Technical Paper

UNDP/FAO AGRICULTURAL SERVICES PROJECT

# Aspects of Soil and Soil Salinity
# in
# the Tihama Region
# Yemen Arab Republi_

Based on the Work of

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## SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| Diw | depth of irrigation water |
| $D_{dr}$ | depth of drainage water |
| $EC_e$ | electric conductivity of saturation extract |
| $EC_{iw}$ | electric conductivity of irrigation water |
| $EC_{1:1}$ | electric conductivity of 1:1 extract |
| ESP | exchangeable sodium percentage |
| ET | evapo transpiration |
| LR | leaching requirement |
| pF | soil water tension measure |
| SAR | sodium absorption ratis |
| adj.SAR | adjusted SAR |
| SP | Saturation percentage |
| b.d. | bulk density |
| CEC | cation exchange capacity |
| mmhs | milli mhs, electric conductivity measure |
| | porosity |
| c.p.s. | counts per second |

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## SUMMARY

The Tihama in the Yemen Arab Republic is a hot semi-arid coastal plain, 30 to 70 km wide, which extends the length of the country, along the Red Sea Coast.

In the first part of this report its physiography is shortly described and the types of soil are indicated. 7 land types are described and a map is derived from an existing topographic map. Based on these land types the Tihama is divided into 5 landscapes:-

a) Coastal landscape with sanddune areas predominantly.
b) Gravel field landscape of the stony and gravelly fans adjacent to the mountains.
c) Alluvial fan landscape with cultivated fields surrounded by dams for the spate irrigation system.
d) Alluvial plain landscape situated between the lower (western) end of the alluvial fans and the coastal belt.
e) Pocket landscape, along a wadi near and in the mountains.

An agricultural evaluation of these landscapes, based on climate, soils, and irrigation water quality shows that the pocket landscape is most suitable for agriculture; second is the alluvial fan landscape.

The second part deals with salinity and alkalinity of Tihama soils

After short descriptions of the general principles on soil salinity and the laboratory facilities in Hodeidah, the chemical composition of ground water and soil-salinity is discussed.

It appears that the high salinity waters have high SAR-values but as these ground waters occur in areas with light textured soils the impermeability hazard is low.

Investigations show that salts in the soil accumulate in fine textured soil layers when these overlay coarser textured layers. This is found locally in the alluvial plain soils, but being torrent deposits, there is much variation between soil profiles even at short distances, and overall effects are limited. In general it can be said that at present other factors are more limiting to agricultural production than soil-and water-salinity.

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# INTRODUCTION

The Assooiate Expert arrived in Hodeidah in May 1976 with the following terms of reference:-

(a) He will be under the supervision of the Irrigation Praotices Offioer and will oarry out soil survey work and applied researoh work on land reclamation related to alkalinity and salinity problems.

(b) He should be prepared to partioipate in training and extension aotivities of the Projeot.

Until December, 1976 the assooiate expert worked close together with the Irrigation Praotices Offioer and the Head of the Soil Section of the Ministry of Agrioulture Hodeidah Directorate. In this period the irrigation trials on cotton and sorghum were executed o.q. prepared.

In Deoember, 1976 the Irrigation Praotioes Offioer ended his assignment. Shortly afterwards the Head of the Soil Seotion reoeived a fellowship to study in the U.S.A. for two years and left also.

No alternative oounterpart was available and as the Assooiate Expert has a very limited knowledge of the Arabio language, work in farmers' fields was difficult. As a result of this the aooent of the subsequent work was put on researoh to speoifio salinity problems.

Contact was made to the British Land Resouroes Development Projeot in the Montane Plains and Wadi Rima (MPWR) and in oo-operation with its 'environmental physioist' and oounterpart researoh was done to soil salinity in relation to soil-water-movements.

Many trips were made to Taiz to disouss the analyses of our soil samples in the laboratory of the Central Agricultural Researoh Organization Project. Regarding (b) in the terms of referenoe co-operation was given to a training course for extension agents. To increase efficienoy subsequent training oourses were held in Zabid with Arabio speaking instruotors only.

# I. PHYSIOGRAPHY AND LANDSCAPE OF THE TIHAMA

## 1.1 GENERAL

The Tihama plain in the Yemen Arab Republic forms a part completely different from the other parts of Yemen both in climate and topography.

It is a hot semi arid coastal plain. The topography is an almost flat plain dissected by a number of Wadies. Some parts are undulating with macro and micro-dunes of windblown sand.

The plain is 30 to 70 km wide and extends the length of the country along the Red Sea.

In this report an attempt is made of explaining its physiography. A number of landtypes are described and from an existing topographic map a map of landtypes has been derived. Indicated is how these landtypes may serve as high classification units in a reconnaissance soil survey.

Most of the previous studies deal with a particular wadi. Although the approach in this report is quite simple and obvious, it is thought to be important to give a picture of the Tihama as a whole

## 1.2 THE TIHAMA CLIMATE

The climate of the Tihama is hot and semi-arid, however there are some significant differences between some parts of it. In general it can be said that near the sea the rainfall is minimal and increases towards the mountains. As example May serve the rainfall data in 1976 from the following places in the Wadi Rima area and Zabid:-

Mishrafah , at mountainfoot : 523 mm
Al Gerubah , 15 km from mountainfoot : 411 mm
Zabid , 25 km from mountain foot, 25 km from the sea, 70 mm.
Al Madaniyah, 15 km from the sea : 8 mm

(Data from 1st quarterly report 1977, British L.R.D. Project).

Data on climatic features from Gumeisha Farm are in Table 1.1 This variation in rainfall has its impact on vegetation, land-form and soils.

An other climatic feature which is very important in the Tihama is the wind. This has two aspects, 1st the damaging influence of the hot winds on the crops, 2nd the effect of the winderosion. Especially during the hot summer months strong winds prevail in the afternoon. They cause considerable damage to crops and in particular to fruit-trees. This is a problem of all the Tihama.

The effect of winderosion on the other hand is limited to the areas with low rainfall, where vast areas exist with drifting sand or moving sand dunes.

## T A B L E 1.1

Data on climatic features at Gumeisha Farm

| Months | | | | | | | | Average 1973 - 1976 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Max. Temp. | 31.8 | 33.4 | 35.1 | 37.5 | 39.3 | 40.9 | 40.9 | 39.0 | 38.7 | 37.5 | 33.8 | 32.0 |
| Min. Temp. | 17.5 | 17.8 | 19.8 | 20.8 | 22.9 | 24.1 | 23.9 | 23.9 | 23.8 | 21.0 | 17.7 | 17.1 |
| Mean Temp. | 24.2 | 25.5 | 26.3 | 29.2 | 31.2 | 32.1 | 33.0 | 31.4 | 30.5 | 29.5 | 26.4 | 24.6 |

| Rainfall (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | 10.0 | - | - | - | 2.9 | - | - | 27.0 | - | - | - | - |
| 1974 | - | - | 28.0 | - | - | - | 8 | 28.6 | 16.5 | - | - | - |
| 1975 | - | 4.8 | - | 5.2 | 1.0 | - | 1.3 | 71.8 | 17.3 | 0.4 | - | 0.7 |
| 1976 | - | 2.4 | 6.8 | 0.1 | 3.5 | - | 0.2 | - | - | - | 18.2 | - |

Detailed data on windspeed and direction for Gumeisha Farm are given in Technical Report C/1, Climatic Feature of Gumeisha Area, 1972-1975, prepared by Mr. B.T. Blagojevic.

From this report the data in Table 1.2 are deducted. In this Table the average maximum speed is related to prevailing wind direction for windspeeds exceeding 20 km. $hr^{-1}$

This 20 km. $hr^{-1}$ is assumed to be the threshold value for sand-movement.

TABLE 1.2

Prevailing winddirections for windspeeds exceeding 20 km. $hr^{-1}$

| Month | (hr) daytime | ($km.hr^{-1}$) av.maximum speed | prevailing direction |
|---|---|---|---|
| July | 8-13 | 22.5 | NW |
| | 13-19 | 48 | W |
| August | 10-19 | 40 | W |
| September | 9-18 | 23 | W |
| October | 14-17 | 29 | SW |
| November | 7-22 | 23 | SW |
| December | 13-15 | 26 | SW |
| January | 0-3 | 28 | S |
| February | 21-24 | 30 | SW |
| | 0-1 | 27 | S |
| March | 6-8 | 27 | S |
| | 16-1 | 22 | SW |
| April | 12-16 | 21 | SW |
| May | 5-6 | 27 | SW |
| | 6-24 | 23 | W |
| June | 0-7 | 25 | W |

## 1.3 VEGETATION

The vegetation responds to the variation in climate, near the mountainfoot are scrubs and threes (acacia), closer to the sea the trees disappear and the scrubs are much smaller. In many areas all scrubs have been removed to use the land for agriculture.

After these fields have been abandoned by the farmer the scrubs are unlikely to return especially in the areas with the lowest rainfall. These fields turn after a short time into an area with drifting sand and moving sanddunes.

In the coastal belt some "oases" exist with datepalms (e.g. Duraihimi). These "oases" are often small wadies or wadi-branches.

1.4 PHYSIOGRAPHY

The Tihama finds it origin in the riftvally which created the Red Sea. On both sides of the present sea the earth was lifted while the middle part sank down (see fig. 1.1). From the mountains alluvial material was brought by the wadi's into this deep valley to build alluvial fans. These alluvial fans eventually merged together to form the present Tihama.

The discharge of a wadi is quite unregular and reflects the rainfall in its catchment area. It is characterized by floods, both big and small. These floods carry all kind of sediments from silt to gravel and stones. The flow pattern is irregular and differs from flood to flood. In this way a pattern of sedimentation is formed that can be called torrent-deposits. It is characterized by a big variation in material, both horizontally and vertically.

Apart from a number of relatively small wadies there are five main wadies. From north to south there are Wadi Mawr, Wadi Surdud, Wadi Siham, Wadi Rima and Wadi Zabid.
Important, but smaller, are south of Zabid the Wadi Nachlah and Wadi Rashyan.

Since centuries the wadi water has been used for irrigation in the spate irrigation system. By means of dam and canals the water is diverted from the wadi-bed to the fields. The gravel and stones, carried by the water, are left behind in the bed or irrigation canal, but huge amounts of silt are deposited on the fields.
Due to cultivation the newly deposited silt is mixed with the underlying soil. In this way deep, uniform, silty soils are formed.

The alluvial fans, especially those of the 5 major wadies, are dissected. The present wadi-bed is lower than the surface of the fan. In this way a number of geological terraces are formed. These are called geological, not to be mixed up with the man-made terraces for the spate irrigation.

An explanation for this fan dissection can be found in the lowering of base level, due to a chnge in sealevel relative to the land.
Also a change in wadi discharge, due to a climatical change, may have had its impact on this.

In the coastal area sanddunes are formed. As rainfall is scarce and irregular, vegetation is nearly absent and large areas are covered with windblown sands and moving sanddunes. In some places a desert pavement has been developed. After silt and sand have been blown away, the coarser particles, gravel and stones, remain and accumulate on the newformed surface. Over this gravelly surface, small 1-2 m high crescent shaped dunes move according to the direction of the wind.

Along the coast occur flat salty lands called sabkha. In the winter season when tides can be higher than normal, they are occasionally inundated by the sea.

## 1.5 TIHAMA LANDTYPES

In the Tihama different landtypes have been developed, due to physiography, parentmaterial and rainfall. To give an idea of how these landtypes fit in the Tihama, their distribution, their approximate area and their relative position, a map has been prepared, showing these landtypes. This map has been derived from the topographic map 1:250,000 'Produced for the Yemen Arab Republic by the Director of Military Survey, Ministry of Defence, United Kingdom, 1974', by copying the landtypes shown on this map and with additional information from own observations.

- -

This map is also not a soilmap, but the mapping units shown can contribute to a better understanding of the physiography of the Tihama and they may serve as the highest classification units of Tihama soils, as will be explained in Chapter 1.7

The landtypes are:-

<u>M</u>: mountainous land; the boundaries are only approximate. Strictly spoken it does not belong to the Tihama.

<u>D</u>: Sanddunes, situated mainly along the coast.

<u>S</u>: Sand and gravel, low dunes situated along the coast and tongueing into the cultivated areas.
1 - 2 m high, crescent shaped dunes moving over a gravelly desert-pavement.

<u>Sc</u>: Scrubs and sometimes low scattered trees on a gravelly soil

<u>Sb</u>: Sabkha, flat salty plains, occasionally inundated by the sea.

<u>W</u>: wadi-bed with gravel and stones, or sands dissected by many small beds.

<u>C</u>: cultivated lands
This unit can be divided into two subunits
$C_1$, alluvial fan in the eastern part and $C_2$ alluvial plain, more to the west.
On the alluvial fan the cultivated land is terraced for the spate irrigation. The soils are deep uniform silty soils.
On the alluvial plain the soils have coarser texture and are stratified by interlayering of aeolean sands.

South of the Mokha - Taiz road the dominant landtypes are sands, low dunes and gravel (S) and wadi-beds and dissected sands (W). North of this road but south of Wadi Zabid, relatively small cultivated areas (C) appear, but low dunes and gravel (S) and scrubs on gravel (Sc) are dominant.
North of Zabid the influence of the major wadies is important and large cultivated areas (C) are situated next to vast areas with windblown moving sands (S and D).

A very schematic distribution of landtypes is given in Fig.1.2

## 1.6 TIHAMA LANDSCAPES

Based on the description of physiography and landtypes the Tihama can be divided in the following landscapes:

### a. Coastal Landscape

A strip ± 30 km wide along the coast with high dunes and low dunes on gravel, enclosing relatively small agricultural areas. Very low rainfall and much affected by wind-erosion.

### b. Gravelfield landscape

Found south of Wadi Zabid. Large areas at the mountain-foot covered by stones and gravel. More or less well defined wadi-beds. Floods occur occasionally and each flood finds it own way over the fan, leaving deposits of mixed material from silt to gravel and stones.

### c. Alluvial fan landscape

Found north of Wadi Zabid. Well defined wadi-beds insected in the alluvial fan. Wadiwater is diverted from the wadi to the agricultural fields (spate irrigation). Fields are levelled and surrounded with dikes to form terraces. Sediments are mainly silt.

### d. Alluvial plain landscape

This is situated between the lower (western) end of the alluvial fans and the coastal belt. The area is almost flat and soils are a mixture of wadi deposits interlayered with windblown sands.

### e. Pocket landscape

Idem as (c) but situated in small pockets where a valley in the mountains widens. Small terraces along the wadi under spate irrigation.

## 1.7 SOILS IN THE TIHAMA

In the Tihama a number of soil surveys have been conducted. Their reports are listed in Table 1.3

Table 1.3 Soil Survey in the Tihama

| | |
|---|---|
| FAO Report 69<br>1953 | Howard J. Ferris<br>Report to the Government of Saudi Arabia on Reconnaissance Soil and Land Classification of the South Asir Tihama. |
| UNDP/FAO<br>1971 | Survey of the Agricultural Potential of the Wadi Zabid, Yemen, Soil and Land Capability, Tesco Viziterv - Vituki, Budapest.<br>AGL : SF/YEM 1 Technical Report No. 8. |
| UNDP/FAO<br>1975 | H.C. Dewan and B.T. Blagojevic.<br>Soil Survey of Gumeisha Farm, Tihama Region. Technical Report S1, AGON/YEM/73/010 and 73/011. |

Beside these, surveys have been made of Wadi Rima area by the B ritish MPWR Project and the Wadi Surdud area by Sir William Halcrow and Partners. At the moment of writing, these reports have not yet been published.

The reports covering one particular wadi are fairly detailed and not useful for a reconnaissance survey.
The report by Ferris (FAO, 1969) covers a larage area and is not restricted to one wadi. The South Asir Tihama, described in this report is just north of the Yemen Tihama and soils and landscape can be considered comparable.

As mentioned in Chapter 1.5 the landtypes can serve as high units in soilmapping. In order to do this the units used by Ferris will be described shortly.

B eside 2 miscellaneous landtypes he desoribes 4 soil associations: Wadi Association, Khabt association, Hazem association and Sabkha association. These associations are divided in soilseries according to texture.

Wadi Association: alluvial soils laid down by stream deposition is found in the major valleys. The soils are stratified, like most waterlaid materials, with texture and depth being the differentiating characteristics.
The series are:

Wadi Silt Loam
Wadi Fine Sandy Loam
Wadi Sand

Khabt Association: Soils in the alluvial plains developed from sandy deposits and reworked by wind and water.
The series are:

Khabt Sandy Loam
Khabt Sand.

Hazem Association: Soils of stony alluvium on gently sloping alluvial fans adjacent to the mountains.

Sabkha Association: Saline soils along the Red Sea Coast.

Miscellaneous Landtypes:

Sanddunes
Rough Broken Land

How Ferris' soil units fit in the landtypes is shown in Table 1.4

Table 1.4 Comparison of Landtypes and Ferris' Soil Units

| Soil Unit | | | Landtype |
|---|---|---|---|
| Wadi Association | | | |
| Wadi Silt Loam | | $C_1$ | cultivated |
| " | Dunephase | S+D | sanddunes and low sand and gravel |
| " | Sandyphase | W | wadibeds and dissected sands |
| " | Shallowphase | $C_1$ | cultivated |
| " | Hummockyphase | S | low sand and gravel |
| Wadi Fine Sandy loam | | $C_2$ | cultivated |
| " | Dunephase | S+D | sanddunes and low sand and gravel |
| " | Hummockyphase | S | low sand and gravel |
| Wadi sand | | W | wadibeds and dissected sands |

| | | |
|---|---|---|
| Khabt Association | | |
| Khabt Sandy Loam | $C_2$ | cultivated |
| " Hummockyphase | S | low sand and gravel |
| Khabt Sand | S+W | low sand and gravel and dissected sands |
| Hazem Association | Sc | gravel with scrubs |
| Sabka Association | Sb | Sabkha |
| Sanddunes | D | sanddunes |
| Rough Broken Land | M | mountains |

A brief description of 2 soils are given below. For more detailed descriptions of soil profiles is referred to the publications in Table 1.3 Profile (a) represents an alluvial fan soil, profile (b) is a layered soil from the alluvial plain. Soils in the Tihama are low in organic matter content. They have a weak structure. Calcium carbonate content is up to 10%.

a. profile from a site near the FAO-camp in Wadi Zabid (Tesco report No. 8 Profile No. 227).

| | |
|---|---|
| 0 - 10 cm | clayey loam |
| 10 - 28 cm | clay |
| 28 - 106 cm | clayey loam |
| 106 - 123 cm | silty clay loam |
| 123 - 170 cm | silty clay. |

b. profile from Gumeisha Farm (Dewan and Blagojevic, 1975, profile No. 21)

| | |
|---|---|
| 0 - 15 cm | sandy loam |
| 15 - 45 cm | loamy sand |
| 45 - 70 cm | sand with layers of sandy loam |
| 70 - 150 cm | sand. |

## 1.8 TIHAMA CROSS-SECTION ALONG SANA'A - HODEIDAH HIGHWAY

The Sana'a - Hodeidah highway follows the course of the Wadi Surdud from Manakha to where it enters the Tihama. Here the road turns south to Bajil and goes via Qutay and Mrawah to Hodeidah.

The cross-section along this road is also not along a straight line from mountains to coast.
According to landtype and soil this area can be divided in four sections:

Section 1:

Wadi Surdud terraces to Bab El Melek

The terraces are 15 to 20 m above the level of the present wadibed. They consist of stony alluvium with boulders of 0.5 m diameter to gravel of 0.5 to 1 cm diameter. In some places a horizontal layering is visible of gravellayers with silty loam layers.

Where the silty loam surfaces a sorghum crop is grown. On other places the surface is stony and gravelly with some scrubs. Towards Bab El Melek the silty loam surface layer gets thicker (± 1 meter). The fields are surrounded with ± 1 meter high dams. Agriculture is rainfed. Water is collected from surrounding hill slopes.

Section 2:

Bab El Melek to limestone outcrops 5 km southwest of Bajil (Cementfactory).

Alluvial fan landscape with silty loam soils. Sometimes these soils are shallow on gravel. Where the silty loam is absent gravel with scrubs occur.
In a gravel quarry, 8 km northeast of Bajil, horizontally layered gravel is visible and the top layer of silty loam has a depth varying from 0 to 80 cm, sometimes within 20 m distance. Macro relief is flat.
Fields are surrounded with 0.5 - 1 m high dams. Agriculture is rainfed, as this area is too far from the wadi-bed to receive spates.
In a quarry near Bajil behind the Highway Authority Camp, also horizontally stratified gravels can be seen covered with a silty loam of 0 - 50 cm thickness.
At ± 2 m below surface another silty loam layer is present.
In this area the alluvial fan is mixed with material from the nearby rock outcrops, Jebel Ad Darb.

Section 3:

Bajil to Qutay.

The limestone outcrops west of Bajil are the abrupt boundary between the silty loam soils and the sandy soils. A profile just west of these outcrops shows a loamy sand texture, gradually changing with depth into sandy loam. The marco relief is undulating. On top of the macrodunes small crescent-like micro-dunes occur.
Agriculture is limited to rainfed millet and beans planted at the end of the rain-season, september, with a planting distance of ± 1 m or more.

Section 4:

Qutay - Mrawah - Gumeisha - Hodeidah

West of Qutay the macro-relief becomes less undulating but more micro-dunes occur. West of Gumeisha macro-relief is flat, micro-relief is hummocky with some scrubs.
The road goes over the sandy area that lies north of the Wadi Siham. On some places a view is possible from this higher sand plateau into the "valley" of Wadi Siham. In this valley soils are composed of alluvial silt, interlayered by aeolean sand. As spates are irregular and not frequent, irrigation is from pump wells.

## 1.9 AGRICULTURAL EVALUATION OF THE LANDSCAPES

For an agricultural evaluation of the landscapes the following factors are considered: climate, soil, quality of irrigation water.

a. Climate : temperature.

Data on temperature are given in Table 1.1 Although the temperature regime is not uniform throughout the Tihama, it is thought that this variation has a minor influence on the agricultural suitability of the different regions.

: wind. The summer afternoon winds in combination with the high temperature are limiting factors for agriculture. Especially fruittrees suffer from this. Hot winds prevail throughout the Tihama except in the pockets near and in the mountains.

: winderosion. In the areas with the lowest rainfall, the coastal belt, the winderosion is considerable and sandstorms are a common feature.

: Rainfall. Rainfed agriculture is possible only in a strip adjacent to the mountains. But rainfall is irregular and changes from year to year.

b. Soil: In the coastal belt soils are rather coarsetextured with a high infiltration rate, also suitable for irrigation. The silty soils have a high waterholding capacity but the infiltration rate can be very low.
On the gravel fields agriculture is difficult because of the many stones and gravel.

c. Quality of Irrigation Water: Wadiwater has better quality than the undergroundwater. This is a point in favour of the spate-irrigated areas. However, wadiwater is not always available in sufficient quantities and additional pumpwell irrigation may be necessary. In areas seldom reached by wadiwater (alluvial plain and coastal belt) agriculture is completely dependent on pumpwell water. Near a wadibed the quality of the groundwater is better than further away. Also going from the sea towards the mountains the quality improves. This means that the areas which depend completely on tubewell irrigation have groundwater of a bad quality, whereas this quality is much better in the spate irrigated and rainfed areas.

