lying. These are shown as Pf 1.1 to 1.3, Pf 2.1 to 2.5 and Pf 3.1 to 3.3 respectively on Soil maps 1, 2 and 3 in Appendix D. These are described in detail by F. N. Muchena (1987).

¹ Soil Samples were taken from 5 representative soil pits for analysis by the KSS National Agricultural Laboratory, but the results were not available at the time of preparing this draft report.

In general, the soils of the slightly high-lying land are moderately-well to imperfectly drained and are characterised by a sandy topsoil of varying thickness (15 to 90 cm) overlying a subsoil which tends to be very hard when dry, moderately to strongly calcareous, strongly saline (ECe 18 to 45 mS/cm), and moderately to strongly sodic (ESP 10 to 62) (Table 3 in Appendix A).

The soils of the slightly low-lying land are, in general, strong structured, well to moderately well drained sandy clay loam to clays, the percentage of clay content increasing with depth. These soils are calcareous throughout; the degree of salinity and sodicity varies widely with depth and from site to site. Top soils are invariably non-saline and non-sodic but subsoil - except for Unit Pf 2.1 - can be strongly saline (ECe 2 to 23 mS/cm) and moderately to strongly sodic (ESP 15 to 50). Mapping Unit Pf 2.1 profiles have a weak to strongly cemented layer of calcium carbonate concretions are varying depths but usually deeper the 125 cm.

Soils of the Pf 2.1 mapping unit are underlain by a layer of gravel size calcium carbonate concretions which appear to facilitate drainage, though this layer is at a deeper depth in the north and west than in the east and south. The clay fraction is also higher where the depth CaCO₃ is greater.

The low-lying lands have imperfectly to poorly drained clay soils with strong vertic properties, and are strongly calcareous throughout. Salinity and sodicity varies from site to site but generally increases with depth. The top 15 to 20 cm of the profile is normally non-saline/non-sodic. Subsoils are generally always sodic (ESP 15 to 45) but may be non-saline to strongly saline (ECe 1 to 26 mS/cm).

2.2 Chemical Properties

Soil Reaction

Soils in the project area which are acid to neutral throughout rarely, if ever occur. Some mapping units (Pf 1.1, 1.2, 1.3 and 2.1) have profiles which are non-calcareous to variable depths and these show acid to neutral pH-values over that depth (Table 4). 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 ranging from 7.5 to 8.5 due to presence of free carbonates. In the remainder of the soils, pH values of 7.5 and more seem to be the result of the combined effect of free carbonates and high sodicity with or without high salinity.

Salinity and Sodicity

In Bura salinity tends to increase with depth, but non-saline conditions prevail in the top layer in all the soil units to 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 with the exception of mapping unit Pf 2.1 which has non-saline but sodic deeper subsoil. Like salinity, sodicity starts at varying depths but all the soils have strongly sodic deeper subsoils. Sodicity tends to increase regularly with depth and maximum ESP values tend to coincide with zones of maximum salinity.

At Hola, soils in the non-irrigated areas tend to be saline from the surface whereas irrigated soils are non-saline to a greater depth, due no doubt to the effect of leaching. Observations indicate that after prolonged irrigation salinity level had decreased in some of the soils to between 60 and 100 cm (ILACO, 1976, Muchena, 1987). However, increases in levels of salinity (and sodicity) have been observed in specific years - no doubt related to lower applications of irrigation water.

The pattern of sodicity in the non-irrigated soils of the Hola Scheme follow a similar trend to those of the Bura Scheme - i.e. ESP values increase regularly with depth. However, in some of the irrigated soils a difference pattern was observed (Muchena, 1987). The irregular pattern can be attributed to the effect of leaching of salts by irrigation water. This leaching seems to result in a corresponding increase of pH and ESP values in the surface horizons, and a decrease in these values in the subsoil of some profiles.

Cation Exchange Capacity and Available Nutrients

Cation Exchange Capacity (CEC) of clay does not show significant differences between various soil types, but CEC-soil shows differences which are (not unexpectedly) due to differences in clay content, varying from 5 to 20 me/100 g in loamy sand-sandy clay loam topsoil to 50 to 60 me/100 g in very clayey subsoils (Tables 3 in Appendix A).

Soil chemical data has not (so far as we know) been calibrated against crop performance under field conditions. In general, the soils are well supplied with required elements (Table 3). Available calcium and magnesium values are high to very high. Potassium levels adequate and phosphorous values range from low to adequate. The organic matter content, and nitrogen levels, are low. It has been observed at Hola that organic matter content increased with irrigation, though still not to very high levels. In theory this should be the case at Bura, but there is no documented evidence.

Given the widespread occurrence of free carbonates and salts in these soils, the inter-relationship between the various cations is important. Nutrients induced deficiencies through ion antagonisms are possible. For example, the high values of calcium and magnesium on the exchange complex may render potassium unavailable to plants. High pH values may depress the availability of micro-nutrients and may also inhibit uptake of phosphates. The high levels of sodium and chloride ions contained in some of the soils may cause toxicity to the crop at the same time result in nutritional imbalance, and such salt concentrations adversely affect the physical characteristics of these soils. The presence of dissolved sodium salts in the soil solution and/or exchangeable sodium ions in the soil adsorption complex can directly or indirectly be responsible for the low fertility of salt affected soils (FAO, 1976).

In view of the complex chemical properties of the soils, the nature and extent of fertility problems and ways to mitigate them should be investigated in detail in the scheme area. Little or no research into these aspects appears to have been done to date at Bura.

Calcium Carbonate Content

Presence of calcium carbonate (CaCO_3) can affect both physical and chemical characteristics of a soil. CaCO_3 occurs in Bura in the 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. Most of the soils react strongly with dilute hydrochloric acid giving an impression that they are moderately to strongly calcareous. However, chemical analysis reveals that the soils in general have low percentages of CaCO_3 - ranging between 0 and 10 percent and tending to increase with depth. Some of the top soils do not have any identifiable CaCO_3 which indicates some degree of decalcification.

For every 100 kg of ammonium sulphate $(\text{NH}_4)_2\text{SO}_4$ fertilizer added to soil, about 45 kg of calcium will be removed and the equivalent of 75 to 150 kg of calcium carbonate will be required to replace the calcium washed out. With ammonium sulphate the NH ion displaces Ca and Mg ions from the exchange complex, producing calcium/magnesium sulphate which then washes down the profile. However on slow draining clay soils such as found at Bura, the effect of ammonium sulphate may not be marked (Ahn, 1970, Russell, 1973).

Gypsum Content

Most of the soils have very low gypsum contents in the upper parts of the profile (less than 0.2 percent). Values of gypsum, up to 1.7 percent have been measured in the deeper subsoil of only a few profiles. The presence of higher accumulations of gypsum could be expected to have a long term beneficial effect on physical soil properties.

2.3 Clay Mineralogy

Clay mineralogy analysis indicate that kaolinite and illite are the predominant clay minerals in the surface horizons of the majority of Bura West soils, the exception being the Vertisols where 2:1 type minerals predominate (Muchena, 1987).

2.4 Infiltration

Infiltration tests (using double rings) in soils of Bura gave high initial rates which decreased rapidly to basic rates of between 7 and 63 mm/hour (Muchena, 1987). Infiltration tests at Hola (Acres/ILACO, 1967) using large (150 square meter) infiltrometers also obtained high initial infiltration rates (120 mm/hour) which decreased over 6 hours to almost zero - the total amount infiltrating over the period being 55 to 60 mm. These low infiltration rates were attributed to the high percentage of exchangeable sodium in these soils.

The great variation in the infiltration rate can probably be attributed to the physical characteristics of these soils. Soils with a loose surface horizon overlaying a cracking subsoil (i.e. Pf 2.2) tend to give a high initial infiltration rates which decrease as the soils swell on wetting. During the field measurements it was observed that on wetting these soils (particularly those of mapping unit Pf 2.2) tended to slake, due to the presence of high exchangeable sodium, and form a surface crust, which substantially reduced infiltration. Water intake is also substantially reduced by any dispersed subsurface layer.

2.5 Hydraulic Conductivity

The results of the hydraulic conductivity tests carried out at Bura indicate that variations occur from soil to soil and within the soil horizons of the same soil depending on soil properties such as the amount of exchangeable sodium, etc. The non-saline and non-sodic top soils showed higher hydraulic conductivities than the saline and sodic subsoils. For example, the soils of mapping unit Pf 2.1 which are non-saline and non-sodic to depths of about 1 meter had hydraulic conductivity values between 0.6 and 1.0 meter/day in the top soil and about 0.15 m/day in the subsoil. Mapping Unit Pf 2.2 which has a full saline and sodic profile showed hydraulic conductivities of between 0.02 and 0.07 m/day. Saline-sodic Vertisols represented by mapping units Pf 3.1 and 3.2 had the lowest values (0.005 m/day). This is in keeping with the observed poor internal drainage characteristics of these profiles (Muchena, 1987).

Because of the very deep ground water table and low rainfall of the area, these tests were done under dry rather than saturated conditions and thus do not represent absolute values. They do, however, give an indication of the internal drainage conditions of the soils tested.

At Hola, typical hydraulic conductivity values (Acres/ILACO, 1967) were 0.9 m/day for top soil and 0.0001 m/day for subsoil. However, the presence sand at depths varying from below 2.5 and 4.0 meters are considered important for subsurface drainage.

2.6 Irrigation Water Quality

Tana River water is classified as low salinity/low sodium water (Richards, 1954), excellent quality for irrigation. However, the implications to soil management of irrigation water of this quality are:

- water of such low salinity can reduce infiltration rates by leaching from the surface soluble minerals and salts which have a strong stabilizing influence on soil aggregation, thus causing surface structure to slake (FAO, 1976 and 1985). This has implications for irrigation scheduling and application rates.
- water of this quality can remove plant nutrients (natural fertility) from soils, and or tie up fertiliser elements, thus depriving crop plants of essential elements.
- water of this quality still contains some salts, and every application of irrigation water will add to the soil salt load. This is important in slow draining soils as there will be a tendency for evaporative forces to draw some of the applied water back to the surface between irrigations, thereby concentrating salts in the root zone.

In addition, Tana River water has a fairly high silt load, even at periods of low flow (200-300 ppm). Nothing is known of how much of original river load reaches the farms and what effect does it have, however, the silt load has a serious negative impact on the irrigation canals and the pumps that lift the water into the canals and the result of the latter mean that the pumps break down relatively frequently and thus make irrigation impossible until repairs are completed..

3.0 SUITABILITY FOR IRRIGATION

Given the soil characteristics of Bura West, less than half the Project area is considered Class 1, while the soils of Bura East have no Class 1 soils (Tables 5a and 5b in Appendix A).

4.0 EXISTING COMMAND AREA

4.1 Soils

The scheme is sited on soils of widely varying suitability, but about 67 percent (4450 ha) of the commanded area is classed as suitable for cotton (Macdonald's, 1977). This included virtually all Soil Units Pf 2.1 and 2.2. Only about 40 percent of the area can be considered suitable for maize as salinity levels can be sufficiently high to severely reduce maize yields (The 10 percent yield reduction threshold for cotton and maize is Eked 10 and 5 MS/cm respectively). The remainder of the service area (approximately 2200 ha) has some degree of limitation to cotton production and serious limitations for maize.

Previous studies indicate that the soils of the area differ considerably in chemical and physical characteristics over short horizontal and vertical distances. These soils appear also to have developed on different types of landscapes and, possibly, parent materials. A serious limitation in assessing how the various soil units respond to irrigation is the fact that the original soil survey, on which soil suitability and scheme lay-out were based, was carried out at an intensity too low to allow the identification of small inclusions of one soil unit within larger areas of another unit. In addition, the actual units mapped include a range of soil characteristics which in general have the characteristics of the mapped unit but which may differ substantially from one another and from the representative profile of the unit. For example, one profile may have a sandy clay loam surface horizon while another site within the same unit will have a clay texture, or the profile will have a non-saline non-sodic layer varying from less than 10 cm to greater than 60 cm. This variability can be seen in the 6 profiles of Soil Unit Pf 2.1 (ILACO, 1976). In the Bura Branch Canal Command, the Pf 3.2 soil unit includes sites (about half) which are non-saline and non-alkaline and therefore will have a higher suitability rating than the typical mapping unit.