The evaluation of the landscapes, regarding these factors is given in Table 1.5

The pocket landscape is most suitable for agriculture, although limited in area. This area receives quite some rain and good quality irrigation water can be taken from the wadi. Strong winds are absent. Soils are silty loam.

The second best is the alluvial fan landscape. There might be some rain, irrigation is by spate irrigation with wadi-water, soils are silty loam, but strong hot winds can damage the crops.

The stony alluvial fan is less suitable becuase of the stony and gravelly soil.

The coastal belt and alluvial plain suffer from stong hot winds, are susceptible to severe wind erosion and have low quality underground water. Their suitability for agriculture is also limited.

Table 1.5 Evaluation of Landscapes to Different Factors

| | Climate | | | Soil | Irrigation water Quality |
|---|---|---|---|---|---|
| | rainfall | wind | erosion | | |
| Coastal Landscape | - | - | - | + | - |
| Gravel field " | +/- | - | + | - | ? |
| All plain " | - | - | - | +/- | - |
| All fan " | +/- | - | + | + | +/- |
| Pocket " | +/- | + | + | +/- | + |

+ = favourable

- = unfavourable

# 2. Salinity and Alkalinity in Tihama Soils

## 2.1 General

In section 1 the physiography of the Tihama plain is shortly described and the types of soil encountered.
Apart from the Sabkha lands the Tihama soils are non-saline of origin. The traditional way of agriculture was twofold:

a) rainfed

b) irrigated by wadispate's

Neither holds hazards for soilsalinisation.
Since about 10 - 15 years a new system is introduced: irrigation from pumpwells. The quality of the groundwater used is much less than the wadiflood water. All groundwater used for irrigation contains dissolved salts. After the water has been used for evapotranspiration the salts remain in the soil. By proper watermanagement the amount of salt in the root zone can be kept at a tolerable level.

First the general pronciples on salt movements in irrigated soils will be discussed shortly, regarding 3 aspects: saltbalance, quality of irrigationwater, tolerable salinity levels in the soil. After this the salinity in the Tihama soils will be sketched, giving chemical characterization of salts in irrigationwater and in soils, experiments on soilsalinity and soilwater movements, regional distribution of groundwater quality and soilsalinity.

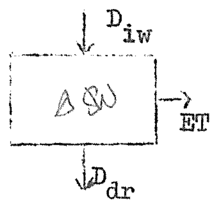
## 2.2 Principles of soil - and water-salinity

### 2.2.1 The saltbalance

The saltbalance is a theoretical aid to calculate the long term effects of the irrigationwater. For this calculation several models have been developed from simple to very complicated.
A simple model requires not very detailed knowledge about water movements in the soil, but the results are not very accurate. A more sophisticated model gives more accurate outcomes but this requires detailed knowledge on soilwater movements, water uptake by the plant, leaching efficienoy etc. In section 2.2.3 is discussed to what degree the salt acoumulation affects the yield. Apart from soilsalinity level many other factors influence the yield, as management,

fertilizer application, pests and diseases etc. Under the conditions prevailing in Yemen at present, yields may not be optimal even in the complete absence of salts. Therefore a very accurate calculation of the saltbalance is superfluous and the simple approach will be dealt with here.

The soil-water-system may be simplified as in fig. 2.1




$D_{iw}$ is the depth of irrigation water
ET is the water used for evapotranspiration
$D_{dr}$ is the depth of water draining from the root zone.

Fig. 2.1

The leaching requirement is defined as $LR = D_{dr}/D_{iw}$
If the amount of salts in the soil is to be kept at a constant level, the removal of salts with the drainage water must equal the supply with the irrigation water and
$EC_{iw} \times D_{iw} = EC_{dr} \times D_{dr}$
or $LR = \frac{EC_{iw}}{EC_{dr}}$ where EC is electric conductivity ($mmho.cm^{-1}$)
LR can be calculated from $EC_e$ and $EC_{iw}$ :

$$LR = \frac{EC_{iw}}{5EC_e - EC_{iw}} \qquad .... (1)$$

$EC_{iw}$ is the conductivity of the irrigation water
$EC_e$ expresses the conductivity of the saturated soil extract
This formula gives the leaching requirement needed, when with irrigationwater of $EC_{iw}$, the level of salts in the soil has to be kept at $EC_e$. The maximum tolerable $EC_e$ depends on the crop and is given in table 2.2

2.2.2 Quality of irrigation water

Evaluation of water quality has different aspects according to different effects on the plant.
These are:

a) total soluble salt content. By improper water management the salts can accumulate in the root zone of the soil. As a result of this the soil-water gets a high osmotic value and water uptake by the plants becomes difficult.

b) amount of sodium relative to calcium and magnesium. This can cause peptization of the clay and consequently the soil becomes impermeable. This impermeability has unfavourable effects on the plants due to waterlogging, salt accumulation in topsoil, oxygen dificiency etc.

c) specifiction toxicity. At high concentrations Boron, Sodium and Chloride ions can be toxic.

In table 2.1 an evaluation of the water quality is given.

The SAR = Sodium Adsorption Ratio is defined as:

$$SAR = NA / \sqrt{(ca + Mg)/2}$$

The adjusted SAR value is : $adj.SAR = SAR \times (1+(8.4-pH_c))$
$pH_c$ is a theoretical pH value. Tables for calculation are given in Ayers and Westcot (1976).

2.2.3 Croptolerance to soil salinity

Wateruptake by plants from the soil is an osmotic process Salts in the soil solution increase the osmotic tension of the water and uptake by the plants is affected.
For purpose of reference the salts in the soil are measured at saturation, and the EC is measured in the extract of the saturated soilpaste, $EC_e$. When 15 - 20% leaching is observed the saturation extract is 1.5 times concentrated compared with the irrigation water :
$EC_e = 1.5 \times EC_{iw}$ (calculated with formula (1) ).
In table 2.2 crop tolerance values are listed as $EC_e$ and $EC_{iw}$ with an allowed yield decrease of 0 %, 10% and 25 %.
For more detailed data is referred to Ayers and Westcot (1976).

Table 2.1 Evaluation of Irrigation Water Quality

Total soluble salt (expressed as EC, $mmho.cm^{-1}$)

| | |
|---|---|
| EC < 0.25 | low salinity water |
| 0.25 < EC < 0.75 | medium salinity water |
| 0.75 < EC < 2,25 | high salinity water |
| 2.25 < EC < 5 | very high salinity water |
| 5 < EC | extremely high salinity water |

permeability problem

| | |
|---|---|
| adj.SAR > 9 | severe problem to be expected |
| 6 < adj.SAR < 9 | increasing problem to be expect |

ion toxicities

sodium hazard if adj.SAR > 9

chloride hazard if Cl > 10 $meq.l^{-1}$

boron hazard if Bo > 2.0 $meq.l^{-1}$

Table 2.2

Crop Tolerance Table (after Ayers and Westcot, 1976)

| CROP | Yield decrement 0% | | 10% | | 25% | |
|---|---|---|---|---|---|---|
| | $EC_e$ | $EC_{iw}$ | $EC_e$ | $EC_{iw}$ | $EC_e$ | $EC_{iw}$ |
| Cotton | 7.7 | 5.1 | 9.6 | 6.4 | 13 | 8.4 |
| Datepalm | 4.0 | 2.7 | 6.8 | 4.5 | 10.9 | 7.3 |
| Sorgum | 4.0 | 2.7 | 5.1 | 3.4 | 7.2 | 4.8 |
| Sudangrass | 2.8 | 1.9 | 5.1 | 3.4 | 8.6 | 5.7 |
| Tomato | 2.5 | 1.7 | 3.5 | 2.3 | 5.0 | 3.4 |
| Cucumber | 2.5 | 1.7 | 3.3 | 2.2 | 4.4 | 2.9 |
| Cantaloupe | 2.2 | 1.5 | 3.6 | 2.4 | 5.7 | 3.8 |
| Alfa Alfa | 2.0 | 1.3 | 3.4 | 2.2 | 5.4 | 3.6 |
| Broad Beans | 1.6 | 1.1 | 2.6 | 1.8 | 4.2 | 2.0 |
| Maize | 1.7 | 1.1 | 2.5 | 1.7 | 3.8 | 2.5 |
| Citrus | 1.7 | 1.1 | 2.3 | 1.6 | 3.2 | 2.2 |
| Sweet Potato | 1.5 | 1.0 | 2.4 | 1.6 | 3.8 | 2.5 |
| Sweet Pepper | 1.5 | 1.0 | 2.2 | 1.5 | 3.3 | 2.2 |
| Onion | 1.2 | 0.8 | 1.8 | 1.2 | 2.8 | 1.8 |
| Beans | 1.0 | 0.7 | 1.5 | 1.0 | 2.3 | 1.5 |

## 2.3 The Hodeidah Soil Laboratory

### 2.3.1 Equipment

In the Hodeidah office of the Ministry of Agriculture a small (2 x 3 m.) room is set up as soil laboratory. At present the equipment is: pH-meter (Beckmann) with glass-calomel combination electrode, Electric Conductivity bridge, Analytical Balance (Zaklady, Gdansk), some glassware, Gypsum blocks (Delmhurst), Stove (Thermolyne), Soilfertility test kit (Soil Test), Hellige pH-kit, moisture cans. The Hellige pH-kit did not satisfy as it gives not enough differentiation in pH for values larger than 7.

The soil fertility test kit did not give reproducible results with the Tihama soils. Moreover the results are obtained in terms of fertilizer units that are needed for the tested soil. For investigations to soilfertility it is recommended that results of soil analyses carried out in the Taiz-laboratory are compared to outcomes of the soilfertility test kit. For the test kit the analysis procedures may be changed slightly and standardized to get reproducible results.

### 2.3.2 Procedures and Calculations

Soilmoisture

With the moisture cans, stove and balance, accurate moisture analyses can be done. The disadvantage of this procedure is that by taking the samples the soil profile is disturbed and a repeated sampling, e.g. before and after an irrigation, at exactly the same site is not possible.

Calculation:

$$\text{gravimetric moist. \%} = \frac{\text{moist weight} - \text{dry weight}}{\text{dry weight} - \text{weight empty can}}$$

The gypsumblocks measure the soil moisture in an indirect way. The resistance over the electrodes inside the blocks changes with the watercontent in t[illegible] blocks. This watercontent changes with the tension of the surrounding soil. A disadvantage is that th blocks do not behave uniformly. A trial installation of 16 blocks close together at one site learned that their standard deviation is approx. 0.1 pF unit. To overcome this difficulty at least 4 blocks have to be installed together and their readings averaged.

It should be understood that the blocks measure tension which is related to the soil water content via the water-retention-characteristic of this soil. In section 2.8 this water-retention-curve is described for two representative soils.

pH and EC.

pH and EC from soil samples are determined in 1:1 soil-water-suspensions. Usually 50 gram soil is mixed with 50 ml distilled water. The soil is air dry and if necessary grinded to pass a 2 mm sieve.

The suspension is shaken by hand every 15 minutes during one hour. Immediately after this pH is measured. As this soil-water-suspension is not buffered the pH is influenced by many factors e.g. $CO_2$ from the air. Therefore pH should be measured shortly after preparation of the suspension. For EC this is less critical as the components which contribute to EC, are all easily soluble and the EC of the suspension does not change much over time.

The standard procedure, adopted internationally, is to measure EC of the saturation-extract. Because of the equipment available in Hodeidah, EC is measured in a 1:1 suspension. For a number of samples the relation between EC 1:1 suspension and EC 1:1 extract is determined. This is presented in fig. 2.2. The relation between EC 1:1 extract and ECe, the EC of the saturation-extract, depends on the quantity of water needed for soil-saturation. This is expressed as Saturation Percentage, SP, which is the gravimetric moisture content of the saturated soil paste. For a number of samples the SP has been determined. In general it can be said that:

| | |
|---|---|
| Loamy Sand | SP = 20 to 24 % |
| Sandy Loam | SP = 24 to 28 % |
| Silty Loam | SP = 28 to 38 % |

The 1:1 extract is more diluted than the saturation extract. Therefore its conductivity should be proportionally lower.

$$ECe = EC_{1:1} \times \frac{100}{SP}$$

This assumes that the soluble salts are dissolved congruently in both extracts. Less soluble components as carbonates may interfere but the variation due to this is considered small.
From formula (2) and fig. 2.2 the conversiontable 2.3 has been prepared.

Table 2.3 Conversiontable for $EC_e$ from $EC_{1:1}$ (mmho. $cm^{-1}$)

| | Loamy Sand | | Sandy Loam | | Silty Loam | | | |
|---|---|---|---|---|---|---|---|---|
| | SP = 20 | | SP = 24 | | SP = 28 | | SP = 38 | |
| $EC_e$ | $EC_{1:1}$ ext. | $EC_{1:1}$ Susp. | $EC_{1:1}$ ext. | $EC_{1:1}$ Susp. | $EC_{1:1}$ ext. | $EC_{1:1}$ Susp. | $EC_{1:1}$ ext. | $EC_{1:1}$ Susp. |
| 4.0 | 0.80 | 0.75 | 0.96 | 0.90 | 1,12 | 1.00 | 1.52 | 1.40 |
| 2.5 | 0.50 | 0.45 | 0.60 | 0.55 | 0.70 | 0.65 | 0.95 | 0.90 |
| 2.2 | 0.44 | 0.40 | 0.53 | 0.48 | 0.62 | 0.57 | 0.84 | 0.79 |
| 1.8 | 0.36 | 0.33 | 0.43 | 0.38 | 0.50 | 0.45 | 0.68 | 0.63 |
| 1.5 | 0.30 | 0.27 | 0.36 | 0.33 | 0.42 | 0.37 | 0.57 | 0.52 |
| 1.0 | 0.20 | 0.18 | 0.24 | 0.22 | 0.28 | 0.26 | 0.38 | 0.35 |

## 2.4 The chemical composition of Tihama groundwaters

Data on analyses of Tihama groundwaters can be found in various reports (Dewan and Goodbody, 1975; Tesco, 1971). Data from the ass.experts sampling are presented in table 1.3.

In preparation by the Central Agricultural Research Organization Project (Taiz) is a report containing all available chemical data concerning Tihama groundwaters.

From data of the wadi Siham area (Dewan and Goodbody, 1975) the figs.2.3 and 2.4 have been prepared.

Between EC and total-soluble-cations the relation is often assumed as:

$$\text{total cations } (\text{meq.l}^{-1}) = 10 \times \text{EC } (\text{mmho.cm}^{-1})$$

Regression analysis on these and other data shows that:

$$\text{total cations } (\text{meq.l}^{-1}) = 10.88 \times \text{EC } (\text{mmho.cm}^{-1}) + 2.73$$

with a residual standard deviation of the EC = 0.43 mmho.cm$^{-1}$.

In fig.2.3 Cl and $SO_4$ are plotted against EC. It is clear that with increasing EC, so increasing salt content, both Cl and $SO_4$ increase, but the level of $SO_4$ is lower than Cl.

In fig. 2.4 Na, Ca, and Mg are plotted against EC. At increasing EC the Na increases but the Ca and Mg increase is much less. This is because of the limited solubility of Ca and Mg (bi) carbonates.

With increase in EC both the absolute and the relative amounts of Na compared to Ca and Mg increase. The SAR and adjusted-SAR values calculated from these waters are plotted in fig. 2.5. It shows that with low EC values SAR is low and with increasing EC the SAR also increases.

As a generalisation it can be said that the waters with EC less than 1.5 mmho.cm$^{-1}$ have adj. SAR less than 10 and/no related problems are to be expected. Waters with higher EC have also higher adj. SAR. The EC analysis, which is simple to perform, even in the field, can be interpreted in terms of SAR.

It is obvious that the accuracy of this interpretation is not very high. If more accurate data are required a complete chemical analysis should be done.

## 2.5 The nitrate content of the irrigation water

Much confusion exists about the suitability for irrigation of the water from the South Gumeisha wells with regard to their high content of nitrate.
From the consultancy report salinity problems of the Gumeisha Farm of the Lowlands Development Project (Smith 1971), the following is quoted:-

"In the neighbouring farm sponsored by the German Democratic Republic the groundwaters ........ contain appreciable nitrates (up to 400 mg. $l^{-1}$)".
"The presence of appreciable nitrate, itself a most unusual constituent of groundwaters, nullifies any attempt to carry out a systematic fertiliser evaluation programme. Further, where as such matters can effectively be used to grow pastures fodder crops and leafy vegetables, theyindrce much vegetative growth in grains, fibre crops and oil seeds ..........."
End of quote.
On the other hand however many workers report a response to N-fertilizers in experiments on field-crops and cotton.
In the following an attempt is made to bring these contradicting views in agreement with the help of the 'classical' theories on plant nutrition by Mitscherlich.

In fig. 2.6 Mitscherlich's theory is demonstrated. All other factors being constant, the yield increases with increase of a certain nutrition factor, say N-input, until a maximum yield is reached. When this input is zero, yield is zero.
This can be expressed in a formula as:-

$$Y = M \ (1 - e^{-c \times I})$$

where

Y = yield
M = maximum yield
C = a constant
I = input (kg N.$ha^{-1}$)

In fertilizer experiments the situation encountered is given schematically in figure 2.7. It is assumed that the same input-yield-relation exists as in figure 2.6. However zero treatment gives a yield Z. It can be rearded as if the yield curve from fig. 2.6 is moved to the left (relative to the abscis) in figure 2.7 over a distance R.

The curve can be formulated as:

$$Y = M (1 - e^{-c \times (I + R)})$$

R represents the amount of input already available to the plant without adding any fertilizer.

In a fertilizer experiment R can be determined by extrapolating the yield curve beyond the zero treatment until the curve reaches the abscis.

R is expressed in the same units as the treatments $I_1$, $I_2$, $I_3$, etc. (Kg $N.ha^{-1}$).

Results from fertilizer experiments are given in figure 2.8 these data were taken from the field crops report 1975-1976 season and the report on the 1976-1977 season. All were carried out on Gumeisha Farm. It should be kept in mind that quantitative interpretation of yield data of experiments is always very risky.

Besides the variable factor, fertilizer application, the yield is influenced by many other factors which are difficult to control as: birds damage, insect damage, uneven water distribution over the treatments, differences in soil properties etc.

In figure 2.8 the yield data are given as percentage of the zero treatment.

It is clear that these curves are not completely conform the theories of Mitschertich, outlined above.

Extrapolation of these curves to the left is difficult but there is a certain amount of Nitrogen available in the order of magnitude of 50 to 100 kg $N.ha^{-1}$.

The irrigation water at Gumeisha contains Nitrates in the amount of 2.2 $meq.l^{-1}$ which is equivalent to 30 mgram $N.l^{-1}$ or 135 mgram $Nitrate.l^{-1}$. To grow a crop like sorghum about 6 irrigations are required although the quantity of water applied with each irrigation is very variable, an average of 100 mm can be assumed.

This means that 6 x 100 mm which is equivalent to $6 \times 10^6$ $liter.ha^{-1}$ water is applied

This contains $6 \times 30.8$ mgram $N.ha^{-1}$ = 185 kg $N.ha^{-1}$

If 50 Vo of this amount is lost due to leaching or denitrification ± 100 kg $N.^{-1}$ is left per ha.

Although many assumptions have been made, this figure is of the same order of magnitude as deducted from the fertilizer experiments.

The high nitrate content of the irrigationwater is also a contribution to the plants needs which has to be supplemented with N-fertilizer.

For sensitive crops like citrus this may cause problems but these crops are not grown on Gumeisha.

For drinking water purposes high nitrate content is unfavourable (Dewan e.a. 1977).
Desirable and maximum levels are given here expressed in various ways:

| Highest desirable level | Maximum permissible level |
|---|---|
| 10 mgram. $l^{-1}$ nitrate | 45 mgram. $l^{-1}$ nitrate |
| 2.2 mgram $l^{-1}$ N | 10 mgram $l^{-1}$ N |
| 0.16 meq.$l^{-1}$ nitrate | 0.73 meq.$l^{-1}$ nitrate |

From the data in Dewan and Goodbody (1975) and in table I,3 it appears that ground-water in the western part of the Tihama has more nitrate than the maximum permissible level. Only the water from Garabeh has nitrate below the highest desirable level.

## 2.6 Chemical characterization of the salinity in Tihama soils

Much work has been done on the chemical composition of the salts in the Tihama soils. Many data have been presented in various reports (see references).
In the following an attempt is made to gather general trends applicable to most soils, from these data with additional data from the ass. expert's analyses presented in table I.2

Saline water percolating through the soil will affect the cation composition of the exchange complex until this is in equilibrium with the composition of the soil-water.
It is a known fact that cations are adsorbed by particles smaller than 0.002 mm.

In figure 2.9 the cation exchange capacity (CEC) of soils from Wadi Zabid is plotted versus the clay %. (Data from Tesco report No. 8). Although the correlation is not very high it appears that the clay % is approximately the same as the CEC, expressed in meq. per 100 gram soil. This leads to suppose that the dominant clay mineral present in these soils is montmorillonite 2:1 clay type as the CEC of montmorillonite is 100 meq. per 100 gram clay.
However, for clay % over 25 the CEC is somewhat less than the clay %. CEC can also approximately be predicted from the clay %. When more than 15% of the CEC is occupied by sodium ions (ESP = exchangeable sodium percentage) a soil permeability hazard exists as the clay will deflocculate, blocking all pores. The ESP is related to the SAR-value of the soilwater.
For soils in the U.S.A. this relation is empirically set as :(USDA, Handbook 60)

$$ESP = 100 \times \frac{(-0.0126 + 0.01475\ SAR)}{1+(-0.0126 + 0.01475\ SAR)}$$

ESP in meq per 100 gram soil
SAR is analysed in the saturation extract

For a number of soilsamples from Gumeisha the exchangeable sodium has been analysed and ESP is estimated as:

$$ESP = Exch.\ Na^{+} / \%\ Clay \times 100\ (\%)$$

In fig. 2.10 this ESP is plotted versus $SAR_{1:1} \times \sqrt{\frac{100}{SP}}$

SAR in the saturation extract is estimated from the $SAR_{1:1}$ as $SAR_{s.e.} = SAR_{1:1} \times \sqrt{\frac{100}{SP}}$

There is a certain positive correlation but not very close. For a better correlation accurate analyses are necessary for exch. $Na^{+}$, CEC and SAR in saturation extract.

If Na-carbonates or bicarbonates are present this will rise the pH values over 8.5
Thus a relation should exist between pH, SAR and total-salt-content expressed as EC.

For Gumeisha soils these data are plotted in fig. 2.11. It is clear that an increase in salt-content (EC) lowers pH, due to the fact that an inceasing amount of $H^{+}$-ions is dispelled from the exchange complex by cations from the soil-solution, thus lowering pH.
Also is clear that higher SAR values are accompanied by higher pH. But it is risky to predict SAR from EC and pH. (see section 2.4 for EC-SAR relation for irrigationwaters).

From these data it can be concluded that the salts in the Tihama soils are predominantly Sodiumsalts which holds the possibility of an alkalinity hazard.
For a further evaluation of this hazard see section 2.9.

## 2.7. Irrigation and Salinity experiments at Gumeisha:

Cotton:

In cooperation with the irrigation practices office an irrigation trial on cotton was carried out. The purpose of this trial was to investigate the optimal irrigation interval under conditions (climate, soil, methods of water application) valid in Gumeisha.

From this trial field soil samples were taken and analaysed to investigate soil Salinity. The The analysis results are presented in table I.2 (Annex I). Analysis were done in the Soil Laboratory of the Central Agricultural Research Organization Project in Taiz. The treatments in this trial were

| | | | | | | |
|---|---|---|---|---|---|---|
| Treatment | 1 | : | 7 days | irrigation | interval, | |
| " | 2 | : | 10 days | " | " | , |
| " | 3 | : | 14 days | " | " | , |
| " | 4 | : | 17 days | " | " | , |
| " | 5 | : | 21 days | " | " | . |

Each treatment contained 7 furrows, 70 cm wide and 80 m long in 4 replications.

Due to lack of labour the care taken of the field was not sufficient and thinning, interplanting on spots of bad germination, weeding, etc. was not done according to plans. Exact yield calculations are therefore not possible.

In each treatment 2 rows were selected for harvesting. The number of plants in these rows was counted and the cotton was picked and weighed separately.

Due to above mentioned difficulties the numbers of plants in a row vary considerably from 100 to 300 not related to treatment. The yield per plant was calculated and is shown in table 2.4.

Table 2.4 Yield of Cotton per plant: total of 2 pickings (gram plant$^{-1}$ )

| Replication | 1 | 2 | 3 | 4 | Total | Average |
|---|---|---|---|---|---|---|
| Treatment 1 | 57.9 | 59.4 | 70.00 | 60.0 | 247.3 | 61.8 |
| 2 | 52.7 | 40.6 | 60.1 | 51.4 | 204.8 | 51.2 |
| 3 | 39.7 | 56.4 | 57.0 | 44.3 | 197.4 | 49.4 |
| 4. | 48.3 | 41.3 | 47.8 | 22.9 | 160.3 | 40.1 |
| 5. | 18.2 | 29.0 | 43.3 | 30.8 | 121.3 | 30.3 |
| Total | 216.8 | 226.7 | 278.2 | 209.4 | 931.1 | |

These data have been subjected to an analysis of variance and from a statistical point of view, the treatments have had a significant effect on the yield per plant.

P(probability lev l) less than 0.005.

The optimal irrigation interval can be calculated if a number of assumptions is made. The validity of these assumptions will affect the validity of the outcome of these calculations to a great extent. First the number of plants per ha is calculated, next costs and benefits are calculated, using estimated figures from the ""Plans of Operations 1976 - 1977 Season" for Gumeisha farm.

If row distance is 70cm and plant distance within the row is 25 cm : area per plant is 0.175$m^2$ or 57 000 plants per ha. For the treatment 1 - 5 the yield per ha can be estimated as: :

Average yield per plant x 57 000 (gr.ha$^{-1}$ )

| | | | |
|---|---|---|---|
| Treatment | 1 : 61.8 x 57 000 = | 3524 | Kg. ha $^{-1}$ |
| " | 2 : 51.2 x 57 000 = | 2918 | " |
| " | 3 : 49.4 x 57 000 = | 2813 | " |
| " | 4 : 40.1 x 57 000 = | 2284 | " |
| " | 5 : 30.3 x 57 000 = | 1728 | " |

The actual yield in the production fields in the 1975 - 1976 season was 1700 Kg. ha $^{-1}$. In the 1976 -77 Plan of Operations a yield was expected of 2500 Kg. ha $^{-1}$.

The following figures are derived from the Plan of Operations.

All figures are per ha.

Price of cotton : 1300 YR. per 1000 Kg.

Labour costs per picking : 1.5 YR. per 12 Kg.
Labour costs for irrigation : 15 YR. per irrigation.

Other labour costs : 240 YR.

Irrigation costs:

Pre-irrigation + 1st irrigation : 240 YR.

Other irrigations : 88 YR. per irrigation.

Other costs (spraying, fertilisers etc.) : 1270 YR.

In table 2.5 costs and benefits are calculated for treatments 1 - 5.

Table 2.5: Costs and benefits per ha. for treatments 1 - 5

| Treatment | No. of irr. | Yield | Income | Labour costs: Picking | Labour costs: irr. | Labour costs: Other | Irrigation costs: pre+1st | Irrigation costs: Other | Other costs | Total costs | Net income |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 3524 | 4581 | 442 | 240 | 187 | 240 | 1408 | 1270 | 3787 | 794 |
| 2 | 11 | 2918 | 3793 | 365 | 165 | 187 | 240 | 968 | 1270 | 3195 | 598 |
| 3 | 8 | 2813 | 3657 | 352 | 120 | 187 | 240 | 704 | 1270 | 2873 | 784 |
| 4 | 6 | 2284 | 2969 | 286 | 90 | 187 | 240 | 528 | 1270 | 2601 | 368 |
| 5 | 5 | 1728 | 2246 | 216 | 75 | 187 | 240 | 440 | 1270 | 2428 | -182 |
| Plan of Operations | 8 | 2500 | 3250 | 314 | 120 | 187 | 240 | 704 | 1270 | 2835 | 415 |

These figures are presented in fig. 2.12.

The yield of treatment 2 is lower than expected from the figures of treatment 1 and 3.

Discarding treatment 2 the net profit is approximately the same for treatments 1 and 3.

At irrigation intervals larger than 14 days the profit decreases and eventually changes into a loss at treatment 5 : 3 weeks interval. As there is a shortage of labour, the 2 weeks interval is the best.

After this experiment soil samples were taken at approximately the same site as before. From these samples the E C has been determined to be compared with E C before cropping. These data are presented in table 2.6.

From these data and from the more extensive data in table 1.2, it appears that there is much variation firstly within each profile in texture and salinity, secondly between the profiles in layering and salinity, although all profiles are situated in one field.

These data are also unsuitable for exact calculations of salinity increase due to the various treatment But they have been

Table 2.6. Comparison of $EC_e$ values resulted before and after cropping: (mmhs.cm-1)

| | Depth | R 1 before | R 1 after | R2 before | R2 after | R3 before | R3 after | R4 before | R4 after |
|---|---|---|---|---|---|---|---|---|---|
| Treatment 1 | 0-20cm | 3.50 | 1.58 | 2.10 | 2.20 | 5.50 | 3.60 | 0.98 | 2.70 |
| Weekly irrigation | -40 | 2.25 | 2.10 | 2.80 | 1.60 | 3.70 | 4.40 | 4.90 | 2.40 |
| | -60 | 2.40 | 4.00 | 3.25 | 0.50 | 4.80 | 6.00 | 4.55 | 3.60 |
| | -80 | 1.20 | 1.60 | 2.43 | 3.20 | 2.70 | 4.30 | 3.23 | 2.10 |
| | -100 | 1.35 | 1.90 | 2.29 | 4.14 | 3.10 | 6.00 | 2.28 | 1.70 |
| | -120 | 1.16 | 2.50 | 2.58 | 1.85 | 2.15 | 4.90 | 1.51 | 29.00 (?) |
| Treatment 3 | 0-20cm | 2.80 | 2,60 | 3.35 | 2.40 | 1.75 | 1.95 | 1.20 | 0.58 |
| 2weekly irrigation | -40 | 1.72 | 2.80 | 3.60 | 3.60 | 2.00 | 4.50 | 2.90 | 3.30 |
| | -60 | 3.80 | 4.40 | 3.60 | 3.20 | 4.00 | 5.60 | 2.60 | 2.70 |
| | -80 | 1.46 | 1.55 | 2.55 | 1.60 | 3.10 | 3.40 | 1.70 | 3.10 |
| | -100 | 1.32 | 1.80 | 1.30 | 2.60 | 2.80 | 3.50 | 1.50 | 2.30 |
| | -120 | 1.80 | 1.85 | 0,95 | 3,70 | 3.00 | 2.80 | 3.20 | 1.55 |
| Treatment 5 | 0-20cm | 1.55 | 0.89 | 2.10 | 2.90 | 1. 5 | 1.20 | 0.87 | 0.71 |
| | -40 | 1.26 | 1.85 | 2.80 | 3.00 | 3.50 | 3.00 | 3.20 | 1.90 |
| | -60 | 0.96 | 0.73 | 4.20 | 3.60 | 4.15 | 42. 0(?) | 3.70 | 1.80 |
| | -80 | 2.59 | 0.85 | 2.35 | 2.60 | 2.25 | 2.20 | 2.45 | 1.85 |
| | -100 | 0.89 | 1.10 | 2.95 | 4.30 | 1.74 | 2.30 | 1.44 | 1.95 |
| | -120 | 1.10 | 1.23 | 1.45 | 3.50 | 2.34 | 3.30 | 0.90 | 1.20 |

used in the previous chapter on the chemistry of the soil salinity. The $EC_e$ values are below or near the limit of suitability for plant growth ($EC_e$= 4 mm ho. $cm^{-1}$ ) and a 10% leaching requirement should be observed. For further evaluation see section 2.10.

SORGHUM:

A similar experiment was carried out on Sorghum:-

The treatments were irrigation intervals of 1 week 1½ week and 2 weeks, applied in basins of 10 x 10 m in 4 replications.

Due to 2 reasons the crop in this experiment was a failure.

a) The experimental site happened to be a spot of high alkalinity.

b) Extensive bird-damage reduced the grain yield to almost zero. Therefore no yield calculations have been made as these would have been very inaccurate. Merely the crop performance has been estimated in 4 classes:-
1. reasonable, 2. moderate, 3. bad, 4 very bad.
One of the plots is divided into 3 parts for different classes (plot.3.3) and two of the plots (plt. 1.3 and plot 4.3) are divided into 2 parts.

Table 2.7 Estimation of Sorghum performance in the irrigation trial.
(Replication, treatment) E.C., P.H.

| Reasonable | moderate | Bad | Very bad |
|---|---|---|---|
| | (1.1)0.595,8.90 | | |
| (2.1.)1.08,7.95 | | | |
| (3.1)0.785,8.95 | | | |
| (4.1.)0.620,8.95 | | | |
| (1.2)0.735.8.90 | | | |
| (2.2)0.530,9.10 | | | |
| | | (3.2)0.710,8.[illegible] | |
| | (4.2) 0.685,8.90 | | |
| | (1.3)0.620, 9.30 | (1.3)0.545,9.35 | |
| | (2.3)0.700,9.20 | | |
| | (3.3)0.[illegible]10,9.30 | (3.3.)0.630,9.40 | (3.3)0.535,9.65 |
| | | (4.3)0.615,9.40) | (4.3)0.920,9.00 |

Of each plot, or part of a Plot, a soil sample was taken from the surface at a site, representative for that plot. EC 1 : 1 and pH were analaysed. The data are presented in table 2.7 according to crop class performancee as follows: (replication, treatment) E C 1: 1, pH..

Replications from 1 to 4; treatment 1 :1week irrigations treatment 2 : 1½ week irrigation from 1 to 4; treatment 1 : 1 week irigation interval, from table 2.7 it can be seen that the soil at this site is not high saline but alkaline as p H .> 8.5 for most samples. Exact yield calculations cannot be made but it is clear that under alkaline soil conditions a short irrigation interval is preferable.

To get a better insight in the development of soil salinity this has been studied in relation to soil-water - movements (see section 2.8).

## 2.8 Studies of soil salinity in relation to Soil- Water Movements:

In cooperation between Dr. J.B, Williams of the British L.R.D. - Project in Wadi Rima and the associate expert, investigations on salinity were carried out in relation to soil - water - movements. Earlier investigations on salinity by the associate expert proved to give results that are difficult to interprete.

Gumeisha farm where these investigations were done is situated near the coastal zone in the alluvial - plain - land type of the Tihama. The soils in these areas show a large variation in parent-material, both horizontally and vertically. They have a stratified profile, which consists of salty alluvial material interlayered by aeolean sands. The infiltration of irrigation water varies enormously from site to site even over a short distance, due to variations in soil profile.

Dr. Williams uses a neutron - probe in his crop - water-requirement studies:

This neutron - probe provides detailed information on the amount of soil water ~~disturbing the soil water~~, without disturbing the soil profile. Repeated probings at exactly the same site are possible. The measuring is performed by lowering a neutron source into an access tube in the soil. Reflections of the neutrons by protons in the soil are counted. These are proportional to the soil water content. It is also obvious to combine these data on soil water with data on soil salinity.

In general the procedure was that after studying the soil water movements with the neutron probe, a soil pit has been dug next to the access tube, to take samples for salinity, texture, and sometimes also bulk density. In case salinity is to be compared before and after irrigation, the first sampling was done by taking soilmaterial from the hole, drilled to install the access tube.

All analysis results from tube samples are presented in Table I.4 - I 8 (Annex I).

2.8.1. Experiments:

The following experiments were done:

a) soil water retention characteristics of Tihama soils.

Water content, measured by neutron probe, was compared with Gypsum blocks.

b) Soil salinity in layered soils:

A bare field in Gumeisha was flooded and next the water distribution in the profile was observed. This was compared with salt accumulations in the profile.

In Madaniyah soil salinity was studied in a layered soil at 2 sites of access tubes.

c) Change in soil salinity after irrigation:

Soil's salinity was measured before and after growing a Sorghum crop, in Wadi Zabid T.D.A.Farm and in Gumeisha Farm.

d) Change in soil salinity after excessive flooding. This was done in Gumeisha farm.

## 2.8.2. Water Retention Characteristics of Tihama Soils

Water Retention Charateristics have been determined at 2 sites where the soils can be considered to be representative for big parts of the Tihama.

These sites are Gumeisha, where soils are textured Sany Loam to Loamy Sand , and Beit Al Habaq with its very uniform silty loam (to Silty clay Loam) soil of the aluvial fan. .

The water content in these soils is measured with the nuutron proble and the tension with Gypsum blocks.

The relation between the resistance in the blocks and chequred easily.in the field.

The range which the blocks are considered to work correctly is 2.3 $\angle$ p F $\angle$ 4.18 or 0.2 $\angle$ Tension (bars) $\angle$ 15 Readings at higher tensions have been obtained by extra polation, but this may not be accurate.

In Gumeisha blocks have been installed in one profile at 10cm, 20cm, 30cm, 40cm, 50cm. and 60cm. depth.

In Beit Al Habg they have been installed in 2 profiles at 20 cm., 40 cm., and 60 cm. depth.

The resulting Water retention curves are given in fig. 2.13. For the Gumeisha soil it is clear that this soil is not uniform. The data from the top 40 cm., differ from the 50 and 60 cm. data. The soil at Beit Habaq behaves more uniformly as expected.

For permanent wilting point the value tension = 15 bar ($p^F$ = 4.2) is often assumed. The corresponding volumetric moisture percentages can be read from fig. 2.13.

| | | |
|---|---|---|
| Gumeish | 0 - 45 cm. | P W P = 9.5 % |
| Gumeisha | deeper than 45 cm. | P W P =11 % |
| Beit Al Habaq | | P W P =17 % |

The Field capacity is more difficult to get in this way. This is defined as the amount of water that remains in the soil when after irrigation, the gravitational water has moved downwards. Usually this takes 2 days,