Salinity constraints, and to some extent those of high sodicity can normally be expected to lessen with continued and well managed irrigation, and thus mapping units downgraded due to these two factors should eventually show improved suitability. Field units and subunits at Bura still show considerable variation indicating that these are not responding to management under irrigation or that other factors such as land levelling and water application have not been optimum. There are also likely to be management difficulties due to texture variation in the surface and the low permeability of the subsurface soils. Instability of some surface soils will also greatly reduce infiltration and cause crops to suffer drought even though regularly irrigated.

This having been said, these soils still have potential and cannot be blamed for the problems that seem to have plagued the project from the outset. The history seems to be one of unreliable supply of water (with breakdowns frequently at critical crop requirement stages) and delayed land preparation. The fact that farmers cannot expect to have the same plot of land two years running is also seen as a limiting factor to land improvement.

Apparently no specific tests have been done on structure stability, but their instability under wet conditions is apparent when samples are shaken in water (soils peds immersed in distilled water, for the

most part, disintegrated rapidly - Table 1.6a and b). Soils with a high pH and low electrical conductivity disperse quickly and remained dispersed.

4.2 Service Areas

The Bura Branch Canal (the northern most service area –Table 6. services approximately 1750 ha, nearly all of it Pf 2.2 or Pf 3.2 soils (roughly 2/3:1/3 respectively). Several farmers on the latter are said to consistently produce high yields (3000 plus kg/ha) of cotton. One suggestion is that this might be due to the fact that these soils are low lying and subject to flooding from the Laga Hiran, and thus more leached than the higher lying soils or other parts of the soil mapping unit. If this is so, then the prospect of improving this mapping unit with irrigation must be good.

The Chewele Branch Canal services approximately 750 ha, virtually all very marginally suited for crop production. Farmers report high field variability with good and bad subunits in every field unit. A largish area (roughly 500 ha) of Pf 3.2 has not been serviced, apparently because it is subject to flooding, and has been allocated to forestry.

All but one of the 10 villages so far settled at Bura are located in the Bura and Chewele Branch commands.

Pumwani Branch Canal was designed to service approximately 2500 ha but not more than 500 ha has actually received water in any one year. The remainder has not been serviced or settled due to lack of sufficient water. About 90 percent of this command has Pf 2.1 soils rated suitable for all crops (Profiles 5, 6 and 7 in Appendix C)

Masatedi Branch Canal was designed to service 150 ha adjacent to the main canal south of the Pumwani take-off. Approximately half of this area is suitable for cotton, (mostly Pf 2.2 soils).

The southernmost command, the Masabubu Branch Canal was designed to service approximately 1500 ha - again nearly all Pf 2.1 soil (Profile 8 in ILACO 1975, Appendix C). Water has yet to reach this area.

5.0 FIELD OBSERVATIONS

Cotton appears to grow satisfactorily (generally speaking) over the areas serviced, through farmers recognise some fields as being better than others. The major limitation appears to be management expressed in terms of timely land preparation and regular irrigation. Adjacent fields are observed to yield significantly different though soil type is the same. Soils obviously do play a role and if management was sorted out variability on soil characteristics would be more obvious and thus more important. Some parts of the serviced are reported to consistently produce good crops, and some farmers are known to consistently produce good crops.

The reasons given for land abandonment and/or non-use of land at Bura include water shortages, soil salinity, hardpan, uneven levelling/land grading.

Problems with irrigation at Bura include:

- slow infiltration due to high sodium and clay content
- slow permeability due to high sodium and clay content
- salinity
- sodicity
- fertility

6.0 LESSONS LEARNT

6.1 Land Management

Mapping unit Pf 2.1 to 2.3 soils, in dry conditions, have a somewhat loose topsoil (very fine crumb or subangular blocky structure) which is very susceptible to wind erosion.

Apparently research work began at Bura in 1984 in Bura Branch Canal Blocks K and L (now used for maendeleo plots). Research shifted to the present site in 1986, though none of the current scientists were employed at that time.

Recommended land preparation is ploughing, harrowing and ridging, but management now thinking of land preparation before maize only, planting cotton on old maize ridges (farmer can reshape/repair ridge with a djembe if necessary) thus reducing one land preparation operation.

5.2 Irrigation Management

Discussion with staff at Bura elicited the following information:

- Soil Pf 2.2 is best soil - it has better infiltration and tends to be more saline than sodic.
- After irrigation, salinity moves below 30 cm but then comes back to surface. It was not clear if this is due to capillary rise and/or perched water table.
- On non-saline sodic soils, hard pans develop in top 30 cm. These are hard and non-friable both before and after irrigation, and water does not percolate into these horizons. Soil Pf 2.4 and Pf 3.1 are hard pan soils and can give poor and patchy yields. Pf 2.4 soils which do not cause problems with farmers give average cotton yields about 500 kg/ha less than from soil Pf 2.2
- In some plots and fields the 2 week irrigation schedule is too long, however this irrigation schedule is only theoretical and is often as long as a month.
- Farmers in Bura Branch Canal Blocks L, M, E and F get highest yields (said to be 3000 kg on 0.625 ha - 4800 kg/ha). These soils subject to short periods of flooding by Laga Hiranman, and this may (partly) explain better yields.

6.3 Mechanization Requirements

The fine texture and heavy nature of these soils will mean that land preparation will require fairly high amounts of power and the cultivation window, in terms of soil moisture content and ease of working, will be relatively narrow.

6.4 Soils of Hola Scheme

At Hola, where the soils have been irrigated for about 31 years, changes in some soil properties such as salinity, sodicity and organic matter content have taken place. However the soils of the Hola Scheme, while similar, are not identical to the Bura Scheme and therefore reaction to irrigation cannot be predicted with total certainty though indications do give some measure of comfort. The following paragraphs are some observations (ILACO, 1976 and 1977; Muchena, 1987) on the response of soils to irrigation at Hola, but as no soil survey was done prior to project implementation it is not possible to quantify any changes as due to irrigation.

- "A comparison of 5 irrigated and 5 non-irrigated soil profiles at Hola showed that, in general, both salinity and sodicity decreased in the irrigated profiles."
- "Soils usually dry out after irrigation up to a depth of 35 cm, allowing storage of some 70 mm of irrigation water. This quantity allows irrigation at 12 day intervals during the period of maximum water demand for cotton."
- "Fertility - there is little response to P and K but significant response to N (economic up to 100 kg N/ha). Deep ripping generally results in increased yields."

- "Water shortages in years 1977 and 1982 resulted in average cotton yields being reduced by up to 1000 kg/ha (i.e., adequate water alone can account for this much yield variation)."
- "Organic matter content under irrigation has increased to 1 to 1.5 percent from 0.2 to 0.7 percent initially." This is a significant increase, and likely reflects slower decomposition rates due to irrigation as much as increased dry matter production.
- "Data for different soil units showed that yields mainly depend on external factors and not on the soil."

According to the Project Manager at Hola:

- Salt problems occur when drains are blocked.
- Soils over years have, on average, improved.
- Powdery soils in some parts wash over surface filling pores and slowing infiltration.
- Rice has been used in trials to assess suitability as means of leaching salts. After 3 seasons (1985-88) of rice, salts concentrated at 150 cm - soils (said to be) still non-saline after 2 season. There was no water for irrigation in the 1989-90. Samples taken in 1990 do show rice area having lower salinity than control, but not appreciably (i.e. 0.5 and 0.55 respectively for the surface horizon and 0.2 and 4.0 respectively at 100+ cm).

7.0 ADDITIONAL LAND FOR EXPANSION

In addition to the MacDonald's irrigation lay-out at Bura West, (ILACO (1975) identified a further 5300 ha (gross) in 3 blocks north of the Bura Branch Canal, and at Rhoka south of the Masabubu Branch Canal (Table 7). These areas are predominately marginally suitable for cotton, but the Rhoka command includes approximately 700 ha of Pf 2.1 soils. However, command of the Rhoka area would require a right hand take-off from the main canal at about the 105 meter contour (approximately opposite the Masatedi take-off) as the present canal alignment swings east to cross the Rhoka drain at about the 90 meter contour.

The broader soil reconnaissance soil survey (Acres/ILACO, 1967 and ILACO, 1975) shows two additional areas of suitable soils. Around and to the north of the present Hola scheme are approximately 3000 ha of marginally suitable soils (Table 7 in Appendix A) which could be served by extending the main canal south from Rhoka. There is also a largish area (500 ha) of suitable soils and a larger area of marginally suitable soils above command to the west of the Masabubu command area. At present there is no economical way of commanding this area, and thus it cannot be considered at this time. If, in future, water can be lifted (approximately 10 meters) or otherwise brought to this area, then in the order of 2500 ha (net) might be added to the scheme.

8.0 DISCUSSION OF 1990 SOIL ANALYSIS AND LABORATORY RESULTS

Spot sampling in identified problem areas and at sites of previous investigation were conducted during the June 1990 field visit of the Soil Scientist. These are identified as A - 1 to 13 and Pit 1 to 8 on Map 1 (Appendix D). These can be compared with earlier chemical analysis of similar sites and typical soil profiles.

Pit Number 2 (Mapping Unit Pf 2.1) shows a small reduction in salinity and slight increase in surface organic matter. This site is currently under grass, having been abandoned due to flooding (its location being at the end of a canal).

Pit Numbers 6 to 8 in Mapping Unit Pf 2.1 are in land which has never been irrigated so can be compared against soils which have been irrigated (Pit Number 5 and Samples C-1 and PB6/1). Differences are not significant. Sample A-11 was taken in field abandoned due to salinity - this is not supported by the chemical analysis.

Pit Number 1 is from a site with a good stand of cotton in Mapping Unit Pf 2.2, while sample sites S1-2 and S1-1 represent before and after irrigation of the same soil respectively. Chemically Pit 5 has lower

pH, salinity and sodicity levels than the typical and thus may reflect the better crop, though this could also be the result of better management.

Pit Number 3 is from an abandoned site (apparently saline) in Mapping Unit 2.3. Chemically there does not appear to any serious limitation.

The samples taken from Chewele B4/2 (Mapping Unit Pf 2.4 and in a sub unit which farmers say has seen yields progressively decrease) show very little variation. The two CB4/2 profiles have appreciably higher sodicity in the surface horizon, but salinity is not sufficiently high to be restrictive to cotton.

Sample site A-9 (Mapping Unit Pf 3.1) compares favourably with earlier analysis for those characteristics measured.

Sample site A-4 shows an appreciably lower pH and higher salinity level than does GU2-1, probably reflecting different locations as much as the 5 years between sampling dates.

9.0 SUMMARY AND RECOMMENDATIONS

9.1 Summary

The scheme is sited on soils of widely varying suitability: about 70 percent (4450 ha) of the commanded area is classed as suitable for cotton and about 40 percent (2500 ha) is classed as suitable for maize. The remainder of the service area (approximately 2200 ha) has some degree of limitation to cotton production and serious limitations for maize. The soils with the best potential, the Pf 2.1 mapping unit, have not yet been used to any extent, and thus expansion should give greater returns to investment.

Salinity and, to some extent, high sodicity levels can normally be expected to lessen with continued and well managed irrigation, and thus mapping units downgraded due to these two factors should eventually show improved suitability. Field units and subunits at Bura still show considerable variation indicating that these are not responding to management under irrigation or that other factors such as land levelling and water application have not been optimum. Management difficulties due to texture variation in the surface and the low permeability of the subsurface soils are also likely to continue for some time - i.e. instability of some surface soils which reduce infiltration and cause crops to suffer drought even though regularly irrigated.

This having been said, these soils still have potential and cannot be blamed for the problems that seem to have plagued the project from the outset. The history seems to be one of unreliable supply of water (with breakdowns frequently at critical crop requirement stages), delayed land preparation and the fact that farmers cannot expect to have the same plot of land from one season to the next.

At Hola, where the soils have been irrigated for about 31 years, changes in some soil properties such as salinity, sodicity and organic matter content have taken place. Because of the discontinuity in information available for any one site at Bura, it is difficult to see this pattern in the chemical analysis data currently available. While the soils of the Hola Scheme are similar, they are not identical to the Bura Scheme and therefore reaction to irrigation cannot be predicted with total certainty though indications do give some measure of comfort.