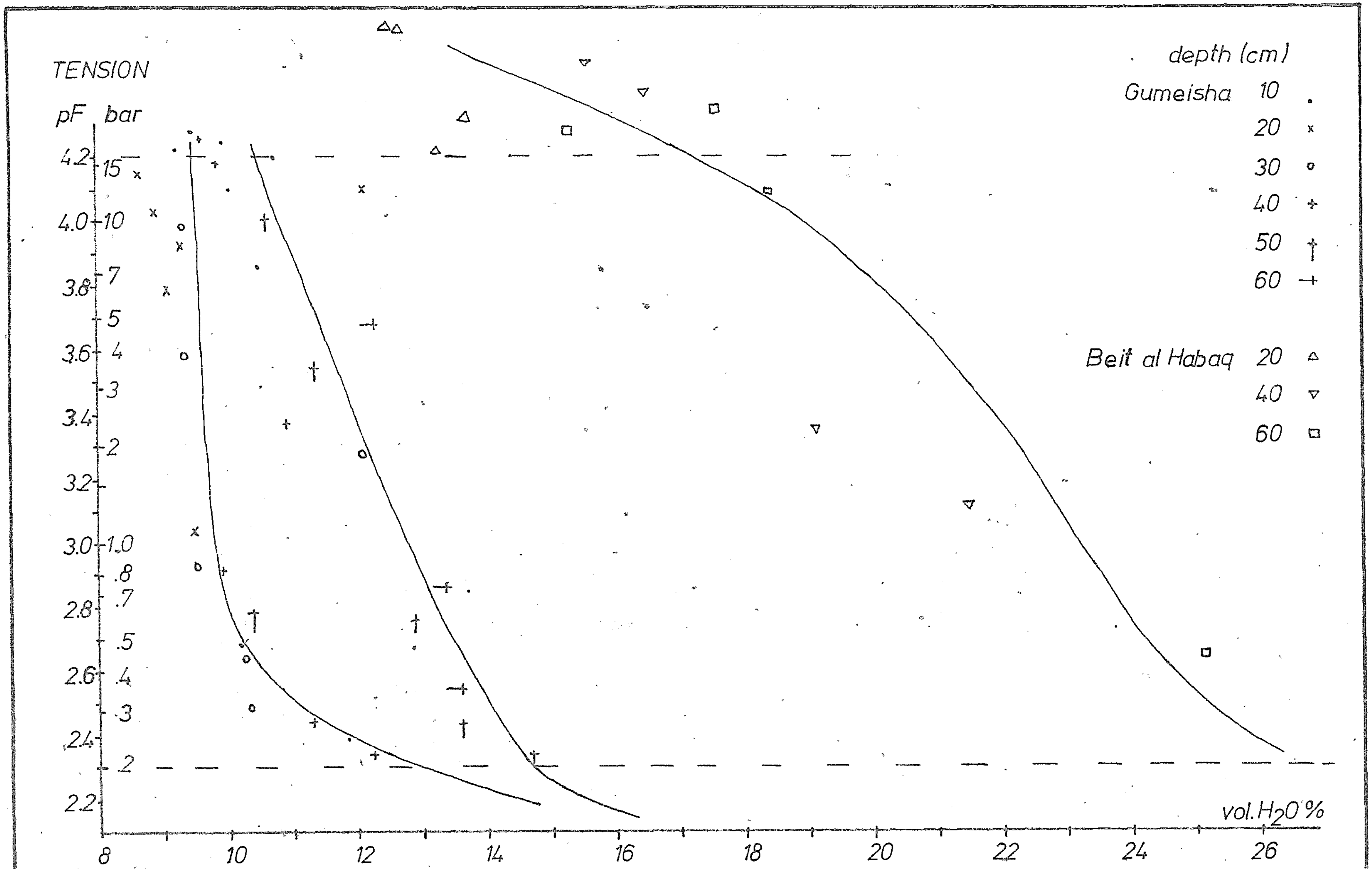



Fig. 2.13 Water retention curves for 2 Tihama soils

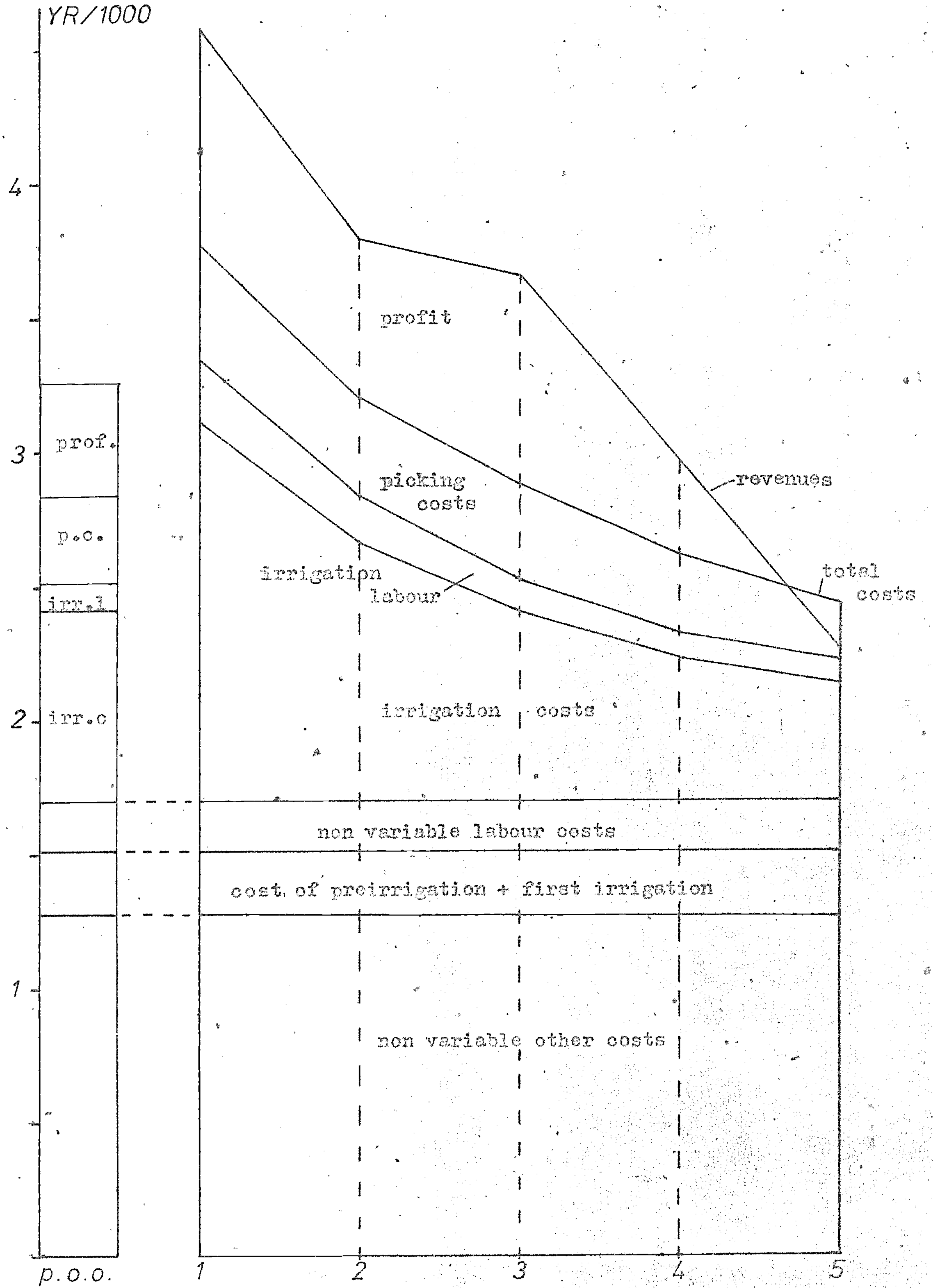



Fig. 2.12. Costs and Benefits Cotton irrigation trial. treatment 1–5

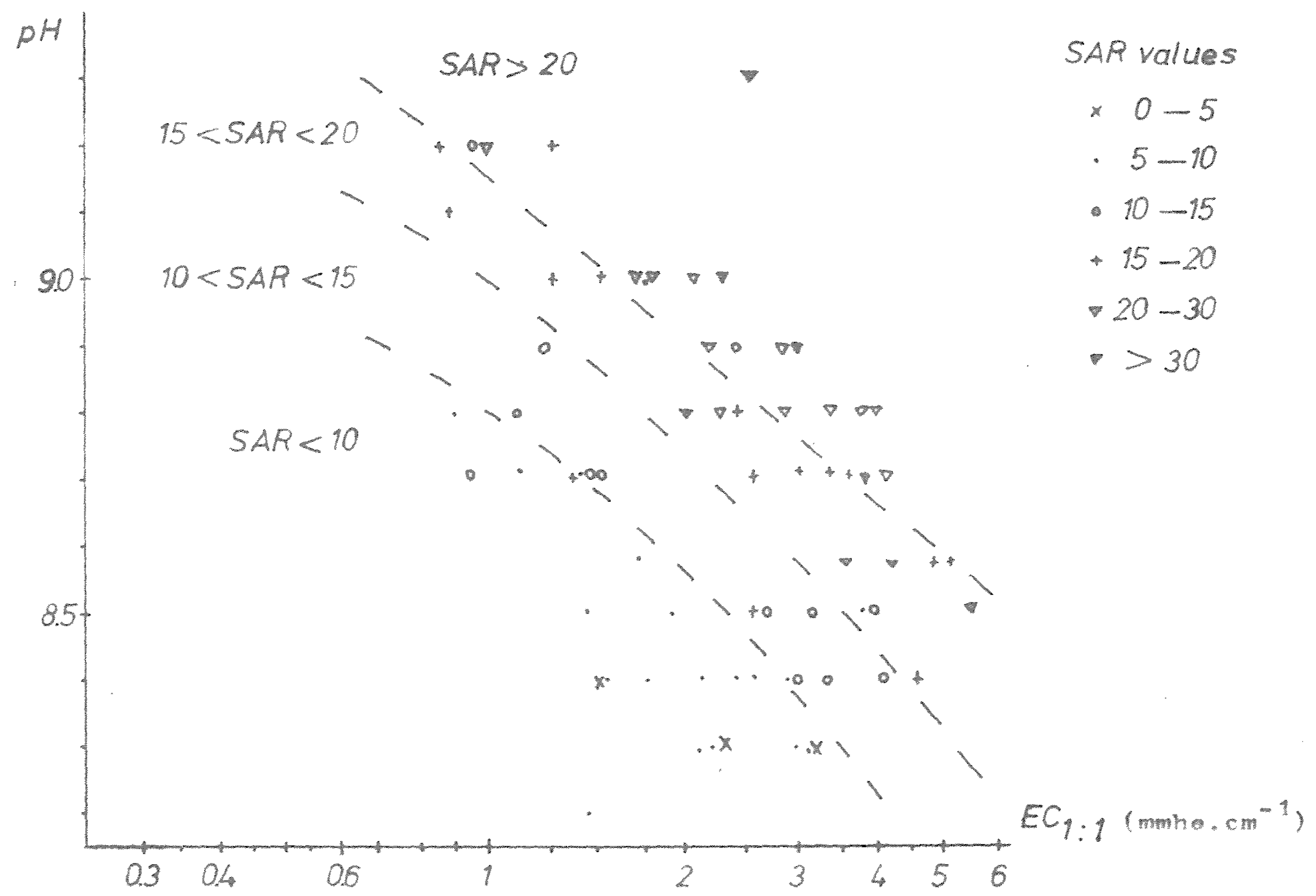



Fig. 2.11 pH—$EC_{1:1}$—SAR. Data from table I.2 (Gumeisha)

The water content in the soil 2 days after irrigation is much more than when the Gypsum blocks indicate 0.3 bar tension( one third atmosphere point). The blocks generally do not show any tension before 1 week after irrigation. The wet end of the curves in fig.2.13 is inaccurate. The water content 2 days after irrigation is given in table 2.8 and is used to calculate the available water.

Table2.8. Available water for Gumeisha and Beit Al Habaq soils:

| | F.C. | P.W.P. | available $H_2O$(%) |
|---|---|---|---|
| Gumeisha 0-45 | 15 | 9.5 | 5.5 |
| " deeper than 45cm | 20 | 11 | 9 |
| Beit Al Habaq | 35 | 17 | 18 |

The available water in soil depth of 120 cm is also for Gumeisha:

$$\frac{5.5}{100} \times 450 + \frac{9}{100} \times (1200 - 450) = 92.3 \text{ mm.}$$

For Beit Al Habaq:

$$\frac{18}{100} \times 1200 = 216 \text{ mm.}$$

2.8.3 Soil Salinity in layered soils:

In Gumeisha farm as well as in other places in the Tihama, locally a hard layer is found in the soil profile. This layer is fine textured Silty Loam to Silty clay Loam and in contrast to the other soil layers, has a strong horizontally orientated platey structure. It occures at depths varying from 30 to 70 cm and its thickness varies from 4 to 20 cm.

At some places 2 to 4 cm thick sandlenses occur and this leads to suppose that the Silty clay Loam is of alluvial origin, while the sandlenses are aeolean, blown in between successive floods.

In a bare plot in Gumeisha, where this layer occurs, 5 access tubes were installed. The plot was irrigated twice. The total depth of applied water is: tube 1 : 251 mm, tube 2 : 212 mm, tube 3 : 282 mm, tube 4 : 245 mm, tube 5 : 302 mm. This variation is due to bad land levelling.

After this soil surface at tubes 1, 3 and 5 was covered with polythene sheet to prevent surface evaporation and to force the soil-water to move downwards. The soil moisture was probed at regular intervals. After 6 we ks soil pits were dug in this way that the access tube coincides with a wall of the pit.

Soil layers were distinguished according to texture. Soil samples were taken to be analaysed on EC and particle seize. From selected layers also undisturbed core samples were taken to determine bulk densities.

These data are given in figs. 2.14 to 2.16. The bulkdensity figures with 2 decimals are measured. The others are estimated from layers with similar texture.

From the bulk density, b.d., and the particle density, p. d., the porosity, por., can be calculated as follows:-

$$Por = ( 1 - b.d. / p.d.) \times 100 (\%)$$

The p.d. is assumed to be 2.65 gram. cm. $^{-3}$ from the porosity, por., the bulk density, b.d., and the E.C. $_{1:1}$ the $EC_e$ can be calculated.

$$EC_e \times (Vol. H_2O\% ) Saturation = EC_{1:1} \times (Vol. H_2O\%)_{1:1}$$

Vol. $H_2O$ % at Saturation equals the porosity. As 1 $cm^3$ soil weighs b.d. grams a 1 : 1 soil -Water mixture contains b.d. ml. water per $cm^3$ soil.

$$So : (Vol\ H_2O\%)\ 1 : 1 = b.d. \times 100(\%)$$

$$EC_e = EC\ 1:1 \quad \times \frac{b.\ d. \times 100}{por.}$$

In this calculation it is assumed that no precipitation takes place. This may not be entirely correct. On concentrating the soil water the carbonates can precipitate, thms reducing $EC_e$.

From the moisture data obtained by regular probing, 5 profiles are given in figs. 2.14 - 2.16 to show the water movements:

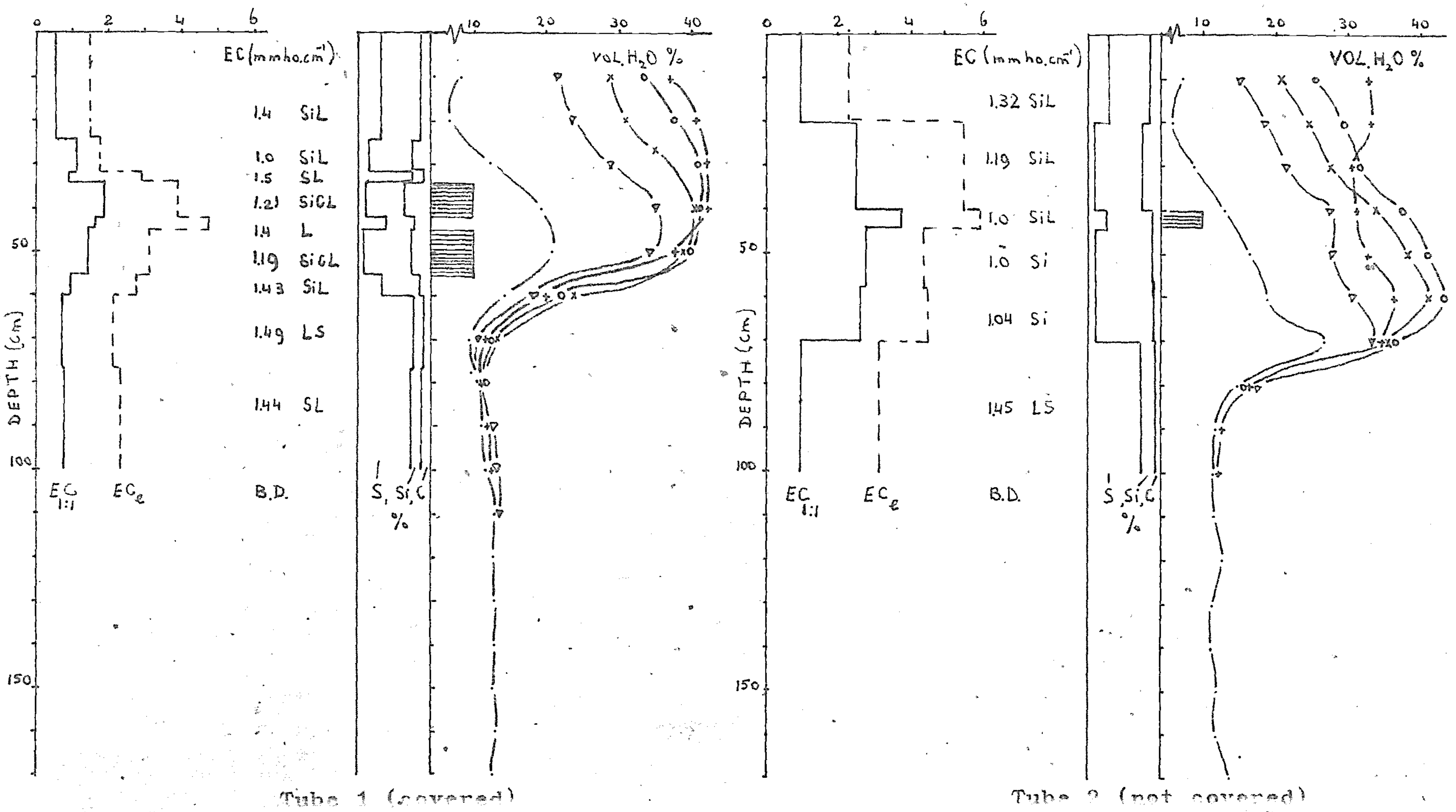



Fig. 2.14 Soil salinity and water movements tubes 1 and 2 (Gumaisha)

▤ Horizontally platey structured layer

Moisture profiles (a) ·—·—· dry
(b) +—+—+ after irrigation
(c) o—o—o 1 day after (b)
(d) x—x—x 1 week after (b)
(e) ▽—▽—▽ 4 weeks after (b)

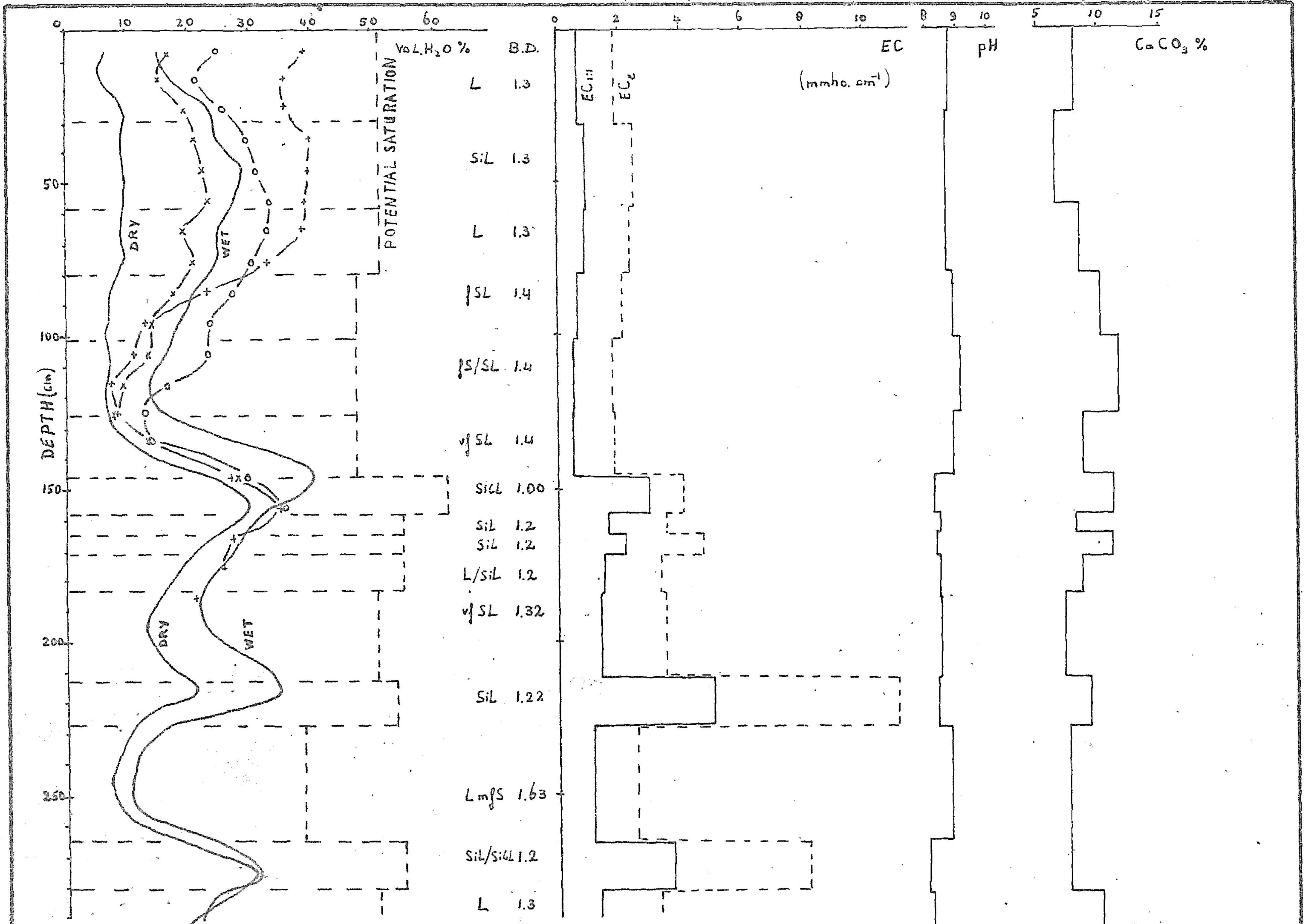



Fig. 2.17 Profile 62 (Yadaniyah)

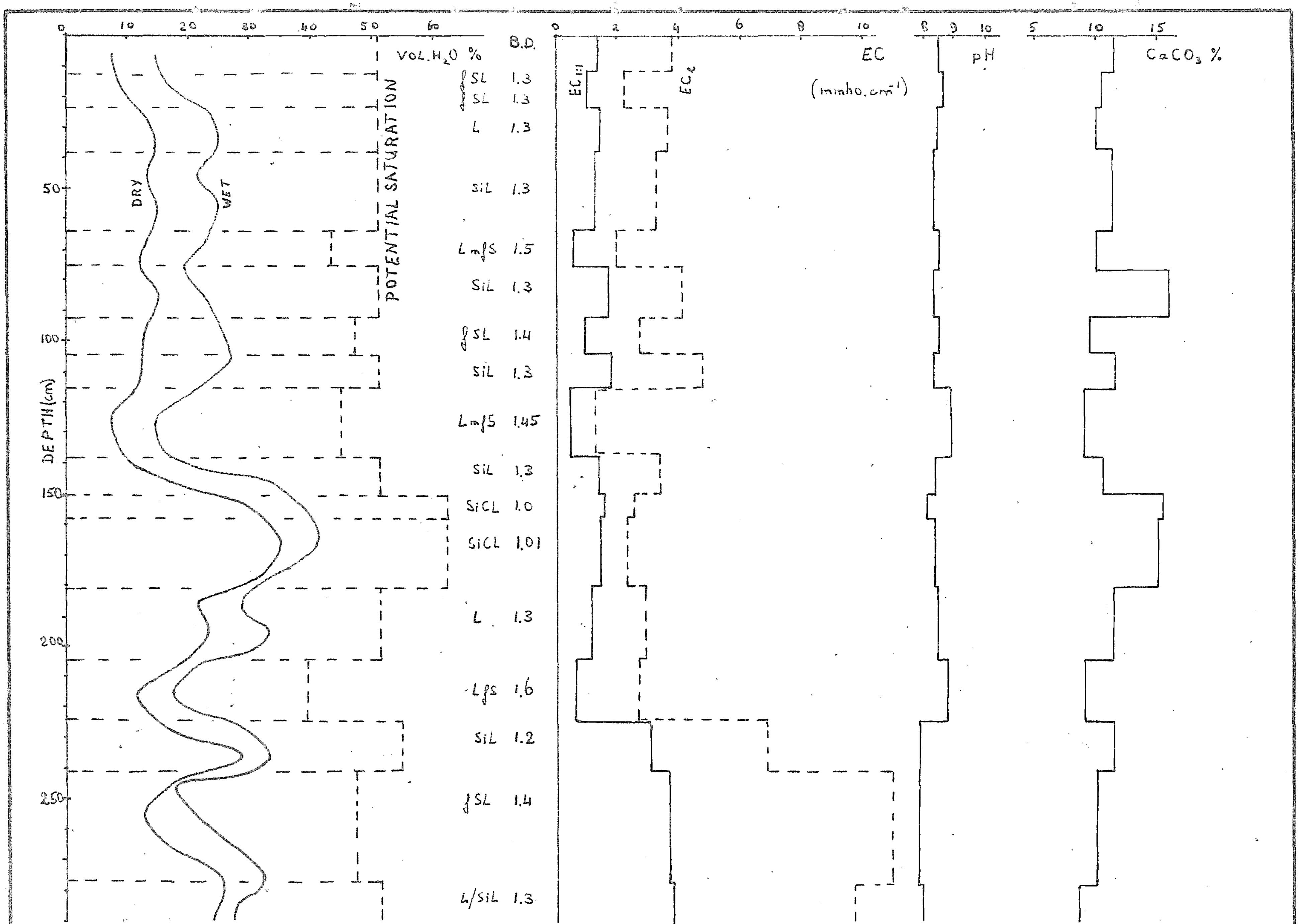
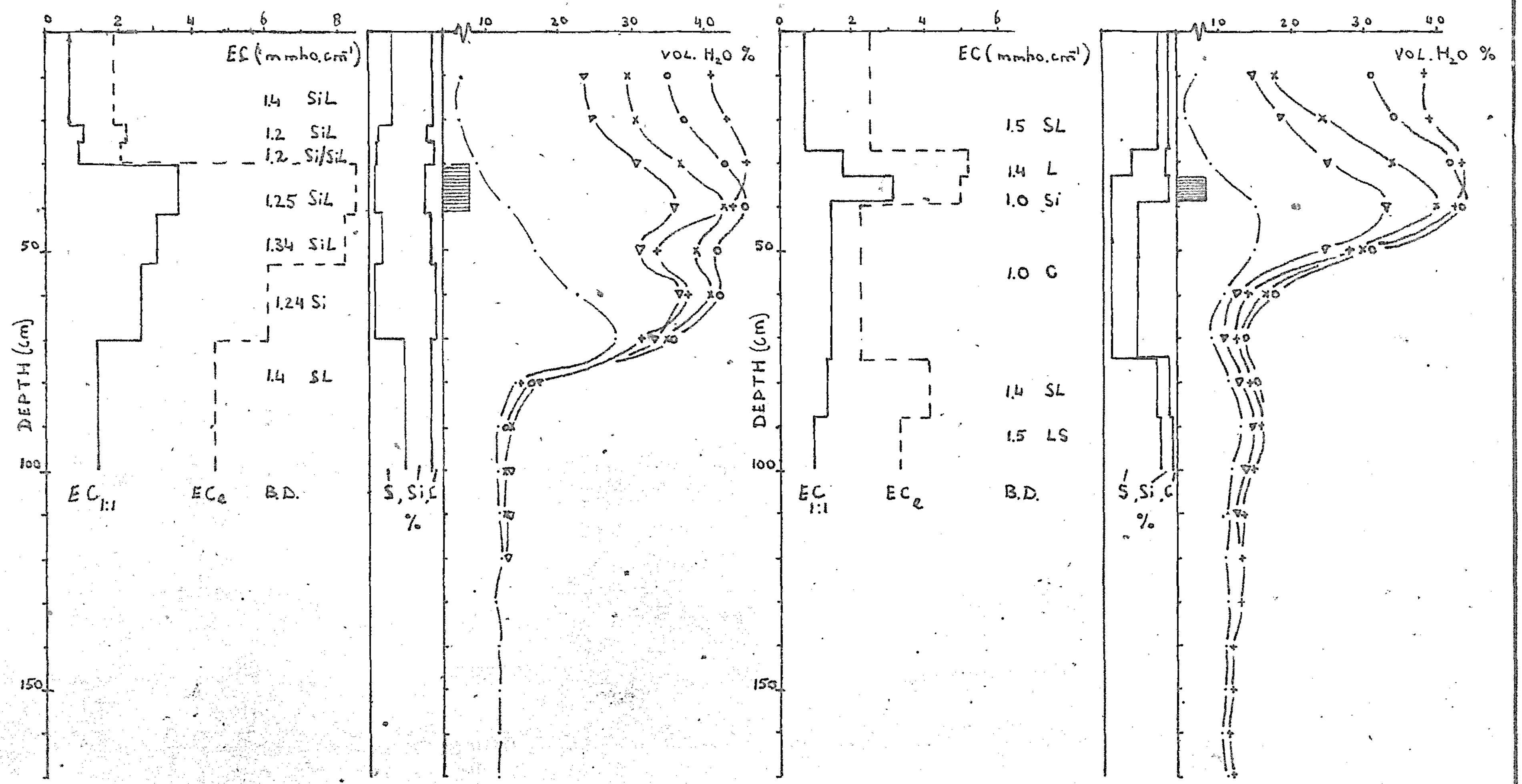
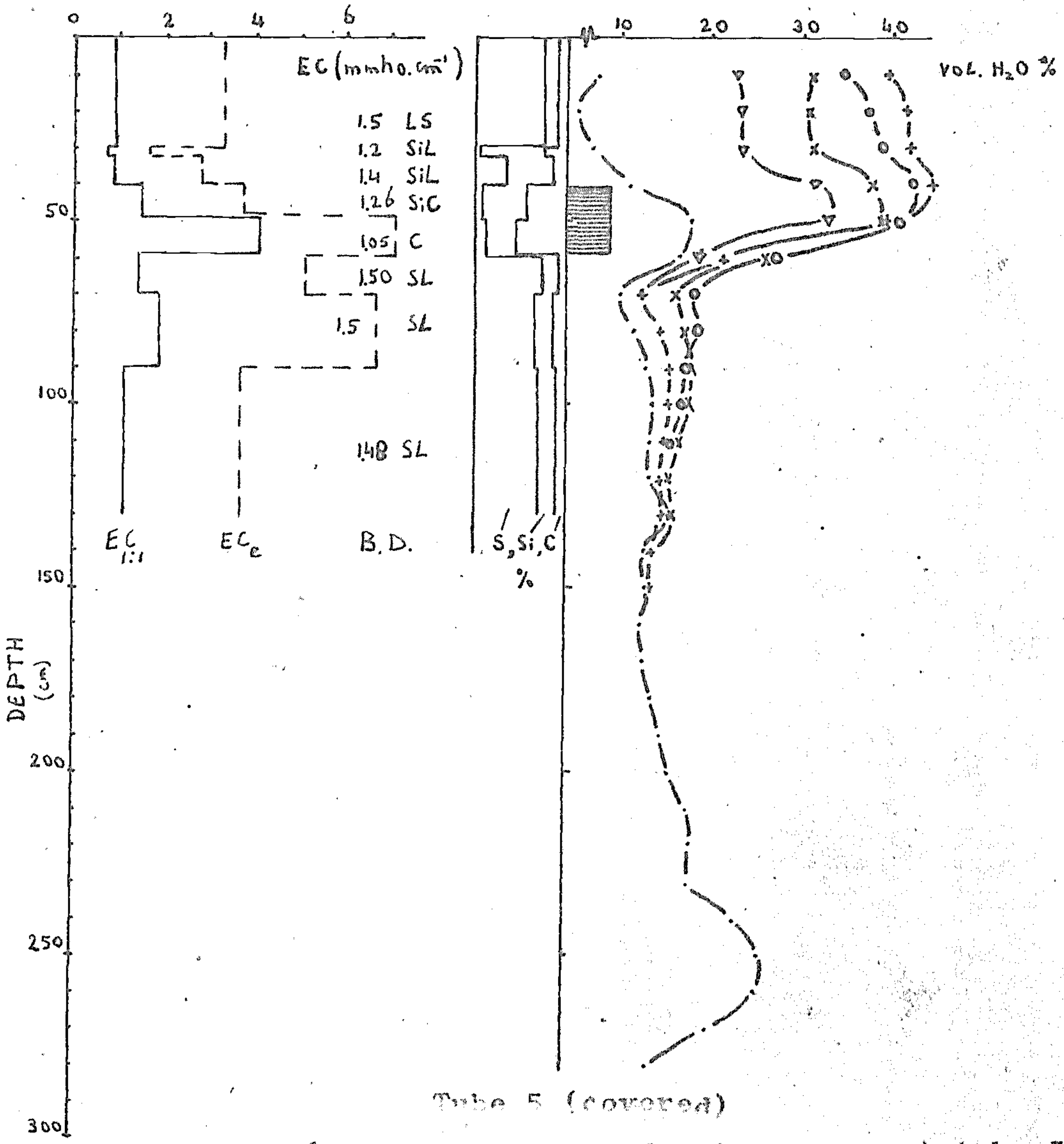