There are variations in crop performance in the different irrigation subunits due to variations in soil conditions such as salinity, sodicity, water retention rates, surface crusting, land levels and management. Low yields of maize are attributed to high levels of salinity and sodicity. The yields of cotton, which is more tolerant to higher levels of these, are better but are still low. Low yields can also be attributed to on-farm management practices and problems of land preparation and water delivery.

9.2 Recommendations

9.2.1 Soil Survey: The present soils information is based on too few data points, and thus for sound future management, the Bura scheme should have a detailed soil survey conducted to identify blocks of similar soils for management purposes. Such a soil survey should recognise that the present scheme lay-out will influence management, and thus soil investigations should be on a unit basis. The survey should be undertaken by the Kenya Soil Survey and be to their specifications, but should be based on (say) 5 observations to 2 meters per unit, one being a soil pit augered to 5 meters. There are 221 units, thus 1105 observations, 221 of which would be pits (half of these should be sampled for detailed chemical and physical analysis). All augerings should have samples taken for EC, pH and be hand soil textured.

9.2.2 Current Problems Soils: Currently a number of Units and Subunits are known to give low yields for a variety of known and unknown reasons. During the next season, each Unit should be visited by the Agronomist and the farmers document the history of the Unit and identify the problem areas. These should then be investigated in detail and a remedial plan initiated. Part of the investigation may be accomplished by the above mentioned soil survey. Remedial measures may include deep ripping of plough pans, land levelling to remove depressions, soil amendments to mitigate capping, etc.

9.2.3 Soil Management Monitoring Programme: In order to benefit from experience gained, a continuing soil management monitoring programme should be devised and initiated. This will start with identifying good as well as problem soil units, monitoring the remedial work, and noting changes in soil characteristics as a result of project management. Such a programme will assist in optimising yields on the current scheme and in selecting new lands for expansion.

Management will need to recognise the high pH and exchangeable sodium values of Bura soils. In general, to enhance soil fertility, the pH of the soils should be brought to neutral or even slightly acid. To enhance infiltration and profile permeability, sodium ions on the exchange complex need to be replaced with calcium. There are a number of techniques and methods for soil acidification and modification of the exchange complex. These include use of calcium and Sulphur based fertilisers, gypsum, sulphur or even sulphuric acid.

Surface soils of some profiles already have a rather low calcium content, suggesting that calcium has been stripped or leached from the surface to the lower profile, thus any treatment which adds calcium to the soil should be of benefit in increasing infiltration rates and structural stability.

The fact that these soils have a high clay content and high levels of exchangeable sodium mean that large quantities of ameliorative materials will be required to effect substantial changes, and thus the quantities of fertilisers applied can be expected to have only minimal effect. However, the choice of fertilisers which contain relatively high calcium and sulphur content will be a positive contribution - for example, sulphate of ammonium (ammonium sulphate) or superphosphate.

It is likely that additional special treatments will be required and it is recommended that basic trials of various treatment combinations be carried out to verify most effective combinations and quantities.

Gypsum application is the standard treatment for reclamation of sodic soils, but requires rather large quantities of material. Treatment with sulphuric acid, either directly or in irrigation waters tends to increase infiltration rates. However, such use of sulphuric acid is not common as it is a highly corrosive substance and requires special equipment and handling. Elemental sulphur is easier to handle and indirectly has the same effect, though the process of conversion to sulphuric acid takes longer.

9.2.4 Infiltration and Hydraulic Conductivity Monitoring: Infiltration rates vary considerably with soil physical characteristics, but generally are sufficiently lower than optimum, thus requiring frequent (and long hours of) irrigations. Hydraulic conductivities are, at best, slow in these soils, and though there is no current evidence to be pessimistic, more intense irrigation over a wider area could result in perched, or even raised, water tables which would have a detrimental effect on the projects viability. Soil

management will influence infiltration rates, but hydraulic conductivity is less amenable. It is recommended that piezometers be installed to monitor changes in water table, and act as early warning systems. These should be to a minimum of 5 meters depth and located across the scheme and particularly in areas though most susceptible. The deep boring discussed in Section ... of the Report could form the basis of this monitoring programme.

9.2.5 Soil Fertility Monitoring: The high pH and imbalance in available nutrients could be a factor in low yields of all crops in the Scheme. As part of the production unit, specific trials and monitoring should be undertaken to determine the optimum fertility requirements of the crops grown.

9.2.6 Field Laboratory: There is currently a field laboratory at Bura, and a considerable amount of laboratory equipment purchased about 10 years ago and never used. As a result there is considerable valuable equipment (and investment) already on site. The Project should:

- a) employ a consultant technician to prepare an inventory of and to clean and repair all existing equipment at Bura, and prepare a list of requirements;
- b) employ a laboratory technician as part of the staff to maintain the field laboratory and carry out essential analysis. The incumbent should be suitably qualified to do general maintenance service on other technical/electronic equipment (i.e. communications) which the project might have.

APPENDIX A: TABLES

Table 1: Cotton Production in Bura West

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	Average
Area Cropped (ha)	-	740.0	739.0	2010.0	2478.0	2372.0	2500.0	2454.0	1362.0	1831.9
Total Production (mill'n kg)	-	1.618	1.482	4.325	5.209	4.271	5.494	5.521	1.433	3.669
Total Value (mill'n Sh)	-	6.051	6.323	20.759	26.019	21.294	23.622	33.125		17.149
Total Production Cost (million Sh)	-	3.278	3.281	8.888	11.548	10.520	11.205	14.108		7.854
Yield/Ha (kg)	-	2186.0	2006.0	2152.0	2102.0	1799.0	2197.0	2249.0	1052.2	1967.9
Production Cost/ha (Sh)	-	4430.0	4440.0	4422.0	4660.0	4433.0	4482.0	5749.0		4077.0
Net Income (mill'n Sh)	-	2.773	3.042	11.871	14.471	10.774	12.417	19.017		9.296
Average Income/ 1.25 Ha (Sh)	-	4684.0	5154.0	7382.0	7300.0	5675.0	6208.0	9687.0		5761.3
Production Costs are:	Fertiliser - five 50 kg bags per 0.625 ha at Sh186/bag (1990) = Sh 1488/ha									
	Pest Control - Sh 3326/ha			Land and Water Charges at Sh 1600/ha						
	Total = Sh 6414/ha = Sh 4009/farmer 0.625 ha plot									

Source: Agronomist, Bura

Table 2: Maize Production in Bura West

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	Average
Area Planted (ha)	200.0	440.0	630.0	620.0	1200.0	500.0	1000.0	800.0	1287.5	809.7
Est. Total Production (million kg)	0.560	1.364	1.449	1.240	2.400	1.000	2.000	2.000	2.575	1.753
Average Yield/Ha (kg)	2800.0	3100.0	2300.0	2000.0	2000.0	2000.0	2000.0	2500.0	2000.0	2237.5
No. of 90 kg bags/0.624 ha	19.44	21.5	16.0	14.0	14.0	14.0	14.0	17.4	14.0	15.6
Production Costs:	Fertiliser - five 50 kg bags per 0.625 ha at Sh186/bag (1990) = Sh 1488/ha									
	Pest Control - Sh 333/ha			Land and Water Charges at Sh 1600/ha						
	Total = Sh 3421/ha = Sh 2138/farmer 0.625 ha plot assuming farmers use fertiliser and pesticides.									
	Average cost of maize production said to be Sh 1771.2.									

Table 3: Chemical Amendment for Representative Profiles - Bura West - Gypsum

Profile No. (Soil Type)	Depth (cm)	Depth (cm)	ECw (mS/cm)	C.E.C. (me/100g)	E.S.P (%)	Gypsum Req'mnt (GR) (kg/20cm .ha)	Efficiency Factor (GRx1.65)	Horizon Depth Adjusted	Req'mnt for Top 100 cm (t/ha)	Req'mnt for Top 60 cm (t/ha)
S1-1 (Pf 2.2)	0	15	0.2	31	4	-4721.4	-7790.3	-5842.7	100.9	28.8
	15	24	0.3	33	13	2523.2	4163.3	1873.5		
	24	70	2.1	40	20	10320.0	17028.0	39164.4		
	70	102	8.0	37	36	24886.7	41063.0	65700.8		
	102	122	7.0	38	44	32982.7	54421.5	54421.5		
	122	150	6.0	40	43	34056.0	56192.4	78669.4		
S1-2 (Pf 2.2)	0	30	0.5	28	4	-4272.5	-7049.6	-10574.4	83.8	5.4
	30	60	1.4	25	20	6450.0	10642.5	15963.8		
	60	90	5.5	24	47	23292.2	38432.2	57648.3		
	90	120	7.5	33	40	25232.4	41633.5	62450.2		
	120	150	7.5	28	63	37740.2	62271.4	93407.1		
Pit 1 (Pf 2.2)	15	0	0.4	25	5	-3199.2	-5278.7	3959.0	13.4	-20.9
	0	14	0.4	27	4	-4148.6	-68453	-4791.7		
	14	57	0.3	37	4	-5650.2	-9322.8	-20044.1		
	57	125	0.9	38	24	13870.1	22885.6	77811.1		
	125	140	1.1	47	29	22843.3	37691.5	28268.6		
Pit 3 (Pf 2.3)	0	26	0.5	31	8	-1589.3	-2622.3	-3409.3	45.05	5.51
	26	76	1.0	28	21	7946.4	13111.6	32778.9		
	76	112	1.9	26	22	7925.8	13077.5	23539.5		
	112	140	2.2	33	33	20650.3	34073.0	47702.2		
S2 (Pf 2.3)	0	19	0.0	32	10	0.0	0.0	0.0	248.47	102.93
	19	35	7.0	37	50	38184.0	63003.6	50402.9		
	35	58	23.0	37	39	27683.4	45677.6	52529.3		
	58	100	24.0	37	54	42002.4	69304.0	145538.3		
	100	125	28.0	37	50	38184.0	63003.0	78754.5		
G-4 (Pf 2.4)	0	18	0.4	25	3	-4551.1	-7509.3	-6758.4	143.24	63.03
	18	69	0.6	38	38	20227.2	33374.9	85105.9		
	69	135	3.4	36	37	25356.2	41837.8	138064.7		
	135	170	3.2	38	47	36274.8	59853.4	104743.5		
CB4/2 (1) (Pf 2.4)	0	30	0.5	31	32	17482.1	28845.4	43268.1	215.93	82.60
	30	60	1.3	39	26	15892.8	26223.1	39334.7		
	60	90	4.0	46	45	41086.5	67792.7	101689.1		
	90	120	6.0	48	41	38390.4	63344.2	95016.2		
	120	150	7.0	52	42	42931.2	70836.5	106254.7		
Pit 4 (Pf 2.4)	0	19	0.3	21	4	-3281.8	-5414.9	-5144.2	78.66	48.04
	19	78	4.0	28	32	158360	26129.5	77081.9		
	78	100	0.5	21	17	3702.3	6108.8	6719.7		
	100	125	5.0	28	50	28483.2	46997.3	58746.6		
N42 (Pf 2.5)	0	16	0.3	30	4	-4644.0	-7662.6	-6130.1	262.66	100.98
	16	38	0.8	33	28	15325.2	25286.6	27815.2		
	38	65	5.0	33	61	43947.7	72513.7	97893.5		
	65	85	7.5	35	66	49845.6	82245.2	82245.2		
	85	130	6.0	37	61	49210.9	81198.0	182695.5		
GU-1 (Pf 3.1)	0	20	0.4	40	10	0.0	0.0	0.0	201.91	67.05
	20	33	2.2	34	23	11504.2	18982.0	12338.3		
	33	60	2.4	34	38	24561.6	40526.6	54711.0		
	60	100	6.5	36	54	40867.2	67430.9	134861.8		
	100	120	7.0	31	65	44556.6	73518.4	73518.4		

Source: KSS and NAL Soil Data and ILACO, 1976)

Table 3: Chemical Amendment for Representative Profiles – Bura West – Gypsum (Continued)