Fig. 2.18 Profile 63 (Madaniyah)




Tube 3 (covered) Tube 4 (not covered)

Fig. 2.15 Soil salinity and water movements tubes 3 and 4 (Gumeisha)
▤ Horizontally platey structured layer
Moisture profiles (a) ·—·—· dry
(b) +—+—+ after irrigation
(c) o—o—o 1 day after (b)
(d) x—x—x 1 week after (b)
(e) ▽—▽—▽ 4 weeks after (b)




Tube 5 (covered)

Fig. 2.16 Soil salinity and water movement tube 5 (Gumeisha)

☰ Horizontally platey structured layer

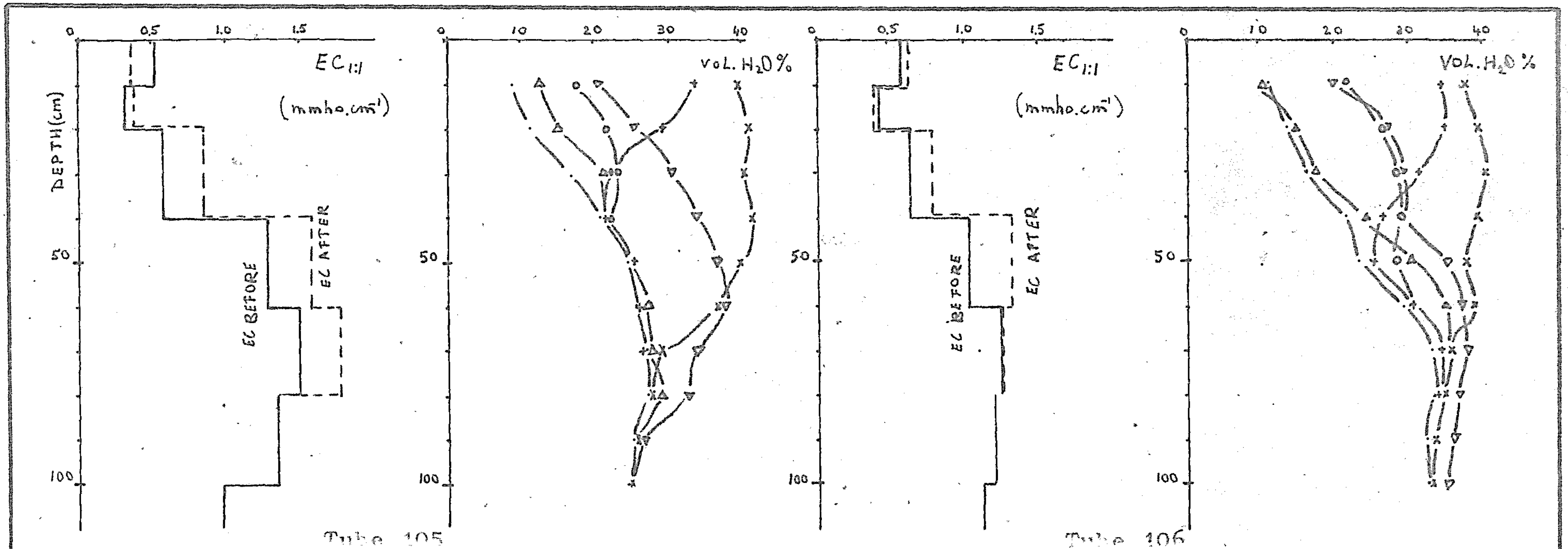
Moisture profiles (a) —·—·— dry

(b) +—+—+ after irrigation

(c) o—o—o 1 day after (b)

(d) x—x—x 1 week after (b)

(e) ▽—▽—▽ 4 weeks after (b)



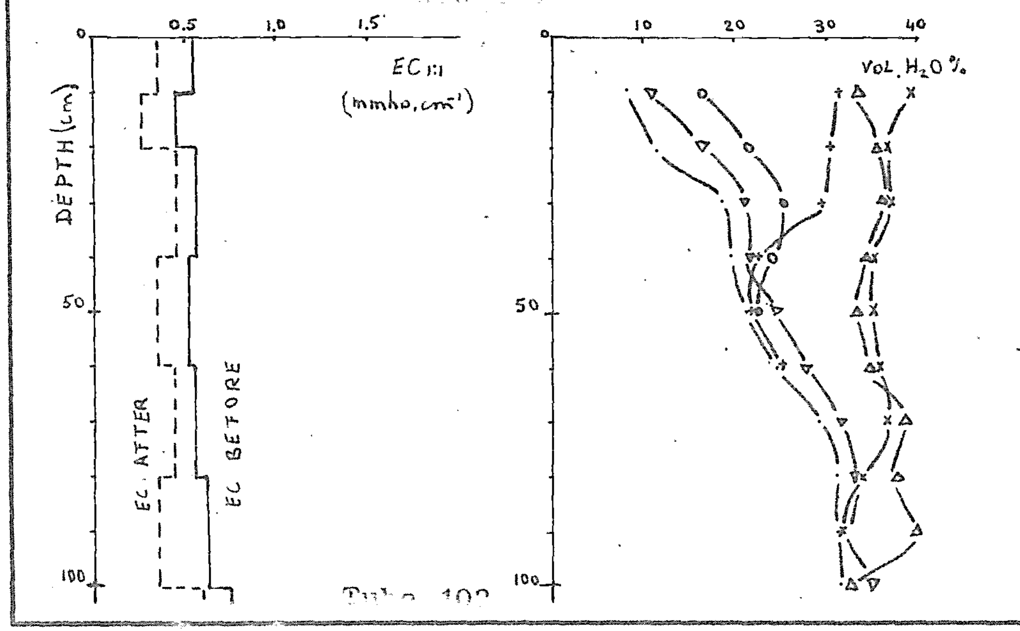




Fig. 2.19 Tube 105, 106, 102 (TDA farm W.Zabid)

Moisture lines 105 and 106:
(a) ·—·—. dry (d) x–x–x after 2nd ir.
(b) +—+—+ after 1st irr. (e) ▽–▽–▽ 10 days aft.d
(c) o—o—o 9 days after (b) (f) △–△–△ 8 weeks aft.d

moisture lines 102:
(a) ·—·—. dry
(b) +—+—+ after 1st irr.
(c) o—o—o 9 days after (b)
(d) x—x—x after 2nd irr.
(e) ▽—▽—▽ dry before next irr.
(f) △—△—△ wet after next irr.

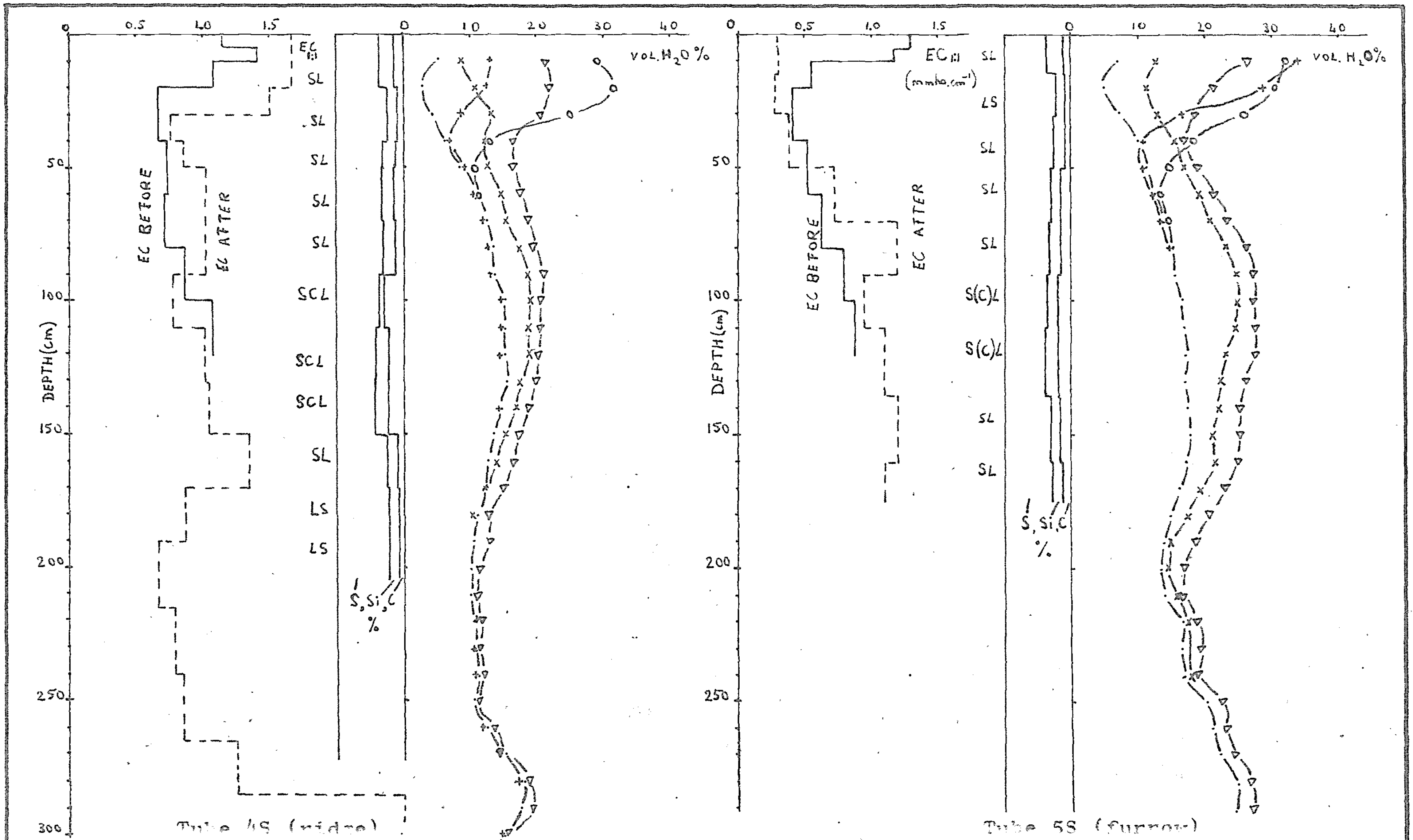



Fig. 2.20 Tubes 4S and 5S (Gumeisha)
Moisture lines (a) ·—·—· dry
(b) +—+—+ after 1st irr.
(c) o—o—o after 2nd irr.
(d) x—x—x before 4th irr.
(e) ▽—▽—▽ after big rainstorm

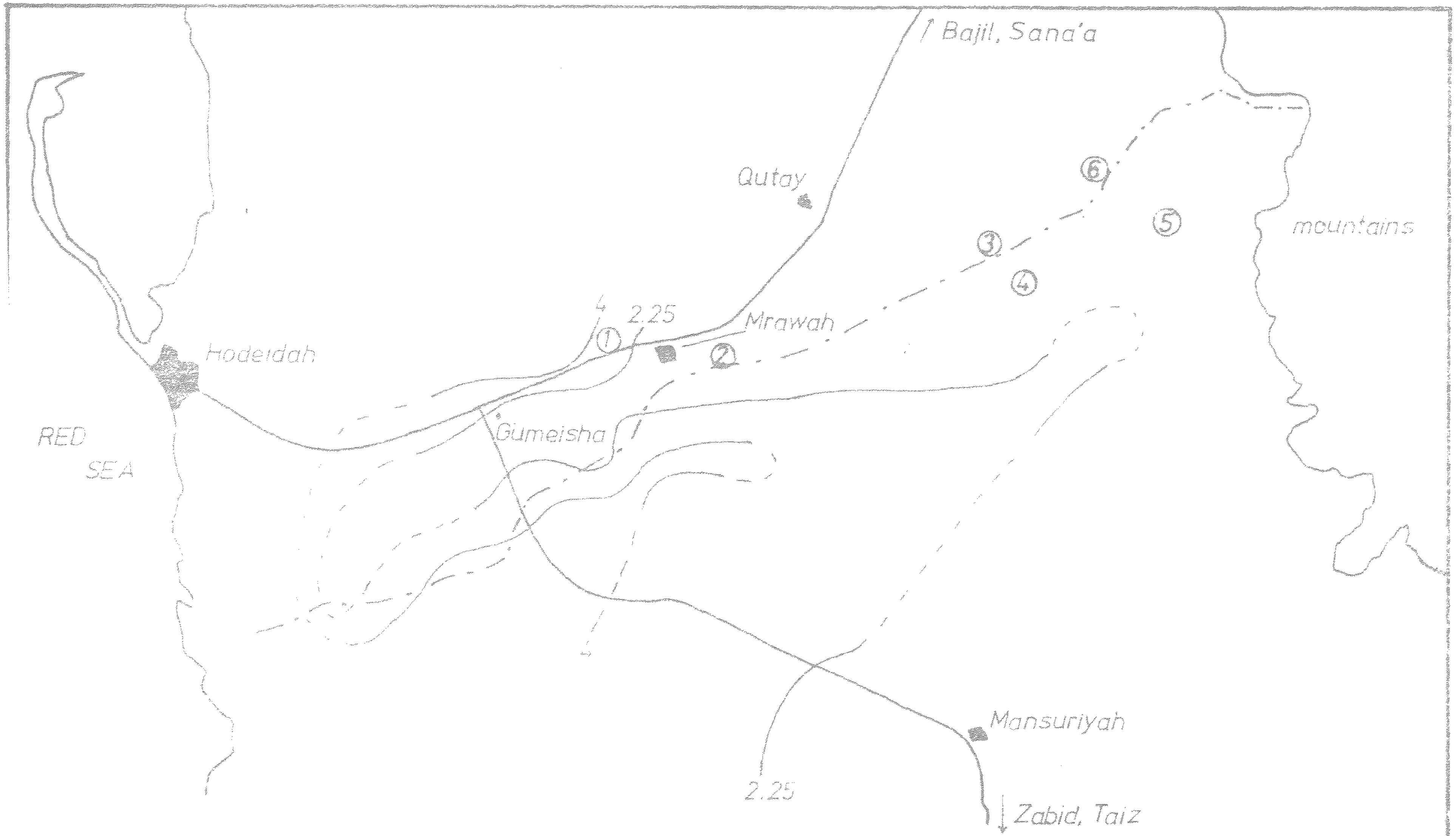



Fig. 2.25 Groundwater salinity in Wadi Siham area (mmho)
①_⑥ : farms of Boushari

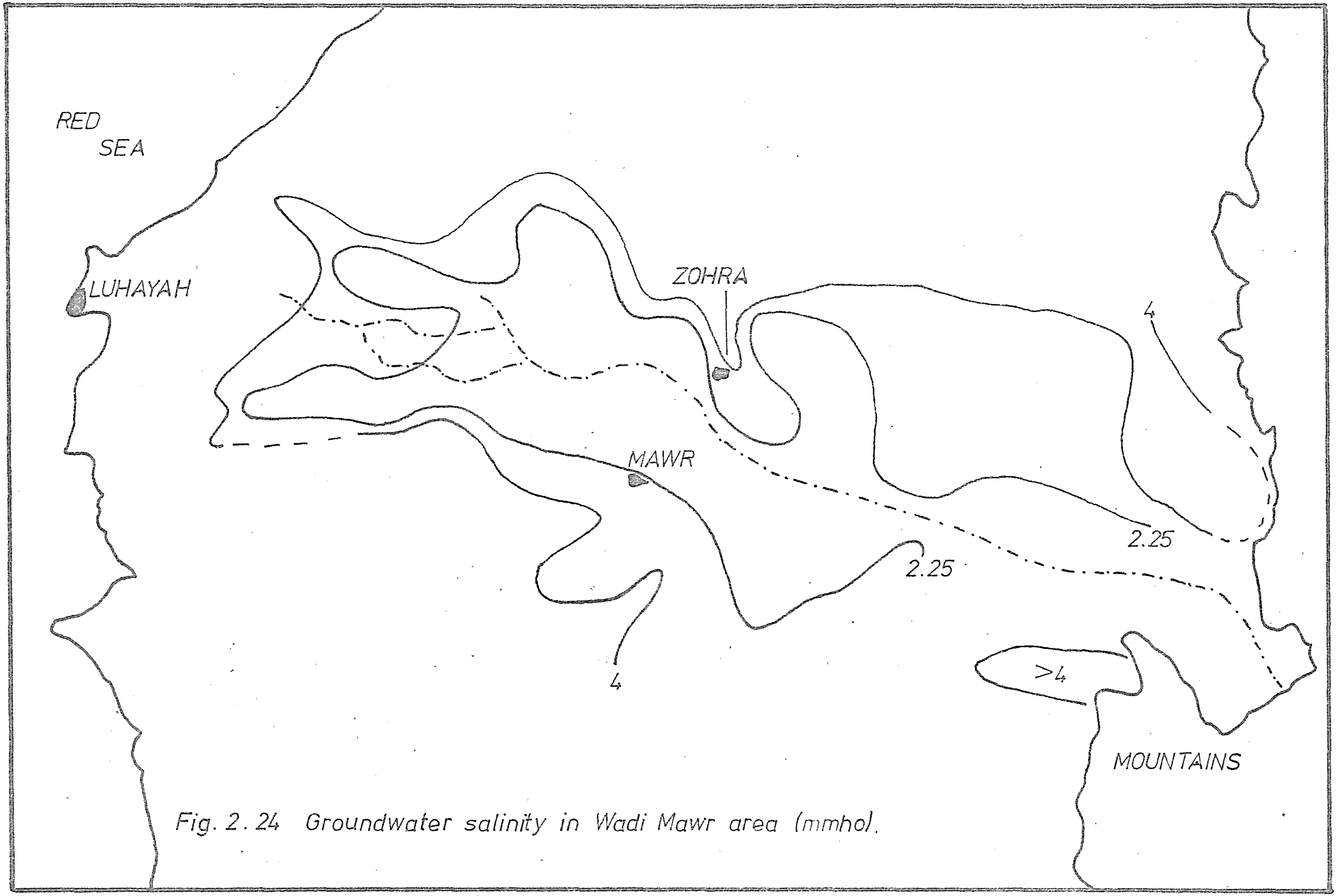



Fig. 2.24 Groundwater salinity in Wadi Mawr area (mmho).

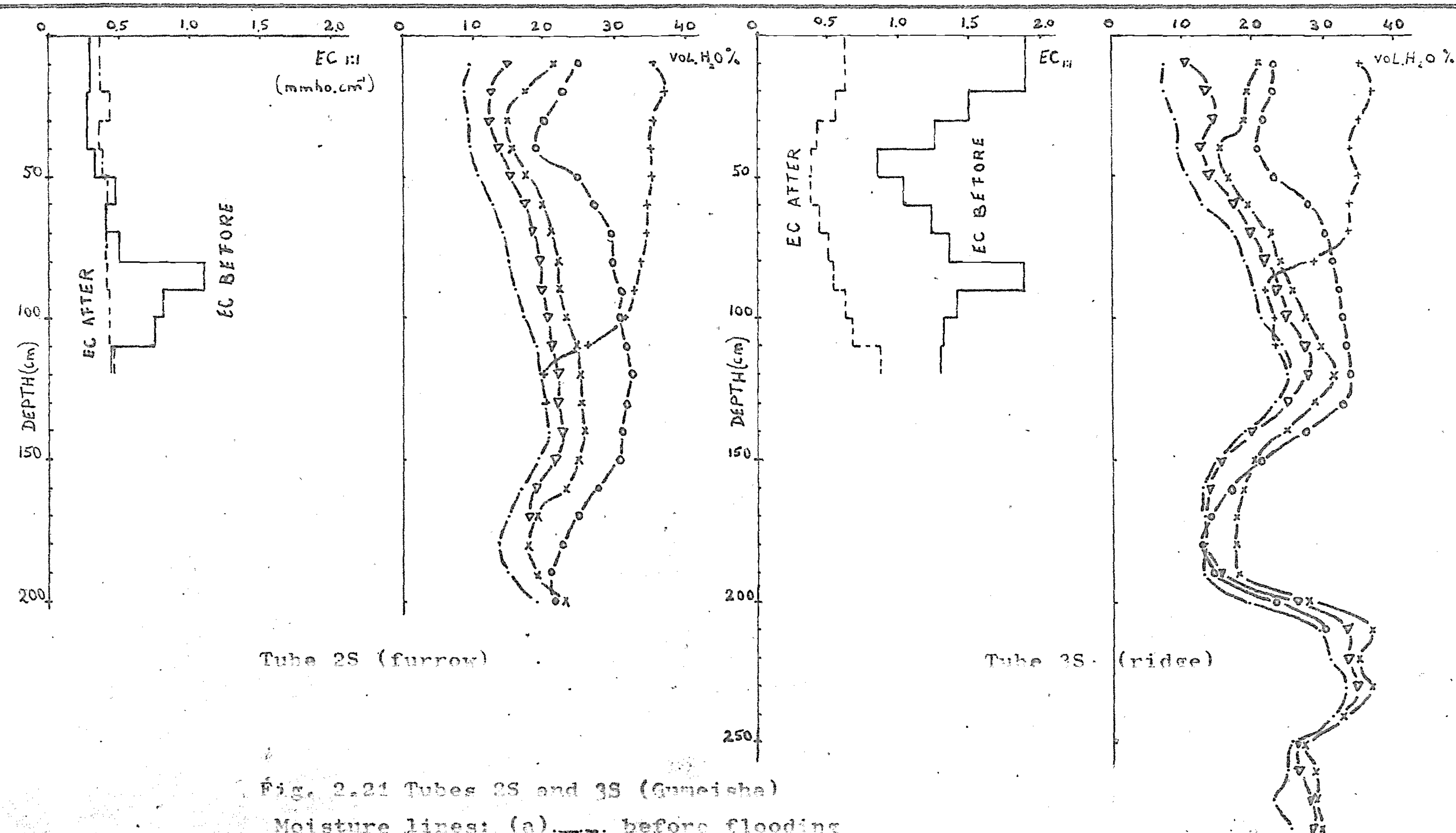



Fig. 2.21 Tubes 2S and 3S (Gumeisha)

Moisture lines: (a) —·—·— before flooding
(b) +—+—+ after flooding
(c) o—o—o 1 day after (b)
(d) x—x—x 1 week after (b)
(e) ▽—▽—▽ 3½ week after (b)

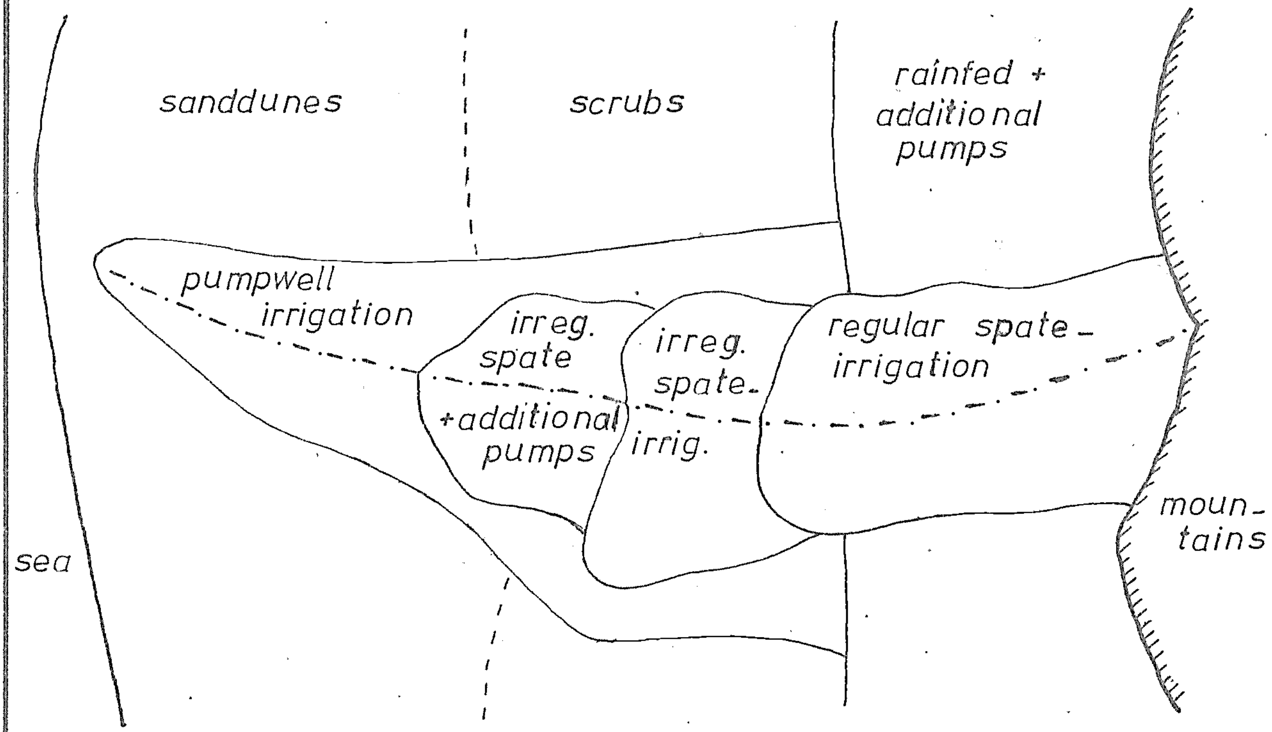



Fig. 2. 22 Schematic distribution of irrigation types

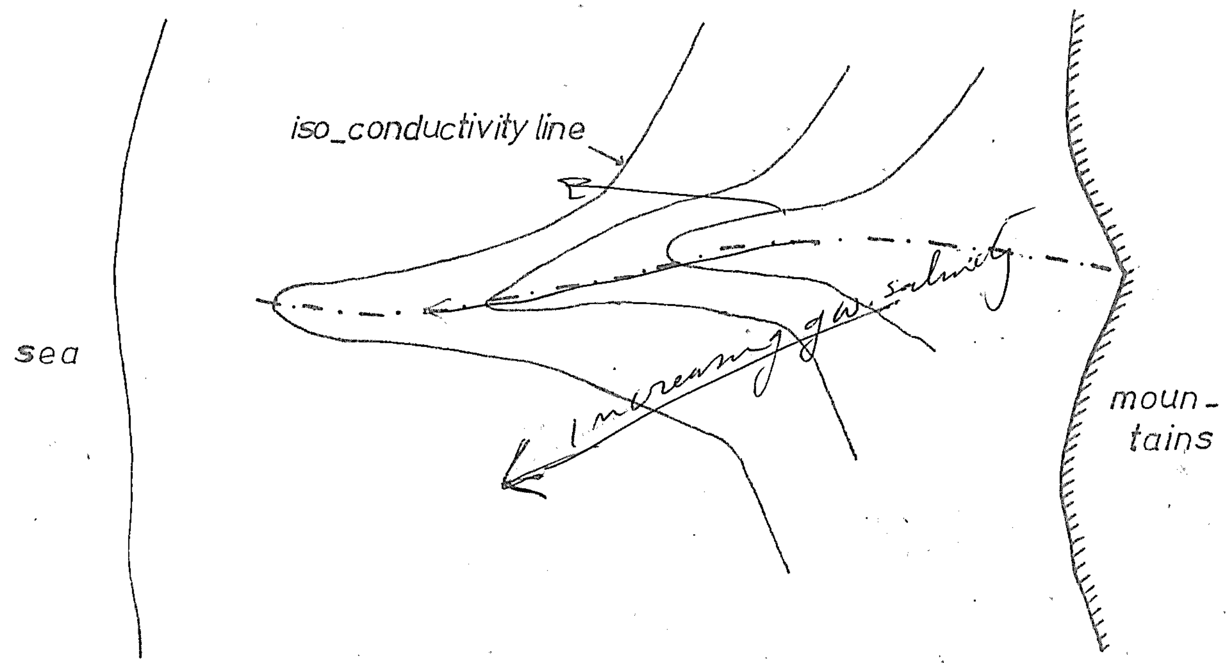



Fig. 2.23 Schematic distribution of groundwater salinity

a) · - · - · dry profile on installation of tubes.

b) + - + - + after 2nd water application

c) O - O - O 1 day later, showing downward movement of water

d) x - x - x 1 week after irrigation showing drying of profile.

e) ∇ - ∇-∇ 4 weeks after irrigation.

The curves of the dry profile (a) indicates texture changes in soil. As fine textured material holds more water than coarse textured at the same tension, an increase in water content in the moisture lines (A) indicates finer texture. The tubes 1, 3 and 5 were covered with polythene and the top 10 cm dried to 22 - 23%. The uncovered sites, tube 2 and 4 dried in the top 10 cm. to 15%.

Characteristic for these 5 profiles is the texture change at 60 to 70 cm depth from Si/SiL/C to LS/SL Water movement is hampered at this transition.

Pore seize in a coarse textured layer is larger than in fine textured. Water coming from a fine textured layer can only enter the pores in the coarse layer that have approximately the same, small, diameter. The bigger pores cannot be filled as the water is retained by the fine layer with a higher tension.

This is also reflected in the salt accumulations in these profiles. The fine layers have a low leaching efficiency as only soil water from the bigger pores can enter the underlying coarse layer. On drying the soil water reatreats to the smallest pores, concentrating the salts from where they are hardly to be leached. Tubes 1,4 and 5 show some water movement into the LS/SL at 70 cm. At tubes 2 and 3 this is almost nil. The salt, accumulation in the fine layer (20/25 cm to 60 - 70 cm) is also more pronounced at tubes 2 and 3 than at tubes 1, 4 and 5. The highest salt accumulations are in the horizontally platey structured layers (shaded in fig 2.14 - 2.16)

The same features were met in 2 layered profiles in Al Madariyah, tube 62 and 63; fig 2.17 and 2.18 Two profiles were examined at sites were access tubes had been probed during 3 years in crop-water-requirement studies. EC irr. = 2 mmhs·cm $^{-1}$. The procedure was as described above.

All analayses results are given in figs. 2.17 and 2.18

$EC_e$ was calculated from EC 1 : 1 and bulk density. The porosity, calculated from bulk density, is given as the potential saturation, all pores filled with water. The moisture curve indicated as "wet" is taken after the last irrigation of a Sorghum crop, when the profile is wet throughout. The "dry" curve is taken at the harvest after the crop has subtracted water from all the profile. In profile 62 3 more curves are shown + - + - + after flooding ; O -O - O 2 days later x - x - x 1 month later. These show that in the first 2 days water is redistributing from the top 80 cm to the depth 80 - 135 cm. Afterthis no more water moves downward.

Here also it is clear that water movement is impeded accross an abrupt texture change from a fine textured-into a coarse textured layer. This corresponds with salt accumulations in profile 62 at 150/170 cm 220cm, 270 cm.

In profile 63 these salt accumulations are less pronounced probably due to a less impeded drainage.

Here salt accumulates at depths below 230 cm. after being leached from the zone.

2.8.4. Change in soil salinity resulting from irrigation:

Soil salinity was measured before and after growing a Sorghum crop soil samples were taken at exactly the same site before and after. This was done in the T.D.A. farm as Wadi Zabid and at Gumeisha. The soil at the T.D.A. farm is uniform silty - Loam to Silty - Clay- Loam. Irrigation water has EC = 0.72 mmhs cm$^{-1}$.

In fig 2.19 the moisture curves and EC $_{1:1}$ curves from tubes 105,106 and 102 are given.

The plot around 105 and 106 is irrigated twice and next allowed to dry. Depth of applied water for tube 105 = 182 mm; for tube 106 = 159 mm. The following moisture lines are given:

(a) . - . - . dry
(b) + - + - + after first irrigation
(c) O - O - O 9 days after (b)
(d) X - X - X after 2nd irrigation
(e) V̄ - V̄ - V̄ 10 days after (d)
(f) △ - △ - △ 8weeks after (d)

It can be seen that the first irrigation wets the top 45 cm (tube 105) resp. 50 cm (tube 106). The second irrigation wets the top 70 cm (tubes 105 and 106). After redistribution the water moves to 90 cm (tube 105) and very little moves to 100 cm (tube

8 weeks later the profiles are almost dry.

As there is no leaching from the top 100 cm the increase in salinity is obvious.

Redistribution after the 2nd irrigation is different for tube 105 and 106. At tube 105 much water moves to 70 cm. depth. At tube 106 this is much less. Salinity increase at tube 105 is more than at tube 106. At both sites the top 20 cm. has only slight change., tube 105 even small decrease in the top 10 cm.

The plot at tube 102 has been irrigated 5 times.

In fig. 2.19 the following moisture curves are shown:

(a) . - . - . dry
(b) + - + - + after 1st irrigation
(c) O - O - O 9 days after (b)
(d) X - X - X after wnd irrigation.
(e) V̄ - V̄ - V̄ dry before next irrigations
(f) △ - △ - △ wet after next irrigations

The first irrigation wets the top 45 cm. The second reaches to 85 cm. depth. Water from next irrigations moves below 1 m. As access tube No.102 is only 1 m. deep no data from greater depth are available. The dry and wet curves before and after next irrigations are also given.

At this site there is leaching of salts from the top meter as is shown by the $EC_{1:1}$ lines.

Although irrigation water salinity is not very high at this farm, compared to other ground waters in the Tihama, a not-sufficient water application leads to increase in soil salinity.

The soil salinity at the three sites investigated, tube 102, 105, 106, is not very high and in observing the necessary leaching requirements, this can be kept at a tolerable level.

In Gumeisah the irrigation water has EC = 2.2 $mmho.cm^{-1}$
As Said before the soils vary enormously over short distance. At the site of tubes 4S and 5S, were change in salinity is studied before and after growing a sorghum crop, the soil profile is quite uniform Sandy Loam to Loamy Sand with very gradual changes between the layers and without clear layering.

This plot has been irrigated 8 times. Shortly after the last irrigation an unusual big rain storm (60mm) flooded the field. Also run off from adjacent fields covered the experimental plot.

The moisture curves shown are :
(a) ●-●-● dry
(b) + -+ -+ after 1st irrigation
(c) O - O - O after 2nd irrigation
(d) x -x -x -before 4th irrigation
(e) ▽ - ▽ - ▽ after big rainstorm

The depth of the first 6 irrigations was as follows:

| | 4S | 5S |
|---|---|---|
| 1 | 31mm | 74mm |
| 2 | 61mm | 53mm |
| 3 | 40mm | 51mm |
| 4 | 69mm | 50mm |
| 5 | 30mm | 26mm |
| 6 | 42mm | 65mm |

It is clear that 5S got more water than 4S. This can also be seen from moisture curve (d) x - x - x before the 4th irrigation. At 100cm 4S has

19 vol% and 5S has 25 vol% (curve(d)) At tube 5S there is a clear decrease in salinity in the top 30cm but at tube 4S there is an increase.

This is also connected with the fact that tube 4S is situated on a ridge and 5S in a furrow. The top of the ridge is not leached through and salinity accumulates here.

As the irrigation water infiltrates in the furrow a clear decrease in salinity in the top soil in the furrow is obvious.

At 4S there some salt accumulation at 50-90cm and 150-170cm. At 5S at 65-90cm and at 130-160cm. These are small accumulations that can easily be leached towards greater depth.

In 4S at depth greater than 260cm the salt accumulates after being leached from the root zone. This is the same feature as encountered in profile No.63 at Madaniyah (fig 2.18)

2.85 Change in soil salirity after excessive flooding

At Gumeisha farm a plot with tubes 2S and 3S was flooded 5 times on the same day. Infiltration rate was quite high and is given in table 2.9.

Table 2.9 Infiltration rate experimental plot Gumeisha

| | access-tube 2S | access-tube 3S |
|---|---|---|
| initial | 83mm $hr^{-1}$ | 99 mm $hr^{-1}$ |
| after 1 hr | 73 mm $hr^{-1}$ | 74 mm $hr^{-1}$ |
| after 2 hrs | 66 "" "" | 66 "" " |
| after 3 hrs | 62 " " | 66 " " |
| after 4 hrs | 58 " " | 63 " " |

In fig. 2.21 the following moisture curves are given:

(a) · - · - · before flooding

(b) + - + - + after flooding

(c) O - O - O 1 day after (b)

(d) X - X - X 1 week after (b)

(e) ∇ - ∇ - ∇ 35 week after (b)

From curves (a) and (b) the total depth of applied water can be calculated for 2S this is 245 mm. For 3S : 195mm. Tube 2S is situated in a furrow, tube 3S on a ridge. This has affected the amount of water infiltrated at these sites.

After the flooding water has infiltrated to 120 cm at 2S and to 90cm and 3S . Next day redistribution has taken place and 2S is wet to 200cm, 3S to 170cm Redistribution continues and it can be seen that 1 week later at 3S the water is moving down to a depth de per than 250 cm.

This has its effects on soil salinity. $Ec_{1:1}$ data before and after flooding are given in fig. 2.21. As result of previous irrigations of sorghum on this plot there is some salt accumulation in these profiles. At 3S there is accumulation in the top soil as this is situated on a ridge. In both 2S and 3S salt accumulates at 80 - 90cm depth these features are also encountered in profiles 4S and 5S (see section 2.8.4).

As result of the flooding the soil salinity has decreased.

The salt accumulation in the ridge has been removed as also this ridge was covered with water. At 80 - 90 cm depth the salt has also been removed.

At 2S, in the furrow, the flooding did not change the salirity in the top soil. Salinity was already low here due to the preceding irrigations.

As result of this studies it can be said that in profiles where the drainage is impeded by abrupt texture changes from fine to coarse texture, salt accumulates in the fine textured layers. This occurs locally in the alluvial plain soils, but as there is much variation even over short distances, the over all effects are limited.

When leaching is not sufficient salt accumulates in the root zone of the profile, not only in Gumeisha, where $EC_{iw}$ = 2.2 mm hs.$cm^{-1}$, but also in Wadi Zabid,

TDA Farm, where $EC_{iw} = 0.72$ mmohs. $cm^{-1}$.
Flooding removes the salts from the root zone as is shown in 2 profiles at Gumeisha.

More detailed analysis of these data are possible in a simulation study on salt and water movement in soils.

## 2.9 Regional distribution of water quality and soil salinity

In the foregoing the chemistry of the groundwater and of the soil salinity is discussed. Another very important question however is in which areas soils are affected by salinity. To get some insight in this matter the origin of the soil salinity should be understood. The soils in the Tihama are wadi and wind deposits. The wadi deposits are freshwater sediments and have a non saline origin. The soil salinity is a result from irrigation with high-salinity-water. The question where to find salt-affected-soils is also directly linked to the regional distribution of the groundwater quality. The wadi water used in the spate irrigation system contains very little salt (EC less than 0.70 mmhs $cm^{-1}$) and no salinity problems occur in these areas. Originally, lands at the lower (western) end of the wadis were under spate irrigation. Increasing skill in building diversion structures and in handling wadi floods opened the possibilities of using the water more upstream and nowadays the spate irrigated lands are concentrated in the eastern part of the wadis. In the western areas the old spate lands receive only occasionally wadi water, once a year or less. Since about 10 years many pumps have been installed here to use groundwater for irrigation. Outside the spate irrigated areas agriculture depends on rainfall, where this is sufficient (in the eastern part of Tihama). Also in these areas pumps have been installed as rainfall is irregular and varies from year to year. In fig 2.22 this is given schematically for an imaginary wadi.

The groundwater is replenished with water infiltrating from the wadi, and it moves slowly westward to the sea. The aquifer consists of deposits containing salt, possibly marine sediments. Also underground rocksalt formations exist. In Salif this formation surfaces and the rock salt is mined. Moving through this aquifer the groundwater dissolves some salt. The general pattern of iso-conductivity lines for an imaginary wadi is given in fig 2.23. Close to the wadi, also close to the source of replenishment, the groundwater contains little salt. With increasing distance from the wadi the salt content increases. In the areas which depend completely on pumpwell irrigations the groundwater quality is worse than in the areas where well irrigation is additional to spates or rainfall. Maps of isoconductivity lines in Wadi Maur, Wadi Siham and Wadi Zabid are given in figs 2.24, 2.25 and 2.26. They have been derived from data in other r ports (see references) but are given here for the sake of completeness.

As outlined in section 1 the easternpart of the Tihama consists of alluvial fans with silty loam soils. The alluvial plain at the lower (western) end of the wadis have sandy loam to loamy sand soils. This division in soil types combined with the general pattern of groundwater salinity gives the following simplified picture.

very high salinity water- sandy loam to loamy sand soils.

medium to high salinity water- silty loam soils

As described in section 2.4 low salinity of Tihama groundwater is linked to low values for SAR and adj. SAR. In general water with EC less than 1.5 mmhs $cm^{-1}$ have adj. SAR less than 10. With regards to the soilpermeability hazard, related to high adj. SAR values, the following balance exists:

- water with high adj. SAR value applied to light textured soil:
  very low probability of incidence of impermeability problems because of the light soil texture.
- water with low adj. SAR value applied to heavier textured soil:
  ~~textured soil:~~
  very low probability of incidence of impermeability problems because of the good water quality.

In general impermeability problems are not likely to occur in the Tihama. There may however be spots where the above mentioned balance not holds and silty soils are irrigated with water with high adj. SAR.

Apart from this, hazards of soil salinization exist. These can be kept in hand with good watermanagement i.e. adequate leaching, which is not hampered by soil permeability.

From a number of farmers fields soil samples have been taken and analyzed on total salt content. These fields are demonstration- fields from the projects extension section. They are located around the extension centres in LaWia, Zaidiya, Zohra, Gumeisha and Bajil. Their location is given on the maps from fig 2.24, 2.25 as far as possible. Analysis data are presented in annex I, table I.1. Interpretation however should be done with much reservation as much variation in soil salinity exists, even in one field.

Soil salinity is high in the LaWia area, particularly in LaWia, Assola and Braihmi. Irrigation water here is extremely-high-salinity-water (EC more than 5 mmhs. $cm^{-1}$), see annex I table I.3. Groundwater salinity in Wadi MaWr and Wadi Siham is higher than in other wadis. Soil salinity is high in Murwagh, Zohra and Mawr. Irrigation water in this area has EC 2 to 4 mmhs. $cm^{-1}$. The fields around Gumeisha (lower end Wadi Siham) show also high soil salinity, EC irrigation water here is 2 to 4 mmhs. $cm^{-1}$. The other fields, around Bajil and around Zaidiya, Dhahi and Quravis have low soil salinity.