Profile No. (Soil Type)	Depth (cm)	Depth (cm)	ECw (mS/cm)	C.E.C. (me/100g)	E.S.P (%)	Gypsum Req'mnt (GR)(kg / 20cm.ha)	Efficiency Factor (GRx1.65)	Horizon Depth Adjusted	Req'mnt for Top 100 cm (t/ha)	Req'mnt for Top 60 cm (t/ha)
B16 (Pf 3.1)	0	25	0.2	30	1	-6942.8	-11455.6	-14319.5	27.51	2.11
	25	76	0.7	13	27	5657.9	9335.6	23805.8		
	76	142	3.7	11	43	9195.1	15171.9	50067.4		
	142	178	4.0	12	45	10565.1	17432.4	31378.3		
GU-2 (Pf 3.2)	0	13	0	31	7	-2368.4	-3907.9	-2540.2	91.39	51.85
	13	32	1	25	32	14076.5	23226.2	22064.9		
	32	72	3	23	34	13993.9	23090.0	46179.9		
	72	115	9	25	27	11140.4	18381.7	39520.7		
GU2-1 (Pf 3.2)	0	16	0	37	8	-1888.6	-3116.1	-2337.1	116.06	42.63
	15	40	1	40	16	6114.6	100891.1	12611.4		
	40	80	4	40	39	19608.0	32323.2	64706.4		
	80	112	4	39	35	24897.0	41080.1	65728.1		
CB4/2 (2) (Pf ??)	0	30	0.6	35	22	10836.0	17879.4	26819.1	218.26	87.03
	30	60	0.5	41	33	24329.4	40143.5	60215.3		
	60	90	4.5	52	39	38532.3	63578.3	95367.4		
	90	120	6.5	53	42	43509.1	71790.0	107685.1		
	120	150	8.5	54	46	50155.2	82756.1	124134.1		
N2-1 (Pf 1.2)	0	22	0.2	20	14	2064.0	3405.6	3746.2	54.4	10.5
	22	40	0.2	24	10	0.0	0.0	0.0		
	40	60	0.5	26	16	4086.7	6743.1	6743.1		
	69	95	1.5	28	32	16119.8	26597.7	34577.1		
	95	130	3.5	26	45	23026.5	37993.7	66489.0		
Pit 2 (Pf 1.2)	0	18	0.3	22	5	-2773.5	-4576.3	-4778.6	6.10	-1.49
	18	37	0.2	27	9	-701.8	-1157.9	-1100.0		
	37	97	0.5	26	13	1981.4	3269.4	9808.1		
	97	150	0.8	30	18	6109.4	10080.6	26713.5		
C-1 (Pf 2.1)	0	18	0.2	26	2	-5283.8	-8718.3	-7856.5	-8.04	-27.59
	18	36	0.1	24	1	-5479.9	-9041.9	-8137.7		
	36	60	0.1	28	2	-5861.8	+9671.9	-11606.3		
	60	84	0.4	26	17	4695.6	7747.7	92606.3		
	84	110	0.4	25	22	7771.0	12822.1	16668.7		
110	155	0.5	24	31	12786.5	21097.7	47469.8			
PB6/1 (Pf 2.1)	0	30	0.5	35	1	-8010.9	-13218.0	-19827.0	-61.87	-43.1
	30	60	0.3	41	1	-9404.1	-15516.8	-23275.1		
	60	90	0.2	33	2	-6708.0	-11068.2	-16602.3		
	90	120	0.3	17	4	-2631.6	-4342.1	-6513.2		
	120	150	0.4	12	6	-1238.4	-2043.4	-3065.0		
Pit 5 (Pf 2.1)	0	23	0.1	8	12	418.0	689.6	793.1	-0.70	-3.71
	23	52	0.3	20	5	-2580.0	-4257.0	-6172.7		
	52	80	2.4	18	16	2709.0	4469.9	6257.8		
	80	130	0.5	19	8	-954.6	-1575.1	-3937.7		
Pit 6 (Pf 2.1)	0	9	0.2	15	4	-2244.6	-3703.6	-1666.6	1.36	-4.9
	9	16	0.4	39	4	-6098.2	-10012.5	-8510.6		
	26	84	3.0	37	12	1883.4	3107.6	9012.1		
Pit 7 (Pf 2.1)	0	10	0.2	25	9	-645.0	-1064.3	-562.1	-19.45	-12.58
	10	27	0.7	30	4	-4266.6	-7534.9	-6404.7		
	27	70	0.2	27	7	-2074.3	-7358.7	-7358.7		
Pit 8 (Pf 2.1)	0	15	0.7	17	7	-1300.3	-2145.5	-1609.1	-24.21	-13.2
	15	30	1.6	19	5	-2476.8	-4086.7	-3065.2		
	30	99	0.0	19	3	3431.4	-5661.8	-19533.2		
	99	125	0.6	9	7	-727.6	-1200.5	-1560.6		

Table 4a: Bura Soils Results of Field Tests

Sample Site	Depth (cm)	pH (1:2.5)	EC (1:2.5) (mS/cm)	Dispersion Rate	Clarity	Comments
A-1 (BG2)	0-10	8.3	0.1	Mod	Clear	Good Cotton Crop
	10-20	8.5	0.2	Mod Rapid	Cloudy	
	20-30	8.6	0.2	Mod Rapid	Cloudy	
	30-40	8.8	3.2	Slow	Cloudy	
	40-50	8.2	4.8	Slow	Cloudy	
	50-70	8.8	7.0	Slow	Cloudy	
	70-100	8.3	10.0	Slow	Cloudy	
	100-120	8.8	11.0	Slow	Cloudy	
A-2 (BH4/1)	15-25	8.1	1.5	Slow	Clear	
	25-35	8.2	1.5	Slow	Clear	
	35-50	8.2	2.0	Slow	Mod Clear	
	50-60	8.5	3.0	Slow	Clear	
A-3 (BH4/1)	0-10	8.5	2.2	Rapid	Clear	Abandoned due to ditch flooding?? Wide cracking-dry
	10-30	8.5	2.5	Rapid	Clear	
	30-50	8.5	2.5	Mod Rapid	Clear	
	50-70	8.5	7.5	Slow	Cloudy	
	70-100	8.7	12.0	Slow	Cloudy	
A-4 (BL4/3)	15-30	8.4	0.5	Rapid	Clear	Ploughed - no crop Maize last year
	3-50	8.2	2.0	Rapid	Clear	
	50-80	7.9	3.5	Rapid	Clear	
	80-100	7.9	4.5	Mod Rapid	Clear	
	100+	7.9	5.6		Clear	
A-5 (BD4/2)	0-20	8.4	1.0	-	Clear	Abandoned Area appears saline
	20-50	8.6	4.0	-	Clear	
	50-80	8.0	9.0	-	Clear	
	100+	8.0	14.0	-	Clear	
A-6 (CB4/3)	0-20	8.4	5.0	Rapid	Clear	Farmers say yields have decreased over past 7 years. Last sample absorbed all water
	40-50	8.9	-	Slow	Cloudy	
	70-80	8.8	20.0	Rapid	Cloudy	
	100+	-	-	Mod Rapid	No Liquid	
A-7 (PB8/1)	0-20	8.3	15.0	-	Clear	No cotton crop this season Last season maize
	55-70	8.4	6.5	Rapid	Clear	
	100-120	8.3	-	Rapid	Clear	
A-8 (PB7/1)	15-30	8.5	0.2	Rapid	Clear	Late planted cotton
	55-70	8.5	0.4	Rapid	Clear	
	100+	8.6	5.0	Mod Rapid	Cloudy	
A-9 (PD4/1)	0-30	8.6	0.4	Rapid	Clear	V. late planted cotton Hardly any liquid
	30-50	8.5	0.5	Rapid	Clear	
	70-90	8.8	5.0	Rapid	Cloudy	
	100+	8.3	7.5	Rapid	Mod Clear	
A-10 (PE2/3)	0-20	9	0.2	-	Cloudy	Never been cultivated
	36-54	8	3.5	-	Mod Clear	
	80-90	7.9	6.5	-	Clear	
A-11 (PB7/4)	0-20	8.2	5.0	Rapid	Clear	Abandoned field
	3-50	8.5	8.0	Rapid	Clear	
	70-90	8.6	0.5	Rapid	Cloudy	
	100-120	8.6	10.2	Rapid	Cloudy	
A-12 (MG6/4)	0-10	5.5	0.4	Rapid	Cloudy	Never been cultivated
	50-60	7.1	6.0	Rapid	Clear	
	110-120	7.2	8.0	Rapid	Clear	
A-13 (PH10/3)	0-10	7.7	0.2	Rapid	Clear	Never been cultivated
	50-60	8.0	0.3	Rapid	Clear	
	110-120	7.8	1.5	Rapid	Clear	

Source: Table 1.6 ILACO, C-1-1.

Table 4b: Bura Soils Results of Field Tests (Soil Pits)

Sample Site	Depth (cm)	pH (1:2.5)	EC (1:2.5) (mS/cm)	Dispersion Rate	Clarity	Comments
Pit 1 (BH4/1)	15-0	7.5	2.8	Rapid	Clear	Good Cotton Crop
	0-14	-	-	Slow	Clear	
	14-57	7.6	3.0	Mod Rapid	Clear	
	57-125	8.0	9.0	Rapid	Mod Clear	
	125-140	8.3	9.5	Rapid	Mod Clear	
Pit 2 (BH4/1)	0-18	7.5	1.0	Rapid	Cloudy	Abandoned due to ditch flooding?? Wide cracking-dry
	18-37	7.4	2.0	Slow	Cloudy	
	37-97	8.2	4.8	Rapid	Cloudy	
	97-150+	8.1	7.0	Rapid	Clear	
Pit 3 (BD4/2)	0-26	7.3	-	Rapid	Clear	Abandoned Area appears saline V. little liquid
	26-76	7.8	1.2	Rapid	Clear	
	76-112	8.0	2.2	Rapid	Clear	
	112-140+	7.9	4.5	Rapid	Clear	
Pit 4 (CB4/3)	0-19	7.6	2.0	Rapid	Clear	Farmers say yields have decreased over past 7 years Last sample absorbed all water
	19-78	8.0	3.0	Rapid	Cloudy	
	78-110	7.6	7.0	Rapid	Clear	
	110-125+	7.7	9.0	Rapid	Clear	
Pit 5 (PB8/1)	0-23	7.8	2.0	Rapid	Clear	No cotton crop this season Last season maize
	23-52	8.0	1.5	Rapid	Clear	
	52-82	8.0	3.5	Rapid	Clear	
	82-130+	8.0	6.5	Rapid	Clear	
Pit 6 (PE2/3)	0-9	7.0	0.4	Rapid	Cloudy	
	9-26	6.3	0.2	Rapid	Cloudy	
	26-50	6.3	4.0	Rapid	Clear	
	90-100	7.2	9.5	Rapid	Clear	
Pit 7 (PJ8/3)	0-10	7.6	0.2	Rapid	Cloudy	
	10-27	6.6	0.0	Rapid	Cloudy	
	27-80	6.6	0.1	Rapid	Clear	
Pit 8 (MF6/2)	0-10	5.6	0.1	Rapid	Cloudy	
	15-25	5.5	2.9	Rapid	Clear	
	30-40	5.7	0.2	Rapid	Clear	
	97-110	7.2	2.3	Rapid	Clear	

Source: Table 1.6 ILACO, C-1-1.

Table 5a: Bura West Soil/Land Classification

Soil Units (Net Ha)	Class 1 (Soil C)	Class 2 (Soil S+N1)	Class 3 (Soil N41+GU+GA)	Class 4 (Rest)	Total
C	2690	0	0	0	2690
S1	0	1755	0	0	1755
GU1	0		240	0	240
N41	0	0	600	0	600
S2	0	0	0	550	550
GU2	0	0	0	500	500
N42	0	0	0	125	125
N2	0	0	0	190	190
Total (Net)	2690	1755	840	1365	6650
%	40	26	13	21	100
Net serviced area as percentage of ILACO gross area = 71.9					

Source: Macdonald (1977), Table 2.3 Vol 2. Annexes: Bura Irrigation Settlement Project: Project Planning Report (Phase I).