## 2.10 Management Practices and Crop Selection

In section 2.2.1 the necessity of leaching is explained when irrigating with water containing soluble salts. The leaching requirement depends not only on the water quality but also on the salt tolerance of the crops under cultivation. In table 2.10 the leaching requirement is given for a number of crops grown in the Tihama. This table has been derived from the crop-tolerance-table (table 2.2) and formula (1) (section 2.2.1). These figures are only approximate, as also the EC values of the irrigation-water are averages for the mentioned area.

Existing irrigation practices are of the basin-irrigation type. In the wadi-irrigated areas the fields are surrounded with dikes. When there is a flood a big quantity of water has to be held on the field as the wadi spates are irregular. Farmers are so familiar with this that the method used with pumpwells is basically an imitation of the spate irrigation. The discharge of a pump is less than a wadiflood but more frequent irrigations are possible. Much smaller basins surrounded by lower ridges are sufficient.

## 2.11 Leaching Requirements for various crops and water qualities in the Tihama (10% yield decrease allowed)

| area | Law ia | W.Mawr | W.Siham | W. Surdud, W. Rima, W.Zabid |
|---|---|---|---|---|
| EC iw (mmhs. $cm^{-1}$) | 5 | 3-4 | 2-3 | 1-2 |
| crop: | | | | |
| very salty tolerant crops: | | | | |
| cotton, | | | | |
| sorghum, | 20% | 10-20% | 10% | 5% |

| area | Lawia | W. Mawr | W.Siham | W. Surdud, W.Rima, W.Zabid |
|---|---|---|---|---|
| millet, sesame, date palm | 20% | 10-20% | 10% | 5% |
| salt tolerant crops: groundnut, tomato, cucumber, cantaloupe, squash, watermelon, sudan grass, alfa alfa | 40% | 20-30% | 10-20% | 5-15% |
| salt sensitive crops: corn, citrus, mango, sweet - potato, pepper, broad beans | | 40-50% | 20-30% | 10-20% |
| very salty sensitive crops: onions, beans | | | | 20-30% |

-: beyond economic limit

The amount of water applied with each irrigation varies enormously. Also the distribution over the field is very uneven. The lower parts of the field are getting much more water than the higher spots. In general an irrigation is finished when the basin is filled, regardless of the evapotranspirative demand of the crop. Without going into details it can be said that this irrigation method results in big field losses. Especially in the beginning of the growing season when plants are small much water moves downward leaching excess salts. The traditional way of irrigation is such that a certain amount of leaching is obtained as part of the system. Improvements in this system should be aimed in the first place at a better water distribution over the field.

This can be achieved in the first place with good levelling of the lands. Basins can be made small but this affects the possibilities of mechanization. Furrow irrigation provides a good water distribution but farmers and land labourers are so accustomed to basin irrigation that they consider the furrows as small basins that need filling to the top. In Gumeisha farm the standard lenght of the furrows is 80m., and the irrigation practices officer showed on a trial-plot that 160m long furrows are also possible. In these furrows the water level never gets high. This is also not necessary as sufficient water infiltrates the soil during the time the stream needs to reach the furrow end. But the labourers, seeing that that the water level in the furrow remains low, start blocking the furrows and cutting the ridges, in order to stop the water from flowing to the end. In this way the irrigation system evaluates into a kind of furrows-in-basins system. But as almost always one furrow is deeper than the other the former one gets far more water. Overhead irrigation systems give a good water distribution on badly levelled fields. However, the technical knowhow required for operation and maintenance and the high investment-and operation-costs make this system less suitable for use in the Yemen. Also the use of irrigation water, containing an appreciable amount of salts may result in burn or death of the plant leaves.
The amount of water applied with each irrigation can be measured rather accurately and excesses giving the necessary leaching have to be applied explicitely. In general when more efficient methods of water application are introduced the necessary leaching requirements should not be neglected.

Suitability of area for certain crops depends on a number of factors : soil condition, irrigation-water-salinity, wind and wind erosion. As outlined in sections 1.2, 1.7 and 2.9 there is quite some variation in these factors for

for different places in the Tihama as example of a sequence across the Tihama from west to east, may serve the lands of the large-land-owner Boushari who lives in Mrawah. These lands are situated in the Wadi Siham area. Their location is shown on map 2.25. Hereunder a short description of each farm is given with the recommended crops.

No. 1: Al Bousharia, located 2 km west of Mrawah, north of Hodeidah-Sana'a road, surrounded by sanddune area.
soil texture: loamy sand
Irrigation water: EC= 2.88 mmhs. $cm^{-1}$; pH=7.3
Suitable for cotton, sorghum and datepalm

No. 2: Deir al Hoba. located 2-3 km. east of Mrawah, southeast of mainroad, surrounded by sanddune area.
soil texture: loam
Irrigation water: EC= 1.26 mmhs $cm^{-1}$; pH=7.5
suitable for sorghum, cotton, maize, tomato.
less suitable for vegetables or onions
not suitable for fruits

No. 3: Waqir, located on lowest terrace, next to the wadibed just behind Jebel Waqir
soil texture: loamy sand
Irrigation water: EC=1.15 mmhs. $cm^{-1}$; pH=7.3
As incidental high floods may cause mechanical damage the crops on the field, bananas or other fruit trees should not be recommended. Suitable for vegetables, tomato, melon, sweet pepper, onion

No. 4: Wadi Siham, located on terrace, ± 1.5 km from wadibed south of no. 3 surrounded by flat terraced land occasionally receiving spates.
soil texture: sandy loam
irrigation water: EC=1.93 mmhs $cm^{-1}$;pH=7.3
suitable for cotton, sorghum, tomato, melon
less suitable for maize, onion, sweetpepper

No. 5 Khaza'a, located 3 km east of Khalifah, surrounded by flat terraced land occasionally receiving spate's
soil texture: loam
irrigation water: EC= 1.32 mmhs $cm^{-1}$; pH=7.3
Suitable for sorghum, cotton, maize, tomato
less suitable for vegetables, onion

No. 6 Mihfaya, **northbank** of Wadi Siham near Jebel Falafilah surrounded by wadi terraces. Due to high location flooding is not likely to occur.
soil texture: silty loam
Irrigation water: EC= 1.15 mmhs $cm^{-1}$; pH=7.6
Suitable for fruits ( banana, mango) and vegetables.

## CONCLUSIONS AND RECOMMENDATIONS

The agricultural land in the Tihama can be divided into 2 main landscapes: the alluvial fan with silty loam soils and the alluvial plain with loamy sand to sandy loam soils. Irrigation on the alluvial fan is by spate irrigation, or rainfed with additional pumpwell irrigation. In the alluvial plain mainly pumpwell irrigation occurs. The groundwater which have high salinity and SAR are mainly used on light textured soils and permeability hazard is low. To avoid salinity hazard the necessary leaching roquirements should be observed. Irrigation practice at present is basin irrigation with much over irrigation giving a certain amount of leaching, although not well controlled. Improvements should be aimed at a better waterdistribution over the field and at reducing field losses, though not neglecting the leaching requirements. The leaching water percolates downwards and will eventually reach the groundwater. In order to cheque the influence on the groundwater salinity of this highly concentrated percolating water, the EC of a number of wells should be chequed at regular intervals e.g. monthly. Regular cheque of the Gumeisha wells did not show a a significant increase in salinity yet. Investigations in layered soils show that soil salinity occurs in fine texture layers, where these overlay coarser textured layers. This is due to an impeded drainage at these texture transitions. It is found locally in the alluvial plain soils, but being torrent deposits, there is much variation between soil profiles even at short distances and the overall effects are limited.

It is shown that if soil salinity has accumulated too much the salts can be leached from the rootzone by flooding the land.

From the main wadi areas, Wadi Mawr, Wadi Surdud, Wadi Siham, Wadi Rima and Wadi Zabid, soil maps or irrigation suitability maps have been prepared or are in preparation. Each of this map is prepared by a different engineering contractor, to a different scale and with a different legend.

It is recommended that these various soil maps are reworked to a uniform legend and that a soil survey of all the Tihama is conducted. The land types described in this report may serve as high mapping and classification units.

When the soil laboratory in Taiz is equipped to analyze microelements, soils and irrigation water should be chequed not only on micronutrient deficiencies, but also on boron toxicity.

At present other factors are more limiting to agricultural production than soil salinity and alkalinity.

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Annex I

This annex contains the following tables:

Table I.1 Data on soil salinity in farmers fields (sampled June 1976)

| Extension Centre | Location | Depth (cm) | Texture | $EC_{1;1}$ mmhs $cm^{-1}$ | pH | Location | Depth (cm) | $EC_{1:1}$ mmhs $cm^{-1}$ | pH |
|---|---|---|---|---|---|---|---|---|---|
| Lawria | Al Morra | 0-30 | SiCl | 0.65 | 8.3 | Al Lawria farm of Abdulla Obeid | 0-20 | 1.10 | 9.2 |
| | | -60 | SiC | 0.31 | 8.4 | | -40 | 1.13 | 9.1 |
| | | -90 | SiC | 1.08 | 8.2 | | -60 | 0.85 | 9.2 |
| | | | | | | | -80 | 2.00 | 9.3 |
| | | | | | | | -100 | 2.10 | [illegible].7 |
| | Al Lawria | 0-30 | SiL | 3.60 | 8.2 | | | | |
| | | -60 | L | 2.60 | 8.2 | | | | |
| | | -90 | L/SL | 1.14 | 8.4 | | | | |
| | Al Abbassi | 0-30 | L | 0.70 | 8.5 | | | | |
| | | -60 | SL | 0.46 | 8.8 | | | | |
| | | -90 | SL | 0.33 | 8.9 | | | | |
| | Assola | -30 | L | 2.05 | 8.5 | | | | |
| | | -60 | L | 1.06 | 8.7 | | | | |
| | | -90 | L/SL | 1.34 | 8.7 | | | | |
| | Al Draihmi | 0-30 | SL | 1.50 | 8.7 | | | | |
| | | -60 | SL | 2.10 | 8.6 | | | | |
| | | -90 | SL | 3.50 | 8.4 | | | | |

Contd.

| Extension Centre | Location | Sample Depth (cm) | Texture | $EC_{1:1}$ mmhs $cm^{-1}$ | pH | Location | Sample Depth (cm) | Texture | $EC_{1:1}$ mmhs $cm^{-1}$ | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| Zaidiya | Dhahi 1 km E | 0-30 | L | 0.53 | 8.7 | Zai-diya 12 kms E. of village | 0-30 | L | 0.46 | 8.6 |
| | | -60 | SCl | 0.57 | 8.7 | | -60 | SiL | 0.27 | 8.8 |
| | | -90 | L | 0.67 | 8.9 | | -90 | SiL | 0.32 | 8.7 |
| | Zaidi-ya ½ kms N. of village | 0-30 | SL | 0.52 | 9.2 | Qunawis 2 kms S. of village | 0-30 | SL | 0.45 | 9.0 |
| | | -60 | SL | 0.46 | 9.2 | | -60 | SL | 0.38 | 9.1 |
| | | -90 | SL/SCL | 0.55 | 9.2 | | -90 | SL | 0.31 | 8.4 |
| | Zaidi-ya 2 kms E. of village | 0-30 | SCL | 0.54 | 9.0 | | | | | |
| | | -60 | SL | 0.60 | 8.8 | | | | | |
| | | -90 | L | 1.24 | 8.9 | | | | | |
| Zohra (Wadi Mawr) | Murwagh | 0-30 | SL | 1.44 | 8.4 | Deiral Sheikh | 0-30 | SL | 0.25 | 9.1 |
| | | -60 | L/SL | 1.60 | 8.3 | | -60 | SL | 0.34 | 9.2 |
| | | -90 | SL | 0.84 | 8.5 | | -90 | SL | 1.50 | 9.3 |
| | Zohra 1 km.W of vil-lage | 0-30 | SL | 2.80 | 8.6 | AL Jubai-riya | 0-30 | SiL/SiCL | 0.32 | 8.5 |
| | | -60 | SiL | 2.55 | 8.5 | | -60 | L | 1.57 | 8.4 |
| | | -90 | L | 1.80 | 8.7 | | -90 | SiL | 0.85 | 8.5 |
| | Mawr ½ km S. of vil-lage | 0-30 | L | 1.00 | 8.6 | | | | | |
| | | -60 | CL | 0.38 | 8.9 | | | | | |
| | | -90 | L | 0.28 | 9.0 | | | | | |

| Extension Centre | Location | Sample Depth | Texture | EC | pH | Location | Sample Depth | Texture | EC | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| Gumeisha | Gumeisha 1 km East | 0-30 | C | 1.85 | 8.6 | km 17 on Taiz road | 0-30 | SL | 1.16 | 8.8 |
| | | -60 | SCL | 0.63 | 8.8 | | -60 | SL | 0.58 | 9.2 |
| | | -90 | SL | 0.63 | 9.0 | | -90 | LS/ SL | 0.50 | 9.3 |
| | Dair AL Zawria | 0-30 | CL | 1.46 | 9.1 | Alzaafaran | 0-30 | SL | 1.85 | 8.8 |
| | | -60 | L | 1.80 | 9.0 | | -60 | SL | 1.50 | 8.7 |
| | | -90 | L | 1.50 | 9.0 | | -90 | SL | 4.20 | 8.2 |
| Bajil | Bajil | 0-30 | L | 0.34 | 8.6 | Bajil 2 kms E | 0-30 | L | 0.88 | 8.4 |
| | | -60 | SL | 0.30 | 8.7 | | -60 | L | 0.74 | 8.5 |
| | | | | | | | -80 | L | 0.76 | 8.5 |
| | Bajil 1½ kms N | 0-30 | SiL | 0.66 | 8.2 | | | | | |
| | | -60 | SL | 0.29 | 8.4 | Bajil 1 Km E | 0-30 | L | 0.55 | 8.5 |
| | | -90 | SCL | 0.24 | 8.4 | | -60 | CL | 0.55 | 8.4 |
| | | | | | | | -80 | CL | 0.62 | 8.4 |

TABLE I-2

| No. | Replication | Treatment | Depth (cm) | % sand | %silt | % clay | USDA texture | pH | $EC_c$ mmhs $cm^{-1}$ | $CACO_3$% | $H_2O$ sol cat. (meg.$L^{-1}$) Ca | Mg | K | Na | EXCH Na megp 100 gr soil |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0-20 | 27 | 57 | 16 | SiL | 8.8 | 3.50 | 5.8 | 3.2 | nil | 0.22 | 32.5 | 7.3 |
| 2 | | | -40 | 25 | 55 | 20 | SiL | 8.9 | 2.25 | 5.2 | 1.0 | 0.4 | 0.12 | 22.5 | 7.0 |
| 3 | | | -60 | 49 | 29 | 22 | L | 8.7 | 2.40 | 4.0 | 3.6 | 0.6 | 0.13 | 22.0 | 5.7 |
| 4 | | | -80 | 85 | 7 | 8 | LS | 8.9 | 1.20 | 1.0 | 1.4 | nil | 0.18 | 12.5 | 4.5 |
| 5 | | | -100 | 75 | 13 | 12 | SiL | 8.7 | 1.35 | 1.3 | 2.4 | 0.8 | 0.34 | 10.0 | 3.6 |
| 6 | | | -120 | 67 | 19 | 14 | SiL | 8.7 | 1.16 | 1.0 | 2.4 | 1.0 | 0.34 | 9.0 | 3.3 |
| 7 | 1 | 3 | 0-20 | 29 | 55 | 16 | SiL | 8.9 | 2.80 | 6.0 | 1.8 | 1.0 | 0.19 | 26.5 | 2.8 |
| 8 | | | -40 | 25 | 57 | 18 | SiL | 9.0 | 1.72 | 6.6 | 0.8 | nil | 0.06 | 15.5 | 7.2 |
| 9 | | | -60 | 25 | 45 | 30 | CL | 8.5 | 3.80 | 6.0 | 14.2 | 2.0 | 0.12 | 35.0 | 5.4 |
| 10 | | | -80 | 84 | 4 | 12 | LS | 8.2 | 1.46 | 1.3 | 2.6 | 0.4 | 0.27 | 11.0 | 3.3 |
| 11 | | | -100 | 76 | 12 | 12 | SL | 8.7 | 1.32 | 1.3 | 3.8 | nil | 0.27 | 14.0 | 3.9 |
| 12 | | | -120 | 72 | 12 | 16 | SiL | 8.5 | 1.80 | 1.8 | 5.8 | 1.4 | 0.43 | 12.5 | 4.2 |
| 13 | 1 | 5 | 0-20 | 40 | 44 | 16 | L | 9.0 | 1.55 | 5.1 | 0.8 | 0.2 | 0.16 | 13.5 | 6.6 |
| 14 | | | -40 | 20 | 60 | 20 | SiL | 9.0 | 1.26 | 6.8 | 1.0 | 0.4 | 0.09 | 16.5 | 6.6 |
| 15 | | | -60 | 74 | 14 | 12 | SiL | 9.2 | 0.96 | 2.2 | 0.6 | 0.8 | 0.07 | 12.0 | 4.1 |
| 16 | | | -80 | 84 | 6 | 10 | LS | 9.3 | 2.59 | 1.3 | nil | nil | 0.12 | 11.0 | 2.8 |
| 17 | | | -100 | 76 | 10 | 14 | SL | 9.2 | 0.89 | 1.5 | 0.8 | nil | 0.25 | 11.5 | 2.8 |
| 18 | | | -120 | 70 | 14 | 16 | SL | 8.8 | 1.10 | 1.7 | 2.8 | nil | 0.38 | 13.5 | 2.0 |
| 19 | 2 | 1 | 0-20 | 37 | 50 | 18 | SiL | 9.0 | 2.10 | 6.5 | 1.0 | 0.4 | 0.13 | 26.5 | 6.5 |
| 20 | | | -40 | 14 | 68 | 18 | SiL | 8.8 | 2.80 | 7.0 | 2.6 | 1.0 | 0.10 | 33.5 | 6.0 |
| 21 | | | -60 | 27 | 64 | 14 | SiL | 8.8 | 3.25 | 5.9 | 6.2 | 1.0 | 0.13 | 36.0 | 5.4 |
| 22 | | | -80 | 18 | 74 | 8 | Si | 8.9 | 2.43 | 5.1 | 4.2 | 4.6 | 0.15 | 28.0 | 4.1 |

Contd....... Table I.2

| No. | Replication | Treatment | Depth (cm) | % sand | % silt | %clay | USDA texture | pH | ECe mmhs cm$^{-1}$ | $CaCO_3$% | Water Sol Cat. meq. L$^{-1}$ Ca | Mg | K | Na | EXCH Na meq/100 gram |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 2 | 1 | 80-100 | 40 | 52 | 8 | SiL | 8.4 | 2.29 | 4.5 | 9.3 | nil | 0.25 | 20.0 | 4.8 |
| 24 | | | -120 | 38 | 54 | 8 | SiL | 8.4 | 2.58 | 2.9 | 10.0 | 6.8 | 0.24 | 18.5 | 1.9 |
| 25 | 2 | 3 | 0-20 | 26 | 58 | 16 | SiL | 8.8 | 3.35 | 6.5 | 2.6 | 0.8 | 0.18 | 35.5 | |
| 26 | | | -40 | 19 | 67 | 14 | Si | 8.8 | 3.60 | 6.7 | 3.2 | 1.0 | 0.10 | 41.5 | |
| 27 | | | -60 | 13 | 69 | 18 | SiL | 8.7 | 3.60 | 6.5 | 5.0 | 0.8 | 0.10 | 40.5 | |
| 28 | | | -80 | 43 | 47 | 10 | L | 8.7 | 2.55 | 1.5 | 5.6 | nil | 0.13 | 28.0 | |
| 29 | | | -100 | 85 | 7 | 8 | SL | 8.7 | 1.30 | 1.0 | 2.8 | 0.8 | 0.20 | 21.0 | |
| 30 | | | -120 | 85 | 7 | 8 | SL | 8.7 | 0.95 | 1.4 | 2.2 | 0.6 | 0.29 | 14.0 | |
| 31 | 2 | 5 | 0-20 | 21 | 65 | 14 | SiL | 9.0 | 2.10 | 7.0 | 0.2 | 2.0 | 0.12 | 27.5 | 6.7 |
| 32 | | | -40 | 19 | 63 | 18 | SiL | 8.9 | 2.80 | 6.8 | 1.6 | nil | 0.15 | 46.5 | 5.5 |
| 33 | | | -60 | 19 | 65 | 16 | SiL | 8.7 | 4.20 | 6.4 | 7.0 | 0.6 | 0.12 | 43.0 | 5.9 |
| 34 | | | -80 | 39 | 51 | 10 | SiL | 8.8 | 2.35 | 5.2 | 3.4 | nil | 0.13 | 28.0 | 4.0 |
| 35 | | | -100 | 25 | 59 | 8 | SiL | 8.4 | 2.95 | 6.3 | 11.4 | nil | 0.18 | 29.5 | 2.7 |
| 36 | | | -120 | 77 | 13 | 8 | LS | 8.7 | 1.45 | 1.8 | 4.0 | 1.8 | 0.21 | 20.0 | 0.9 |
| 37 | 3 | 1 | 0-20 | 25 | 59 | 16 | SiL | 8.5 | 5.50 | 6.2 | 5.0 | 2.0 | 0.30 | 46.5 | 5.9 |
| 38 | | | -40 | 19 | 63 | 18 | SiL | 8.8 | 3.70 | 7.1 | 3.0 | 0.8 | 0.14 | 37.0 | 6.7 |
| 39 | | | -60 | 19 | 65 | 16 | SiL | 8.6 | 4.80 | 6.2 | 11.2 | nil | 0.13 | 42.0 | 6.6 |
| 40 | | | -80 | 39 | 51 | 10 | SiL | 8.5 | 2.70 | 5.2 | 5.2 | nil | 0.13 | 24.5 | 3.8 |
| 41 | | | -100 | 33 | 59 | 8 | SiL | 8.3 | 3.10 | 5.6 | 11.6 | 1.2 | 0.27 | 24.0 | 2.4 |
| 42 | | | -120 | 82 | 10 | 8 | LS | 8.4 | 2.15 | 1.5 | 7.0 | 0.1 | 0.29 | 15.0 | 0.7 |
| 43 | 3 | 3 | 0-20 | 26 | 58 | 16 | SiL | 9.0 | 1.75 | 6.2 | 0.4 | nil | 0.13 | 20.5 | |
| 44 | | | -40 | 20 | 62 | 18 | SiL | 8.8 | 2.00 | 6.6 | 1.6 | nil | 0.15 | 32.5 | |
| [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | SiL | 8.6 | 4.00 | 6.4 | 6.6 | 0.2 | 0.14 | [illegible] | |