Table 5b: Bura East Soils Suitable for Irrigation

Mapping Unit	Land Area(ha)	Suitability for Irrigation					
		Cotton	Maize	Rice	Sugarcane	Cowpeas	Groundnuts
Ps 2.1	930	S2	S2	S2	S2	S2	S2-S3
Ps 2.2	1150	S2	S2-S3	S2	S2	S2-S3	S2-S3
Ps 2.3	1310	S2	S2	S2	S2	S2-S3	S2-S3
Ps 2.4	3000	S2	S2-S3	S2-S3	S2-S3	S2-S3	S2-S3
Ps 2.5	2210	S2-S3	S2-S3	S2-S3	S2-S3	S2-S3	S2-S3
Ps 2.6	4080	S3	S3	S2-S3	S3	S3	S3
Ps 2.7	2200	S3	S3	S2-S3	S3	S3	S3
Ps 2.8	2420	S3	S3	S3	S3	S3	S3
Ps 2.11	3260	S3	NS	NS	NS	NS	NS
Ps 1.1-1.3	17650	NS	NS	NS	NS	NS	NS
Ps 2.9-2.17	38620	NS	NS	NS	NS	NS	NS
Ps 3.1-3.2	5100	NS	NS	NS	NS	NS	NS
TOTAL	81630						
S2		6390	930	3390	3390	930	0
S2-S3		2210	6360	11490	5120	7670	8600
S3		11960	10010	2420	8700	8700	8700
TOTAL S		20560	17300	17300	17300	17300	17300
TOTAL NS		61070	64300	64330	64300	64300	64300
TOTAL		81630	81630	81630	81630	81630	81630
Est'd Net S at 75%		15420	12975	12975	12975	12975	12975

Source: Muchena, 1978

Table 6: Bura West Soil/Land Classification

Scheme	Area	Gross Ha	Net Ha	%
Northern	Bura	1750	1620	
Centre	Masa	1790		
	Pumwani	2585	4050	
Southern	Masabubu	2385		
	Rhoka	3150	5125	
Total		11660	10795	
%		100.0		92.6
Hola	North Hola	2600	3260	
	Present	850		
Total		15110	14055	93.0
%		100.0		

Source: ILACO, 1975

Table 7: Additional Commandable Land For Development At Bura West

Location	Class 1	Class 2	Class 3	Total (Gross)	Total (Net)
Tuni Branch	0	260	120	380	300
Yedi Branch	0	990	430	1420	1200
Bobwani Branch	0	135	110	245	200
Rhoka Branch	700	2225	345	3270	2700
TOTAL (Gross)	700	3610	1005	5315	4400
Hola Branch	0	2000	1000	3000	2500
TOTAL (Gross)	700	5610	2005	8315	6900

Source: Table C.9, Annex C, ILACO, 1975, Bura Irrigation Scheme Feasibility Study: Final Report

Estimated total additional net area for development not including land above canal = 6900

Total existing development at Bura West and Hola = 7400

Net potential gravity fed production area in Bura West/Hola = 14300

Estimated additional new area above canal if commandable = 2500

Maximum potential production area in Bura West/Hola = 16800

APPENDIX B: REFERENCES

1. Acres/ILACO, 1967, Survey of the irrigation potential of the Lower Tana River Basin, FAO, Rome.
2. Aerial Photographs:
 - Gauff, 1988, Aerial photographs (oblique angle??), Scale 1:10,000 - (Seen in Survey Office at Bura).
 - Geosurvey, 19, Aerial Photographs, Scale 1:10,000? - Seen in Survey Office at Bura)
 - Hunting's, 1976, Uncontrolled Mosaics from 1960 and 1975 aerial photography, Scale 1:20,000; - (Seen in Survey Office at Bura)
 - RAF, 1975, Aerial Photographs, Scale 1:10,000 - (Seen in Survey Office at Bura)
3. FAO, 1976, Prognosis of Salinity and Alkalinity, Soils Bulletin Number 31, Rome.
4. FAO, 1985, Water quality for agriculture, Irrigation and Drainage Paper Number 29, Rome.
5. IBRD, 1985, Midterm Evaluation Report 1984, Bura Irrigation Settlement Project.
6. ILACO, 1976, Bura Irrigation Scheme: Memorandum on the suitability of soils in the Bura Area for irrigated cotton production, Arnhem, The Netherlands.
7. ILACO, 1977, Hola Pilot Demonstration and Training Project, Final Report 1973-76. (Seen in KSS Library). http://www.wossac.com/search/wossac_detail.cfm?ID=41327
8. Sir M. Macdonald and Partners, 1977, Bura Irrigation Settlement Project: Project Planning Report.
9. Maps:
 - Bura Estate 77/42, Scale 1:10,000 (January 1978)
 - Sheet 140 (Korokoro), Series Y633, Scale 1:100,000, Survey of Kenya (1963)
 - Sheets 126/3 (Garissa), 140/1/2/4 (Hamaruis, Korokoro and Nanigi) and 154/2 (Bura), Series Y731, Scale 1:50,000, Government of Kenya (1979).
10. 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. PhD Thesis, Wageningen. http://www.wossac.com/search/wossac_detail.cfm?ID=42646
11. Mugai, E.N.K. and van der Pouw, B.J.A., 1978, Detailed Soil Survey of an Experimental Site for the Bura Irrigation Settlement Project, KSS Report D12, Nairobi.
12. Richards, L.A. (ed), 1954, Diagnosis and improvement of Saline and Alkali Soils, Agriculture Handbook No. 60, USDA.

APPENDIX C: PERSONAL CONTACTS/SOURCES OF INFORMATION

Mr. Alfrick Birgen, Managing Director, TARDA
Mr. Colin Read, Project Engineer, TARDA
Mr. Wolf Baur, Financial Controller, TARDA
Mr. Joseph Koech, Soil Technician, TARDA

Mr. David Nyasani, Project manager, Bura
Mr. ? Ndunda, Irrigation and Drainage Research Officer, Bura
Mr. P.K. Kuria, Agricultural Manager, Bura
Mr. ? Macharia, Entomologist and Sr. Research Officer, Bura
Mr. ? Galana, Irrigation Officer, Village 10, Bura
Mr. T.F. Wamalwa, Supply Officer, Bura
Mr. John Dhadho, Irrigation Officer, Bura
Mr. Daniel Babu, Senior Surveyor, Bura

Mr. Edward arup Too, District Officer, Bura East
Mr. Yusef Jama, Assistant Chief, Bura East

Mr. ? Muthai, Project Manager, NIB, Hola
Mr. ? Mulwa, Acting Senior Research Officer, Hola
Mr. Raymond E. Njagi, Soils Laboratory Technician, Hola

Dr. Fred Muchena, Director, National Agricultural Laboratory (NAL) and Kenya Soil Survey (KSS),
Nairobi

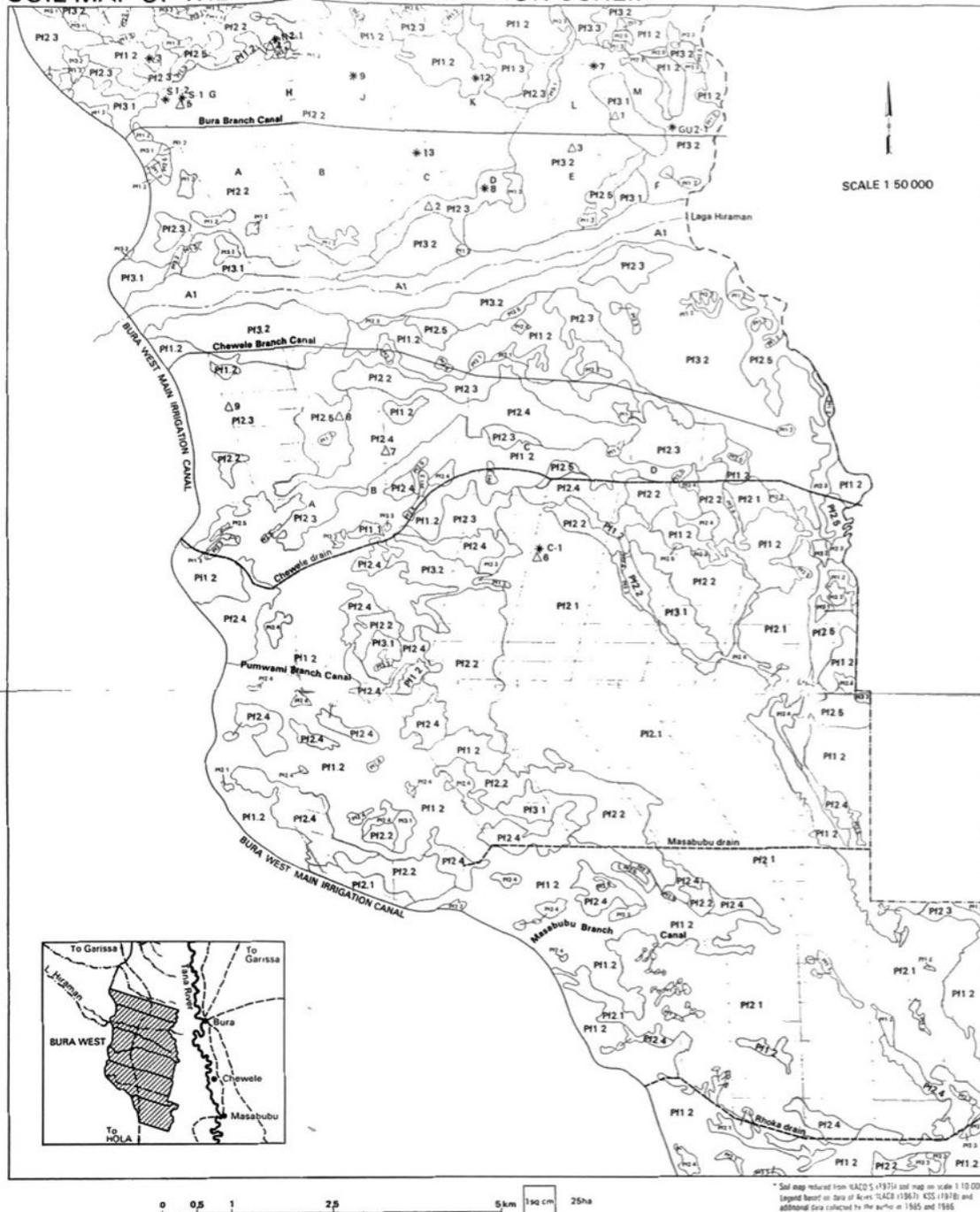
Mr. J.N. Qureshi, Chief Soil Scientist, NAL, Nairobi
Mr. ? Gatei, Chemist, NAL, Nairobi
Mr. Paul Oduor, Chemist, KSS, Nairobi
Mr. M. Gatahi, KSS, Nairobi
Mr. S.M. Wokabi, Head of KSS, Nairobi
Mr. Michael O. Aguno, Librarian, KSS, Nairobi
Mr. C.M. Njihia, Irrigation/Drainage Spec., NAL, Nairobi
Mrs. Esther Gikowyo, Soils Laboratory, NAL, Nairobi
Mr. N? Sanga, Senior Soils Technician, NAL, Nairobi

Dr. John Okelebo, Research Officer, KARI, Maguga

APPENDIX D: SOIL MAPS

Map 1: Bura West.....Page 21
Map 2 Bura EastPage 22
Map 3: Hola.....Page 23

SOIL MAP OF THE BURA WEST IRRIGATION SCHEME



SYMBOL	GENERAL DESCRIPTION		CALCAREOUSNESS		SALINITY		SODICITY		CLASSIFICATION		SOIL TAXONOMY (USDA, 1975)
	SUBSOIL	TOPSOIL	NON-CALCAREOUS	CALCAREOUS	NON-SALINE	SALINE	NON-SODIC	SODIC	FAO/UNESCO (1974)	FAO-REVISED (1987)	
P PLAINS											
Pf SEDIMENTARY PLAIN OF LARGE ALLUVIAL FANS All soils are developed on Old Alluvial deposits											
Pf1 SLIGHTLY HIGH - LYING LAND											
Pf1.1	well drained to moderately well drained, very deep, brown to dark brown, firm, sandy clay loam to clay with a clear hardpan	50-90cm of dark reddish brown to dark brown, loose sand to sandy loam	0-90cm	>90cm slightly to moderately calcareous	0-70/115cm	>70/115cm slightly to strongly saline	0-50/90cm	>50/90cm moderately to strongly sodic	Orthic SOLONETZ partly saline phase	Haplic SOLONETZ partly saline phase	Typic NATRARGIDS
Pf1.2	moderately well drained to imperfectly drained, very deep, dark reddish brown to dark brown, firm, sandy clay to clay	15-40cm of dark red to reddish brown, loose sand to sandy clay loam	0-15/40cm	>15/40cm moderately to strongly calcareous	0-15/40cm	>15/40cm strongly saline	0-15/40cm non to slightly sodic	>15/40cm moderately to strongly sodic	Orthic SOLONETZ saline phase	Calcareo-haplic SOLONETZ saline phase	Typic NATRARGIDS
Pf1.3	moderately well drained to imperfectly drained, very deep, dark brown to dark greyish brown, firm, sandy clay to clay	2-15cm of dark red to dark brown, loose to friable, loamy sand to sandy clay loam	0-10/15cm	>10/15cm moderately to strongly calcareous	0-10/15cm	>10/15cm strongly saline	0-10/15cm non to slightly sodic	>10/15cm strongly sodic	Orthic SOLONETZ saline phase	Calcareo-haplic SOLONETZ saline phase	Typic NATRARGIDS
Pf2 SLIGHTLY LOW - LYING LAND											
Pf2.1	well drained, very deep, dark reddish brown to dark brown, friable, sandy clay to clay	10-30cm of dark red to reddish brown, friable, sandy clay loam to sandy clay	0-15/50cm	15/50cm slightly to moderately calcareous	0-100/125cm	>100/125cm slightly saline	0-60/125cm	>60/125cm slightly to strongly sodic	Haplic XEROSOLS partly sodic phase	Chromic-calcic CAMBISOLS partly sodic phase	Typic CAMBORTHIDS
Pf2.2	well drained, very deep, dark red to dark reddish brown, friable to firm, sandy clay to clay	20-30cm of dark red to reddish brown, friable, sandy clay loam to sandy clay	-	moderately to strongly calcareous throughout	0-20/40cm	>20/40cm moderately to strongly saline	0-20/40cm non to slightly sodic	>20/40cm moderately to strongly sodic	Haplic XEROSOLS saline sodic phase	Chromic-calcic CAMBISOLS saline sodic phase	Typic and Natric CAMBORTHIDS
Pf2.3	As Pf2.2	As Pf2.2 but 10-20cm deep	-	As Pf2.2	0-10/20cm	>10/20cm moderately to strongly saline	0-10/20cm non to slightly sodic	>10/20cm moderately to strongly sodic	Haplic XEROSOLS saline sodic phase	Chromic-calcic CAMBISOLS saline sodic phase	Typic and Natric CAMBORTHIDS
Pf2.4	well drained to moderately well drained, very deep, dark reddish brown, firm clay	15-30cm of dark reddish brown, friable, sandy clay loam to sandy clay	0-15/30cm non to slightly calcareous	>15/30cm moderately to strongly calcareous	0-60/70cm	>60/70cm strongly saline	0-15/30cm	>15/30cm strongly sodic	Orthic SOLONETZ saline phase	Calcareo-haplic SOLONETZ saline phase	Typic NATRARGIDS
Pf2.5	well drained to moderately well drained, very deep, reddish brown to dark reddish brown, firm clay	10-15cm of reddish brown to brown, friable, sandy clay loam to sandy clay	0-10/15cm non to slightly calcareous	>10/15cm moderately to strongly calcareous	0-40/50cm	>40/50cm moderately to strongly saline	0-10/15cm	>10/15cm strongly sodic	Orthic SOLONETZ saline phase	Calcareo-haplic SOLONETZ saline phase	Typic NATRARGIDS
Pf3 LOW - LYING LAND											
Pf3.1	moderately well drained to imperfectly drained, very deep, dark reddish brown to dark brown, firm, cracking clay	15-30cm of reddish brown to dark brown, friable, sandy clay to clay	-	strongly calcareous throughout	0-20/80cm	>20/80cm moderately to strongly saline	0-20/30cm	>20/30cm moderately to strongly sodic	Chromic VERTISOLS saline sodic phase	Chromic-calcic VERTISOLS saline sodic phase	Typic TORRENTS
Pf3.2	moderately well drained to imperfectly drained, very deep, dark reddish brown, firm to very firm, cracking clay	10-15cm of dark reddish brown, friable, sandy clay to clay	-	strongly calcareous throughout	0-15/30cm	>15/30cm moderately to strongly saline	0-10/15cm	>10/15cm moderately to strongly sodic	Chromic VERTISOLS saline sodic phase	Chromic-calcic and Chromic-haplic VERTISOLS saline sodic phase	Typic TORRENTS
Pf3.3	imperfectly drained to poorly drained, very deep, dark brown to dark greyish brown, firm to very firm, cracking clay	15-20cm of dark brown, friable, sandy clay to clay	-	strongly calcareous throughout	0-50/70cm	>50/70cm moderately to strongly saline	0-15/25cm	>15/25cm strongly sodic	Chromic VERTISOLS saline sodic phase	Chromic-calcic VERTISOLS saline sodic phase	Typic TORRENTS
A FLOODPLAIN (low-lying lands of the Tana Floodplain) Soils developed on Young Alluvial deposits											
A1	imperfectly drained, very deep, dark brown to brown, firm to very firm, stratified cracking clay	15-20cm of dark brown to brown, friable, sandy clay to clay	0-20/30cm non to slightly calcareous	>20/30cm slightly to moderately calcareous	0-70/100cm	>70/100cm slightly to moderately saline	0-20/30cm non to slightly sodic	>20/30cm moderately to strongly sodic	Calcareo FLUVISOLS sodic phase, in places saline phase	Vertic-calcareo FLUVISOLS sodic phase, in places saline phase	Vertic TORRIFLUVENTS

thickness soil in cm	symbol	name
0-60	shallow	shallow
60-80	moderately deep	moderately deep
80-120	deep	deep
>120	very deep	very deep

ECe (mmhos/cm)	EC (1:2.5) (mmhos/cm)	salinity classes
0-4	0-0.9	non saline
4-8	0.9-2.0	slightly saline
8-16	2.0-4.0	moderately saline
>16	>4.0	strongly saline

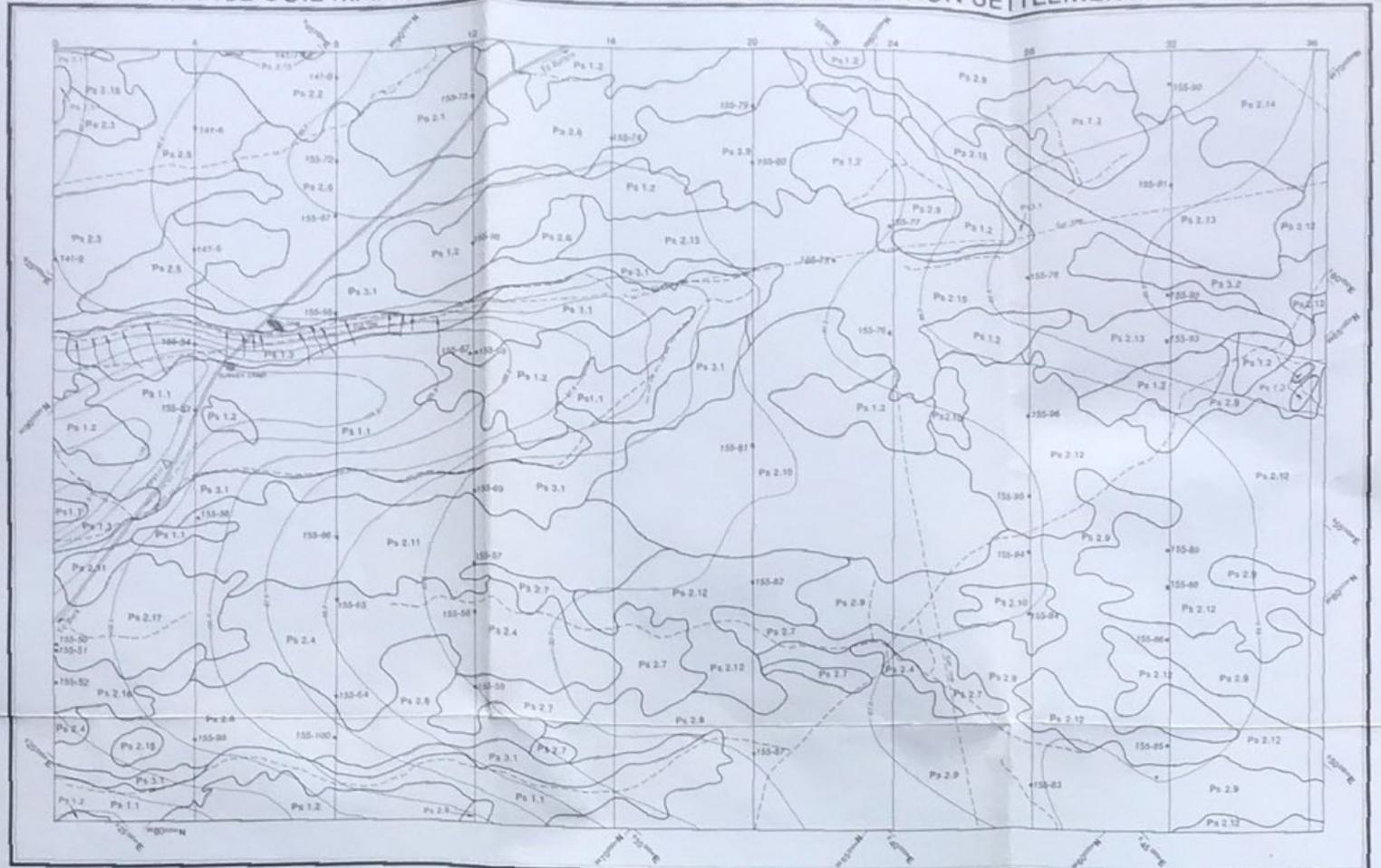
ESP	CLASS
0-5%	non sodic
5-10%	slightly sodic
10-15%	moderately sodic
>15%	strongly sodic

KEY

- soil mapping symbol
- drain
- road
- Profile with number
- soil boundary
- boundary of study area
- canal
- river
- Sampling sites for pf data



RECONNAISSANCE SOIL MAP OF THE PROPOSED BURA EAST IRRIGATION SETTLEMENT



Base map derived from topographical map surveyed by Geosurvey Scale 1:50,000

LEGEND

Ps SEDIMENTARY PLAINS (slopes less than 2%)

All soils are developed on Tertiary/Quaternary marine/Lacustrine sediments

SYMBOL	SUBSOIL	TOPSOIL	CALCAREOUSNESS		SALINITY		SODICITY		CLASSIFICATION		
			NON-CALCAREOUS	CALCAREOUS	NON-SALINE	SALINE	NON-SODIC	SODIC	FAO/UNESCO (1974)	FAO REVISED (1987)	SOIL TAXONOMY (SOILS 1975)
Ps1 SLIGHTLY HIGH-LYING LAND											
Ps 1.1	imperfectly drained, very deep, greyish brown to dark greyish brown, fine sandy clay to clay with a clear horizon	10-15cm of dark greyish brown to very dark greyish brown, friable, sandy clay loam to sandy clay	0-10/15cm	>10/15cm strongly calcareous	0-10/15cm	>10/15cm moderately to strongly saline	-	0-10/15cm slightly to moderately sodic; >10/15cm moderately to strongly sodic	gleyic SOLONETZ, saline phase	Calcari-gleyic SOLONETZ, saline phase	Typic and Aquic NATRARGIDS
Ps 1.2	As Ps 1.1	As Ps 1.1, but in places 10-40cm deep	0-10/40cm non to slightly calcareous	>10/40cm strongly calcareous	0-10/40cm	>10/40cm moderately to strongly saline	-	0-10/40cm slightly to moderately sodic; >10/40cm moderately to strongly sodic	gleyic SOLONETZ, saline phase	Calcari-gleyic SOLONETZ, saline phase	Typic and Aquic NATRARGIDS
Ps 1.3	imperfectly drained, very deep brown to dark greyish brown, fine sandy clay to clay with a clear horizon	10-30cm of dark brown to very dark greyish brown, friable, sandy clay loam to sandy clay	-	0-10/30cm slightly calcareous >10/30cm strongly calcareous	0-10/30cm	>10/30cm moderately to strongly saline	-	0-10/30cm slightly sodic >10/30cm strongly sodic	gleyic SOLONETZ, saline phase	Calcari-gleyic SOLONETZ, saline phase	Typic and Aquic NATRARGIDS
Ps2 SLIGHTLY LOW-LYING LAND											
Soils which are non-saline and non to slightly sodic to a depth of at least 60cm											
Ps 2.1	moderately well drained, very deep, greyish brown to dark greyish brown, friable clay	10-30cm of greyish brown to dark greyish brown, friable clay	throughout	-	0-100/150cm	>100/150cm non to slightly saline	0-100cm	>100cm slightly to moderately sodic	lentic XEROSOLS	Gleyic LUVISOLS	Typic HAPLARGIDS
Ps 2.2	moderately well drained to imperfectly drained, very deep, greyish brown to dark greyish brown, friable to firm, clay	10-30cm of dark greyish brown to dark grey, friable to firm, clay	0-10/15cm	>10/15cm slightly to strongly calcareous	0-70/100cm	>70/100cm slightly to moderately saline	0-70/100cm	>70/100cm slightly to moderately sodic	lentic XEROSOLS	Calcari-gleyic LUVISOLS	Typic HAPLARGIDS
Ps 2.3	imperfectly drained, very deep, greyish brown to dark greyish brown, friable to firm, clay	10-30cm of dark greyish brown, friable clay	-	moderately to strongly calcareous throughout	0-80/120cm	>80/120cm slightly saline	0-80/120cm non to slightly saline	>80/120cm moderately to strongly sodic	haplic XEROSOLS, sodic phase	Calcari-gleyic and Calcari-vertic CAMBISOLS sodic phase	Typic and Natric CAMBORTHIDS
Soils which are non-saline to a depth of at least 60cm and non to slightly sodic to a depth of at least 20cm											
Ps 2.4	moderately well drained, very deep, reddish brown to dark brown, friable to firm, clay	10-30cm of dark brown, friable clay	-	moderately to strongly calcareous throughout	0-70/100cm	>70/100cm slightly to moderately saline	-	0-30/70cm slightly to moderately sodic >30/70cm strongly sodic	haplic XEROSOLS, sodic phase	Calcari-vertic and Chromo-calcari CAMBISOLS sodic phase	Typic and Natric CAMBORTHIDS
Ps 2.5	moderately well drained to imperfectly drained, very deep, grey to greyish brown, friable to firm, clay	10-30cm of dark greyish brown, friable, sandy clay to clay	-	moderately to strongly calcareous throughout	0-40/80cm	>40/80cm slightly to moderately saline	0-30cm to slightly sodic	>30cm moderately to strongly sodic	haplic XEROSOLS, saline-sodic phase	Vertic haplic and Lovi-haplic CALCISOLS sodic phase	Natric CAMBORTHIDS
Ps 2.6	imperfectly drained to poorly drained, very deep, dark brown to dark grey, friable to firm, clay	15-20cm of greyish brown to dark greyish brown, friable clay	0-10/20cm non to slightly calcareous	>10/20cm moderately to strongly calcareous	0-40/80cm	>40/80cm slightly to strongly saline	0-30/80cm non to slightly sodic	>30/80cm slightly to strongly sodic	haplic XEROSOLS, saline-sodic phase	Vertic haplic and Lovi-haplic CALCISOLS sodic and sodic phase	Typic and Natric CAMBORTHIDS
Ps 2.7	imperfectly drained, very deep, dark brown to dark greyish brown, friable to firm, clay	10-30cm of dark greyish brown, friable clay	0-10cm non to slightly calcareous	>10cm strongly calcareous	0-80/100cm	>80/100cm moderately to strongly saline	0-30cm non to slightly sodic	>30/70cm slightly to moderately sodic >70cm strongly sodic	lentic XEROSOLS, saline-sodic phase	Calcari-gleyic LUVISOLS sodic sodic phase	Typic HAPLARGIDS
Soils which are non-saline and non to slightly sodic to a depth of at least 20cm											
Ps 2.8	moderately well drained to imperfectly drained, very deep, dark brown to dark greyish brown, friable to firm, clay	10-20cm of dark brown to very dark greyish brown, friable, sandy clay to clay	0-1/100cm non to slightly calcareous	>1/100cm strongly calcareous	0-35/90cm	>35/90cm slightly to strongly saline	0-30/90cm non to slightly sodic	>30/90cm moderately to strongly sodic	haplic XEROSOLS, saline-sodic phase	Vertic haplic CALCISOLS sodic sodic phase	Natric CAMBORTHIDS
Ps 2.9	imperfectly drained, very deep brown to dark greyish brown, friable to firm, clay	10-20cm of dark greyish brown to dark brown, friable to firm, clay	-	moderately to strongly calcareous throughout	0-40/80cm	>40/80cm moderately to strongly saline	0-30/80cm non to slightly sodic	>30/80cm strongly sodic	urtic SOLONETZ, saline phase	Calcari-haplic SOLONETZ, saline phase	Typic NATRARGIDS
Soils which are both saline and sodic (kindest) throughout											
Ps 2.10	imperfectly drained, very deep, greyish brown to dark greyish brown, fine clay	10-20cm of dark greyish brown, friable to firm, sandy clay	0-5/100cm non to slightly calcareous	>5/100cm strongly calcareous	0-40/80cm non to slightly saline	>40/80cm moderately to strongly saline	0-10cm non to slightly sodic	>10cm moderately to strongly sodic	gleyic and gleyic SOLONETZ saline phase	Calcari-haplic and Calcari-gleyic SOLONETZ sodic phase	Typic and Aquic NATRARGIDS
Ps 2.11	imperfectly drained to poorly drained, very deep, greyish brown to dark greyish brown, friable to firm, clay	10-20cm of dark brown to dark greyish brown, friable, sandy clay to clay	0-10cm non to slightly calcareous	>10cm moderately to strongly calcareous	0-30/80cm	>30/80cm moderately to strongly saline	-	moderately to strongly sodic throughout	haplic XEROSOLS, saline-sodic phase and urtic SOLONETZ, saline and gleyic phase	Calcari-haplic and Calcari-gleyic CAMBISOLS LUVISOLS, sodic-sodic phase	Natric CAMBORTHIDS and Typic and Aquic NATRARGIDS
Ps 2.12	imperfectly drained to poorly drained, very deep, dark brown to very dark greyish brown, firm clay	10-20cm of very dark greyish brown, friable to firm, clay	0-10cm non to slightly calcareous	>10cm moderately to strongly calcareous	0-30/50cm non to slightly saline	>30/50cm moderately to strongly saline	-	moderately to strongly sodic throughout	haplic XEROSOLS, saline-sodic phase and urtic SOLONETZ, saline phase	Calcari-haplic and Calcari-gleyic SOLONETZ sodic phase	Typic and Aquic NATRARGIDS
Ps 2.13	imperfectly drained to poorly drained, very deep, dark brown to dark greyish brown, firm, clay	70cm of dark brown, to very dark greyish brown, friable to firm, clay	-	strongly calcareous throughout	0-30/40cm non to slightly saline	>30/40cm moderately to strongly saline	-	0-30/40cm slightly sodic >30/40cm moderately sodic	urtic SOLONETZ, saline phase	Calcari-haplic and Calcari-gleyic SOLONETZ sodic phase	Typic and Aquic NATRARGIDS
Soils which are both saline and sodic (kindest) throughout											
Ps 2.14	imperfectly drained to poorly drained, very deep, dark greyish brown, firm clay	10-20cm of dark greyish brown to dark grey, friable to firm, clay	-	moderately to strongly calcareous throughout	0-4/10cm	>4/10cm moderately to strongly saline	0-10/20cm	>10/20cm slightly to strongly sodic	urtic and gleyic SOLONETZ saline phase	Calcari-haplic and Calcari-gleyic SOLONETZ sodic phase	Typic and Aquic NATRARGIDS
Ps 2.15	imperfectly drained to poorly drained, very deep, greyish brown to dark greyish brown, firm clay	10-20cm of dark greyish brown to grey, friable to firm, clay	-	moderately to strongly calcareous throughout	0-20/35cm	>20/35cm moderately to strongly saline	0-10/40cm non to slightly sodic	>10/40cm moderately to strongly sodic	haplic XEROSOLS, saline-sodic phase	Vertic haplic CALCISOLS and Calcari-vertic CAMBISOLS sodic sodic phase	Typic and Natric CAMBORTHIDS
Gull associations											
Ps 2.16	Association of moderately well drained, very deep, dark brown, friable clay	10-20cm of dark brown to dark greyish brown, friable, sandy clay to clay	0-10/20cm	>10/20cm moderately to strongly calcareous	0-40cm	>40cm moderately to strongly saline	0-40/80cm non to slightly sodic	>40/80cm moderately to strongly sodic	haplic XEROSOLS, saline-sodic phase	Lovi haplic CALCISOLS sodic sodic phase	Typic CAMBORTHIDS
Ps 2.17	Association of moderately well drained, very deep, dark brown to dark reddish brown, friable to firm, clay	20-30cm of dark brown, friable, sandy loam to sandy clay	0-20/30cm	>20/30cm moderately to strongly calcareous	0-20/30cm	>20/30cm moderately to strongly saline	0-20/30cm	>20/30cm slightly to moderately sodic	haplic XEROSOLS, saline-sodic phase	Lovi haplic CALCISOLS sodic sodic phase	Typic CAMBORTHIDS
Ps 2.18	Association of moderately well drained, very deep, reddish brown to brown, friable to firm, clay	20-30cm of reddish brown to dark reddish brown, friable, sandy loam to sandy clay	0-40/70cm	>40/70cm moderately to strongly calcareous	0-30/80cm	>30/80cm slightly to moderately saline	0-10/70cm non to slightly sodic	>10/70cm moderately sodic	lentic XEROSOLS, saline-sodic phase	Calcari-chronic LUVISOLS sodic sodic phase	Typic FAELARGIDS
Ps 2.19	moderately well drained to imperfectly drained, very deep, reddish brown to brown, friable to firm, clay	10-20cm of dark greyish brown, friable clay	0-10cm non to slightly calcareous	>10cm strongly calcareous	0-40/80cm	>40/80cm moderately to strongly saline	0-40/70cm non to slightly sodic	>40/70cm moderately to strongly sodic throughout	urtic SOLONETZ, saline phase	Calcari-haplic SOLONETZ sodic phase	Typic NATRARGIDS
Ps3 LOW LYING LAND											
Ps 3.1	poorly drained, very deep, dark grey to dark greyish brown, firm to very firm, cracking clay	10-15cm of grey to dark grey, friable to firm, clay	-	moderately to strongly calcareous throughout	0-20/40cm non to slightly saline	>20/40cm moderately to strongly saline	0-20/40cm non to slightly sodic	>20/40cm moderately to strongly sodic	chromic VERTISOLS, saline-sodic phase	Chromic basic VERTISOLS sodic sodic phase	Typic TORRENTS
Ps 3.2	poorly drained, to very poorly drained, grey to dark grey, firm, clay	70cm of dark greyish brown to dark grey, friable clay	-	moderately to strongly calcareous throughout	0-30/40cm	>30/40cm moderately to strongly saline	-	-	-	-	-

KEY

- Ps 3.1 soil mapping symbol
- 755-87 representative profile pit with reference number
- soil boundary
- main road
- minor road
- ~ river
- contours V.E. 2.5m



KEY TO DEPTH CLASSES

Thickness soil in cm	Symbol	Name
0-30	shallow	
30-80	moderately deep	
80-120	deep	
>120	very deep	

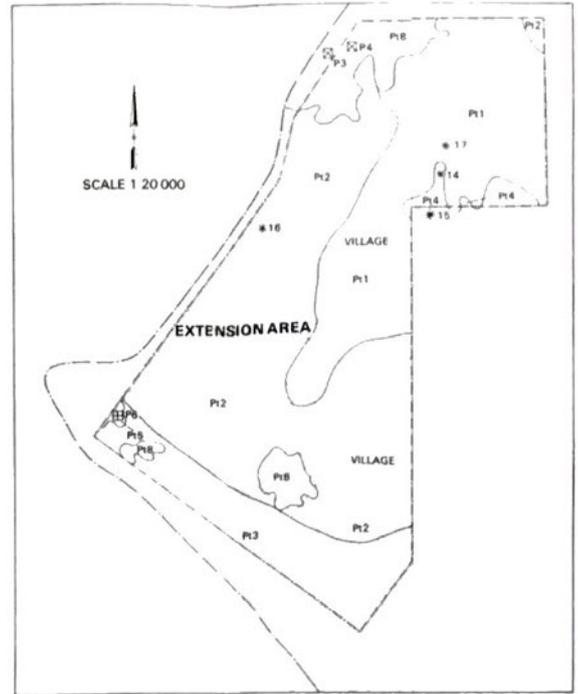
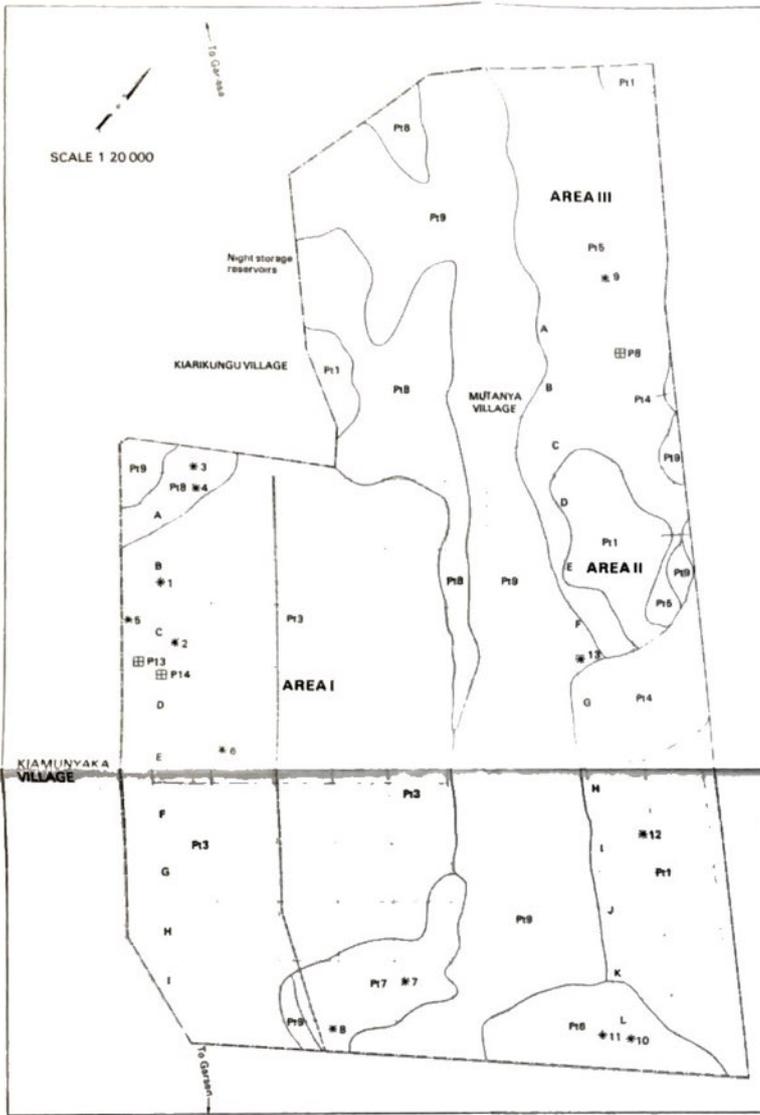
KEY TO SALINITY CLASSES

ECe (mmhos/cm)	EC (1:2.5) (mmhos/cm)	Salinity classes
0-4	0-0.8	non-saline
4-8	0.8-2.0	slightly saline
8-16	2.0-4.0	moderately saline
>16	>4.0	strongly saline

KEY TO SODICITY CLASSES

ESP	CLASS
0-5%	non-sodic
5-10%	slightly sodic
10-15%	moderately sodic
>15%	strongly sodic

SOIL MAP OF THE HOLA IRRIGATION SCHEME



* Soil map boundaries according to SAO (1988) and AAZ/ISS (1976).
 Legend based on data from AAZ (1988), ICZ (1975 and 1978) and additional data collected by the author in 1985 and 1986.

LEGEND

SYMBOL	GENERAL DESCRIPTION		CALCAREOUSNESS		SALINITY		SODICITY		CLASSIFICATION		
	SUBSOIL	TOPSOIL	NON-CALCAREOUS	CALCAREOUS	NON-SALINE	SALINE	NON-SODIC	SODIC	FAO UNESCO (1974)	FAO-REVISED (1987)	SOIL TAXONOMY (1975)
P PLAINS											
Pt SEDIMENTARY PLAIN OF UPPER TANA RIVER TERRACE											
All soils developed on Old Alluvial deposits											
P1	well drained to moderately well drained, very deep, dark reddish brown to dark brown, friable to firm, sandy clay to clay	20-40cm of dark brown, friable sandy clay	-	moderately to strongly calcareous throughout	0-70/100cm (irrigated) 0-15/40cm (non irrigated)	>70/100cm slightly to strongly saline >15/40cm slightly to strongly saline	0-40/50cm moderately to strongly sodic 0-15/25cm moderately to strongly sodic	>40/50cm moderately to strongly sodic >15/25cm moderately to strongly sodic	Haplic XEROSOLS sodic phase (saline sodic phase) Orthic SOLONETZ saline phase	Chromic-calcareic and Calcargylic CAMBISOLS sodic phase (saline sodic phase) Calcari-haplic SOLONETZ saline phase	Netric CAMBORTHIDS (irrigated) Typic NATRARGIDS
P2	as P1	as P1 but 10 to 20cm deep	-	as P1	as P1	as P1	as P1	as P1	Haplic XEROSOLS sodic phase (saline sodic phase) Orthic SOLONETZ saline phase	Chromic-calcareic CAMBISOLS sodic phase (saline sodic phase) Calcari-haplic SOLONETZ saline phase	Netric CAMBORTHIDS (irrigated) Typic NATRARGIDS
P3	well drained to moderately well drained, very deep, dark reddish brown to dark brown, friable to firm, clay in places of cracking	20-30cm of dark reddish brown to dark brown, friable clay	-	moderately to strongly calcareous throughout	0-80/100cm (irrigated) 0-10/20cm (non irrigated)	>80/100cm moderately to strongly saline >10/20cm moderately to strongly saline in places moderately to strongly saline from the surface	0-20/30cm non to slightly sodic (irrigated) 0-10/20cm non to strongly sodic (non irrigated)	>20/30cm moderately to strongly sodic (irrigated) >10/20cm moderately to strongly sodic (non irrigated)	Haplic XEROSOLS saline sodic phase Orthic SOLONETZ saline phase	Calcari-vertic CAMBISOLS sodic phase Calcari-haplic SOLONETZ saline phase	Netric CAMBORTHIDS (irrigated) Vertic CAMBORTHIDS (irrigated) Ustollic NATRARGIDS (irrigated)
P4	moderately well drained to imperfectly drained, very deep, reddish brown to dark brown, friable to firm, sandy clay to clay	5-35cm of reddish brown to greyish brown, loose to friable loamy sand to sandy clay	0-30/35cm non to slightly calcareous	>30/35cm moderately to strongly calcareous	0-10/15cm	>10/15cm slightly to strongly saline	0-5/10cm	>5/10cm strongly sodic	Orthic SOLONETZ saline phase	Calcari-haplic SOLONETZ saline phase	Typic NATRARGIDS
P5	moderately well drained to imperfectly drained, very deep, dark reddish brown to dark greyish brown, firm clay	20-30cm of dark brown to dark greyish brown, friable sandy clay to clay	0-20/30cm non to slightly calcareous	>20/30cm moderately to strongly calcareous	0-40/70cm (irrigated) 0-20/40cm (non irrigated)	>40/70cm moderately to strongly saline >20/40cm moderately to strongly saline	0-30/40cm moderately to strongly sodic 0-15/30cm strongly sodic (non irrigated)	>30/40cm moderately to strongly sodic >15/30cm strongly sodic	Orthic SOLONETZ saline phase	Calcari-haplic SOLONETZ saline phase	Ustollic NATRARGIDS (irrigated) Typic NATRARGIDS
P6	moderately well drained to imperfectly drained, very deep, dark brown, firm clay	15-25cm of brown to dark brown, friable sandy clay to clay	0-15/25cm non to slightly calcareous	>15/25cm moderately to strongly calcareous	0-60/100cm (irrigated) 0-10/20cm (non irrigated)	>60/100cm slightly to strongly saline >10/20cm slightly to strongly saline	0-25/50cm (irrigated) 0-10/20cm (non irrigated)	>25/50cm moderately to strongly sodic >10/20cm strongly sodic	Orthic SOLONETZ saline phase	Calcari-melic SOLONETZ saline phase Calcari-haplic SOLONETZ saline sodic phase	Ustollic NATRARGIDS (irrigated) Typic NATRARGIDS
P7	moderately well drained to imperfectly drained, very deep, dark reddish brown to dark brown, firm, cracking clay	20-30cm of reddish brown to dark yellowish brown, friable, clay loam to clay	-	strongly calcareous throughout	0-45/70cm (irrigated) 0-20/30cm (non irrigated)	>45/70cm slightly to strongly saline >20/30cm moderately to strongly saline	0-20/60cm (irrigated) 0-15/30cm (non irrigated)	>20/60cm moderately to strongly sodic >15/30cm moderately to strongly sodic	Chromic VERTISOLS saline sodic phase	Chromic-haplic and Chromic vertic VERTISOLS saline sodic phase	Typic TORRERTS
P8	moderately well drained to imperfectly drained, very deep, dark reddish brown to dark brown, firm to very firm, cracking clay	20-30cm of dark brown to dark yellowish brown, friable clay loam to clay	-	strongly calcareous throughout	0-40/50cm (irrigated) 0-10/25cm (non irrigated)	>40/50cm slightly to strongly saline >10/25cm moderately to strongly saline	0-15/30cm (irrigated) 0-10cm or less from the surface	>15/30cm moderately to strongly sodic >10cm moderately to strongly sodic	Chromic VERTISOLS saline sodic phase	Chromic-haplic and Chromic vertic VERTISOLS saline sodic phase	Typic TORRERTS
P9	imperfectly drained, very deep, brown to dark brown, firm, cracking clay	15-20cm of dark brown, friable sandy clay to clay	-	strongly calcareous throughout	0-60/90cm	>60/90cm slightly to strongly saline	0-15/25cm in places non to slightly sodic up to 80cm deep	>15/25cm strongly sodic	Chromic VERTISOLS saline sodic phase Haplic XEROSOLS saline sodic phase	Chromic-calcic VERTISOLS saline sodic phase Calcari-vertic CAMBISOLS saline sodic phase	Typic TORRERTS Netric CAMBORTHIDS

thickness soil in cm	symbol	name
0-50	shallow	shallow
60-80	moderately deep	moderately deep
90-120	deep	deep
>130	very deep	very deep

ECe (mmhos/cm)	EC (1:2.5) (mmhos/cm)	salinity classes
0-4	0-0.8	non saline
4-8	0.8-2.0	slightly saline
8-16	2.0-4.0	moderately saline
>16	>4.0	strongly saline

ESP	CLASS
0-5%	non sodic
6-10%	slightly sodic
10-15%	moderately sodic
>15%	strongly sodic

KEY

- road
- main drainage canal
- soil boundary
- - - boundary of the study area
- irrigated areas
- main conveyance canal
- ⊠ P14 Profile pit (1974)
- ⊠ Profile pit 1985