Contd.............. Table I.2

| NO. | Repli- cation | Treat- ment | Depth (cm) | % sand | %silt | %clay | USDA tex- ture | pH | ECe mmhs $cm^{-1}$ | $CaCO_3$% | Water Sol. Cat. meq $L^{-1}$ Ca | Mg | K | Na | EXCH Na meq/ 100 gr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | | | -80 | 24 | 62 | 14 | SiL | 8.5 | 3.20 | 6.1 | 7.2 | 0.6 | 0.15 | 25.0 | |
| 47 | | | -100 | 14 | 74 | 12 | SiL | 8.4 | 2.80 | 6.3 | 10.4 | 0.6 | 0.18 | 20.5 | |
| 48 | 3 | 3 | 100-120 | 48 | 36 | 16 | L | 8.3 | 3.00 | 4.1 | 13.6 | 2.4 | 0.22 | 15.5 | |
| 49 | 3 | 5 | --20 | 32 | 52 | 16 | SiL | 9.0 | 1.75 | 6.1 | 1.4 | nil | 0.16 | 18.0 | 5.2 |
| 50 | | | -40 | 28 | 50 | 22 | SiL | 8.6 | 3.50 | 6.5 | 3.2 | 2.8 | 0.15 | 37.5 | 4.9 |
| 51 | | | -60 | 28 | 56 | 16 | SiL | 8.4 | 4.15 | 5.3 | 14.6 | 1.2 | 0.23 | 32.0 | 3.5 |
| 52 | | | -80 | 36 | 52 | 12 | SiL | 8.3 | 2.25 | 5.5 | 7.2 | nil | 0.19 | 15.5 | 2.1 |
| 53 | | | -100 | 36 | 54 | 10 | SiL | 8.4 | 1.74 | 4.1 | 7.0 | nil | 0.21 | 11.5 | 1.6 |
| 54 | | | -120 | 20 | 64 | 16 | SiL | 8.3 | 2.34 | 4.3 | 10.8 | 0.8 | 0.22 | 10.5 | 1.7 |
| 55 | 4 | 1 | 0-20 | 26 | 58 | 16 | SiL | 9.2 | 0.98 | 5.4 | 0.6 | nil | 0.09 | 12.0 | 5.1 |
| 56 | | | -40 | 24 | 52 | 24 | SiL | 8.6 | 4.90 | 6.2 | 10.2 | nil | 0.14 | 39.0 | 6.1 |
| 57 | | | -60 | 16 | 66 | 18 | SiL | 8.4 | 4.55 | 5.8 | 12.4 | 2.6 | 0.15 | 36.5 | 5.1 |
| 58 | | | -80 | 26 | 61 | 13 | SiL | 8.4 | 3.23 | 4.9 | 7.6 | 0.8 | 0.13 | 22.5 | 4.3 |
| 59 | | | -100 | 30 | 69 | 11 | SiL | 8.3 | 2.28 | 4.3 | 5.8 | 10.0 | 0.16 | 15.0 | 1.7 |
| 60 | | | -120 | 16 | 69 | 15 | SiL | 8.4 | 1.51 | 6.0 | 16.4 | nil | 0.15 | 12.5 | 3.5 |
| 61 | 4 | 3 | 0-20 | 24 | 61 | 15 | SiL | 9.2 | 1.20 | 5.4 | 1.2 | nil | 0.18 | 15.0 | |
| 62 | | | -40 | 42 | 39 | 19 | L | 8.7 | 2.90 | 4.7 | 5.2 | nil | 0.27 | 29.0 | |
| 63 | | | -60 | 56 | 35 | 9 | SL | 8.5 | 2.60 | 7.0 | 6.0 | 1.0 | 0.34 | 21.0 | |
| 64 | | | -80 | 64 | 27 | 9 | SL | 8.6 | 1.70 | 6.3 | 5.6 | nil | 0.27 | 14.5 | |
| 65 | | | -100 | 56 | 35 | 9 | SL | 8.4 | 1.50 | 6.5 | 5.0 | 3.0 | 0.25 | 10.0 | |
| 66 | | | -120 | 42 | 49 | 9 | L | 8.3 | 3.20 | 7.0 | 15.8 | 2.6 | 0.29 | 13.0 | |
| 67 | 4 | 5 | 0-20 | 26 | 55 | 19 | SiL | 9.2 | 0.87 | 9.0 | nil | 1.8 | 0.14 | 15.0 | 4.7 |
| 68 | | | -40 | 27 | 69 | 9 | SiL | 8.7 | 3.20 | 8.8 | 6.2 | nil | 0.15 | 30.0 | 4.9 |
| 69 | | | -60 | 18 | 73 | 9 | Si | 8.5 | 3.70 | 8.5 | 10.2 | 5.8 | 0.19 | 27.5 | 3.8 |

Contd............ Table I.2

| NO. | REPLI-CATION | TREAT-MENT | DEPTH (cm) | %sand | %silt | %clay | USDA tex-ture | pH | $EC_e$ mmhs $cm^{-1}$ | $CaCO_3$ % | Water Sol. Cat. meq. $L^{-1}$ Ca | Mg | K | Na | EXCH Na meq/ 100 gr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | | | -80 | 20 | 71 | 9 | Si | 8.4 | 2.45 | 7.5 | 6.6 | 2.8 | 0.18 | 20.0 | 2.2. |
| 71 | | | -100 | 24 | 67 | 9 | SiL | 8.5 | 1.44 | 7.8 | 4.0 | 1.6 | 0.18 | 14.0 | 1.6. |
| 72 | | | -120 | 22 | 69 | 9 | SiL | 8.8 | 0.90 | 8.0 | 3.6 | nil | 0.15 | 11.0 | 5.7 |

Table I.3 Irrigation water analysis results

| Location | pH | E C mmhs $cm^{-1}$ | Ca | Mg | K | Na | $HCO_3$ | $CO_3$ | Cl | $SO_4$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (meq-$L^{-1}$) | | | | | | | | |
| 1. LaW ia | 7.7 | 4.20 | 6.6 | 8.6 | 0.11 | 27.5 | 7.7 | nil | 24.4 | 13.3 | 1.53 |
| 2. LaW ia | 7.6 | 3.25 | 7.4 | 6.6 | 0.10 | 21.0 | 7.9 | nil | 19.0 | 6.6 | 1.32 |
| 3. Al Gerubah | 7.4 | 0.80 | 4.2 | 0.8 | 0.12 | 3.0 | 5.8 | nil | 2.0 | 0.4 | 0.21 |
| 4. Assulah (Law ia) | 7.3 | 4.40 | 8.0 | 8.4 | 0.11 | 33.5 | 4.3 | nil | 39.0 | 7.3 | 1.43 |
| 5. Maghalisah (Law ia) | 7.7 | 5.50 | 5.8 | 9.0 | 0.11 | 39.0 | 9.6 | nil | 36.0 | 7.5 | 1.65 |
| 6. Maghalisah (LaW ia) | 7.6 | 4.10 | 6.6 | 7.8 | 0.12 | 37.0 | 5.2 | nil | 31.0 | 13.4 | 1.93 |
| 7. Algarbah (Law ia) | 7.4 | 7.70 | 13.2 | 16.4 | 0.17 | 51.5 | 7.0 | nil | 62.5 | 10.8 | 1.57 |
| 8. Algarbah (Law ia) | 7.5 | 8.50 | 7.8 | 17.0 | 0.15 | 90.0 | 10.2 | nil | 68.8 | 12.1 | 2.07 |
| 9. Wadi Makhel (LaW ia) | 7.6 | 8.30 | 8.8 | 19.0 | 0.07 | 60.0 | 5.7 | nil | 65.5 | 16.6 | 1.57 |
| 10. Taif | 8.0 | 4.30 | 6.6 | 5.0 | 0.24 | 42.5 | [illegible] | nil | 30.0 | 7.0 | 0.57 |
| 11. Al Mangoom (Law ia) | 7.6 | 3.75 | 7.4 | 5.2 | 0.17 | 28.5 | 28.5 | nil | 23.2 | 6.1 | 1.04 |
| 12. Al Draihmi | 7.4 | 8.50 | 15.4 | 16.8 | 0.22 | 55.0 | 55.0 | nil | 62.0 | 17.9 | 1.71 |
| 13. Al Garabeh No. 1 | 7.7 | 0.77 | 5.0 | 4.2 | 0.06 | 2.8 | 5.2 | nil | 7.2 | 1.4 | 0.06 |
| 14. Al Garabeh No. 2 | 7.7 | 0.77 | 5.2 | 4.0 | 0.05 | 3.3 | 5.0 | nil | 7.0 | 1.4 | 0.07 |
| 15. Mishrafah | 7.4 | 0.56 | 3.4 | 1.4 | 0.11 | 2.6 | 3.4 | nil | 3.7 | 0.8 | 0.21 |
| 16. Wadi Nachlah | 7.6 | 0.65 | 5.4 | 5.2 | 0.09 | 1.7 | 5.6 | nil | 5.8 | 1.2 | 0.06 |
| 17. North Gumeisha | 8.1 | 3.70 | 8.2 | 5.0 | 0.14 | 29.5 | 5.5 | nil | 21.0 | 12.6 | 3.71 |
| 18. South Gumeisha No. 2 | 7.7 | 2.26 | 2.4 | 2.6 | 0.06 | 21.5 | 7.0 | nil | 12.0 | 6.3 | 2.27 |

Contd......... Table I.3

| LOCATION | pH | E C mmhs $cm^{-1}$ | Ca | Mg | K | Na | $HCO_3$ | $CO_3$ | Cl | $SO_4$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | meq. $L^{-1}$ | | | | |
| 19. South Gumeisha No. 4 | 7.8 | 2.28 | 3.0 | 2.0 | 0.13 | 22.5 | 6.8 | nil | 8.8 | 9.2 | 2.25 |
| 20. South Gumeisha No. 5 | 7.7 | 2.05 | 2.2 | 2.8 | 0.07 | 18.5 | 18.3 | nil | 7.4 | 5.8 | 2.36 |
| 21. South Gumeisha No. 6 | 7.6 | 2.05 | 2.2 | 0.6 | 0.07 | 22.5 | 8.8 | nil | 6.4 | 6.4 | 2.04 |
| 22. South Gumeisha No. 7 | 7.8 | 2.06 | 1.8 | 1.6 | 0.09 | 20.0 | 8.3 | nil | 6.4 | 5.4 | 1.92 |
| 23. South Gumeisha No. 8 | 7.7 | 1.93 | 2.8 | 0.2 | 0.07 | 18.5 | 8.3 | nil | 5.8 | 5.7 | 2.11 |
| 24. South Gumeisha No. 9 | 7.5 | 1.94 | 2.0 | 2.8 | 0.07 | 18.5 | 8.3 | nil | 6.[illegible] | 5.5 | 2.04 |

Contd...... Table I.3

| NO. | LOCATION | Description of samples |
|---|---|---|
| 1 | Law. ia | pumpwell, farm of Sheikh Yahia Al Zeghir |
| 2 | Law ia | pumpwell, farm of Aldulla Obeid |
| 3 | Al Gerubah | statefarm, Wadi Rima, pumpwell |
| 4 | Assulah | pumpwell, farm of Waheeb Wahbah |
| 5 | Maghalisah | village well |
| 6 | Maghalisah | pumpwell, farm of Saleh Wahban |
| 7 | Al Garbah | pumpwell, farm of Ahmed Abdulla |
| 8 | Al Garbah | pumpwell, farm of Hassan Kalfoot |
| 9 | Wadi Makhel | pumpwell, farm of Youssef Obeid |
| 10 | Taif | drawwell near the coast |
| 11 | Al Mangoom | village well |
| 12 | Al Draihmi | pumpwell, farm of Taha Magbool |
| 13 | Al Garabeh | statefarm, Wadi Surdud, pump no. 1 |
| 14 | Al Garabeh | statefarm, Wadi Surdud, pump no. 2 |
| 15 | Mishrafah | wadi water Wadi Rima |
| 16 | Wadi Nachlah | wadi water Bani Sari area |
| 17 | North Gumeisha | statefarm, pumpwell |
| 18-24 | South Gumeisha | statefarm, pumpwell no. 2, 4-9 |

Table I.4 tube 1-5 (Gumeisha)

| Sample depth | pH | $EC_{1:1}$ | $CaCO_3$% | % S | %Si | %C | texture | Location |
|---|---|---|---|---|---|---|---|---|
| 0-25 | 8.9 | 0.51 | 12.5 | 34 | 53 | 13 | Sil | tube 1 |
| -32 | 8.5 | 1.10 | 12.5 | 16 | 59 | 25 | Sil | " |
| -34 | 8.8 | 0.84 | 18.0 | 78 | 13 | 9 | SL | " |
| -42 | 8.4 | 1.75 | 11.5 | 8 | 59 | 33 | SiCl | " |
| -44 | 8.5 | 1.60 | 10.0 | 40 | 39 | 21 | L | " |
| -55 | 8.3 | 1.40 | 15.0 | 6 | 67 | 27 | SiCl | " |
| -60 | 8.4 | 0.90 | 7.0 | 32 | 53 | 15 | SiL | " |
| 74-77 | 8.8 | 0.62 | 7.5 | 78 | 14 | 8 | LS | " |
| 93-97 | 8.6 | 0.75 | 11.5 | 76 | 14 | 10 | SL | " |
| 0-20 | 8.8 | 0.98 | 11.5 | 30 | 68 | 12 | Sil | tube 2 |
| 30-40 | 8.4 | 2.50 | 13.0 | 12 | 66 | 22 | Sil | " |
| 40-44 | 8.1 | 3.70 | - | 25 | 55 | 20 | Sil | " |
| 44-58 | 8.3 | 2.70 | 12.5 | 12 | 78 | 10 | Si | " |
| -70 | 8.1 | 2.60 | - | 12 | 79 | 9 | Si | " |
| -100 | 8.6 | 0.97 | 11.5 | 78 | 14 | 8 | LS | " |
| 0-10 | 9.0 | 0.65 | 7.0 | 34 | 52 | 12 | SiL | tube 3 |
| 21-25 | 8.7 | 1.02 | 14.0 | 14 | 66 | 20 | SiL | " |
| -30 | 8.9 | 0.94 | 12.5 | 10 | 80 | 10 | Si/SiL | " |
| -41 | 8.1 | 3.60 | 12.5 | 8 | 70 | 22 | SiL | " |
| -52 | 8.3 | 3.00 | 11.0 | 20 | 64 | 16 | SiL | " |
| -70 | 7.9 | 2.60 | 12.5 | 4 | 90 | 6 | Si | " |
| -100 | 8.5 | 1.52 | 7.5 | 48 | 38 | 14 | SL | " |
| 0-27 | 9.0 | 0.72 | 11.0 | 78 | 12 | 10 | SL | tube 4 |
| -32 | 8.5 | 1.75 | 13.0 | 40 | 46 | 14 | L | " |
| -37/39 | 8.3 | 3.10 | 16.0 | 8 | 80 | 12 | Si | " |
| -75 | 8.6 | 1.40 | 11.5 | 11 | 39 | 50 | C | " |
| -88 | 8.5 | 1.37 | 7.0 | 76 | 14 | 10 | SL | " |
| -100 | 8.6 | 0.95 | 13.0 | 80 | 12 | 8 | LS | " |
| 0-30 | 9.1 | 0.97 | 12.5 | 78 | 12 | 10 | LS | tube 5 |
| -32 | 9.0 | 0.76 | 9.0 | 6 | 72 | 22 | SiL | " |
| -40 | 8.5 | 0.97 | 12.0 | 32 | 54 | 14 | SiL | " |
| -49 | 8.0 | 1.58 | 15.0 | 3 | 55 | 45 | SiC | " |
| -58 | 8.1 | 4.09 | 12.5 | 11 | 35 | 54 | C | " |
| -70 | 8.3 | 1.47 | 7.0 | 77 | 15 | 8 | SL | " |
| -90 | 8.2 | 1.90 | 8.0 | 69 | 17 | 14 | SL | " |
| -130 | 8.4 | 1.08 | 13.5 | 71 | 17 | 12 | SL | " |

Table I.5 tube 62 and 63 (Madaniyah)

**Tube 62**

| Sample depth | pH | $EC_{1:1}$ |
|---|---|---|
| 0-29 | 8.1 | 0.74 |
| -59 | 8.1 | 0.95 |
| -80 | 8.1 | 0.93 |
| -101 | 8.3 | 0.71 |
| -126 | 8.5 | 0.58 |
| -146 | 8.5 | 0.59 |
| -158 | 7.9 | 2.53 |
| -165 | 8.0 | 1.61 |
| -171 | 7.9 | 2.18 |
| -183 | 8.0 | 1.53 |
| -213 | 7.9 | 1.34 |
| -227 | 7.4 | 5.1 |
| -265 | 7.6 | 0.58 |
| -281 | 7.2 | 3.70 |
| -298 | 7.5 | 1.27 |
| -323 | 7.3 | 2.00 |

**Tube 63**

| Sample depth | pH | $EC_{1:1}$ |
|---|---|---|
| 0-13 | 7.5 | 1.48 |
| -23 | 7.6 | 0.89 |
| -48 | 7.3 | 1.45 |
| -64 | 7.3 | 1.27 |
| -75 | 7.6 | 0.575 |
| -93 | 7.2 | 1.63 |
| -105 | 7.4 | 0.91 |
| -115 | 7.1 | 1.88 |
| -138 | 7.8 | 0.41 |
| -150 | 7.6 | 1.34 |
| -158 | 7.6 | 1.55 |
| -181 | 7.8 | 1.44 |
| -205 | 7.8 | 1.12 |
| -224 | 8.0 | 0.66 |
| -241 | 7.4 | 3.13 |
| -277 | 7.3 | 3.70 |
| -294 | 7.3 | 3.81 |

Table I.6 Tube 102, 105, 106 (TDA farm, Wadi Zabid)

| | BEFORE CROPPING | | AFTER CROPPING | | |
|---|---|---|---|---|---|
| Sample depth | pH | $EC_{1:1}$ | pH | $EC_{1:1}$ | Location |
| 5-10 | 8.0 | 0.54 | 7.7 | 0.338 | tube 102 |
| 15-20 | 8.2 | 0.45 | 8.1 | 0.250 | " |
| 35-40 | 8.1 | 0.56 | 8.0 | 0.435 | " |
| 55-60 | 8.2 | 0.51 | 8.2 | 0.350 | " |
| 75-80 | 8.1 | 0.56 | 8.1 | 0.425 | " |
| 95-100 | 8.0 | 0.62 | 8.1 | 0.355 | " |
| 115-120 | 8.0 | 0.74 | 8.0 | 0.60 | " |
| 5-10 | 8.0 | 0.51 | 8.0 | 0.358 | tube 105 |
| 15-20 | 8.3 | 0.335 | 8.3 | 0.370 | " |
| 35-40 | 8.1 | 0.59 | 8.0 | 0.85 | " |
| 55-60 | 7.8 | 1.28 | 7.8 | 1.58 | " |
| 75-80 | 7.7 | 1.50 | 7.7 | 1.77 | " |
| 95-100 | 7.7 | 1.35 | - | - | " |
| 115-120 | 7.9 | 0.99 | - | - | |
| 5-10 | 8.0 | 0.57 | 8.0 | 0.61 | tube 106 |
| 15-20 | 8.2 | 0.405 | 8.2 | 0.395 | " |
| 35-40 | 8.1 | 0.63 | 8.1 | 0.795 | " |
| 55-60 | 7.9 | 1.02 | 7.8 | 1.31 | " |
| 75-80 | 7.8 | 1.24 | 7.8 | 1.22 | " |
| 95-100 | 7.8 | 1.20 | - | - | " |
| 115-120 | 7.9 | 1.12 | - | - | " |

Table I.7 Tube 4S, 5S (Gumeisha)

| BEFORE CROPPING | | | AFTER CROPPING | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample depth | pH | $EC_{1:1}$ | Sample depth | pH | $EC_{1:1}$ | $\%CaCO_3$ | %S | %Si | %C | texture | Location |
| surface | 8.0 | 1.15 | | | | | | | | | tube 4S |
| 5-10 | 7.9 | 1.42 | 10-15 | 8.3 | 1.65 | 5.5 | 63 | 20 | 17 | SL | " |
| 15-20 | 8.0 | 1.08 | 20-25 | 8.4 | 1.50 | 5.5 | 77 | 12 | 11 | SL | " |
| 36-40 | 8.3 | 0.66 | 30-35 | 8.7 | 0.75 | 3.0 | 77 | 10 | 13 | SL | " |
| 55-60 | 8.3 | 0.72 | 40-45 | 8.5 | 0.85 | 3.5 | 69 | 16 | 15 | SL | " |
| 75-80 | 8.2 | 0.71 | 60-65 | 8.3 | 1.02 | 3.0 | 67 | 16 | 17 | SL | " |
| 95-100 | 8.0 | 0.87 | 80-85 | 8.3 | 1.02 | 2.5 | 69 | 14 | 17 | SL | " |
| 115-120 | 7.8 | 1.06 | 100-105 | 8.4 | 0.76 | 4.0 | 61 | 8 | 31 | S.Cl.L | " |
| | | | 120-125 | 8.3 | 1.01 | 4.0 | 59 | 18 | 23 | S.Cl.L | " |
| | | | 140-145 | 8.3 | 1.03 | 5.0 | 59 | 18 | 23 | S.Cl.L | " |
| | | | 160-165 | 8.1 | 1.33 | 9.0 | 76 | 14 | 10 | SL | " |
| | | | 180-185 | 8.2 | 0.86 | 10.5 | 78 | 14 | 8 | SL/LS | " |
| | | | 200-205 | 8.4 | 0.65 | 9.5 | 78 | 14 | 8 | SL/LS | " |
| | | | 225-235 | 8.5 | 0.78 | 9.0 | | | | | " |
| | | | 250-260 | 8.4 | 0.85 | 9.0 | | | | | " |
| | | | 270-280 | 8.3 | 1.23 | 13.0 | | | | | " |
| | | | 290-300 | 8.3 | 2.50 | | | | | | " |

Contd...... Table I.7

| | BEFORE CROPPING | | AFTER CROPPING | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample depth | pH | $EC_{1:1}$ | pH | $EC_{1:1}$ | $\%CaCO_3$ | %S | %Si | %C | texture | Location |
| surface | 7.9 | 1.30 | | | | | | | | tube 5S |
| 5-10 | 7.9 | 1.19 | 8.8 | 0.30 | 3.0 | 63 | 25 | 12 | SL | " |
| 15-20 | 8.2 | 0.550 | 8.5 | 0.29 | 3.0 | 79 | 11 | 10 | SL/LS | " |
| 35-40 | 8.4 | 0.412 | 8.6 | 0.39 | 1.5 | 75 | 15 | 10 | SL | " |
| 55-60 | 8.2 | 0.510 | 8.4 | 0.72 | 3.0 | 71 | 15 | 14 | SL | " |
| 75-80 | 8.2 | 0.63 | 8.2 | 1.20 | 2.0 | 69 | 15 | 16 | SL | " |
| 95-100 | 8.0 | 0.80 | 8.3 | 0.95 | 5.5 | 63 | 17 | 20 | S(CI)L | " |
| 115-120 | 7.8 | 0.88 | 8.1 | 1.10 | 4.0 | 61 | 19 | 20 | S(CI)L | " |
| 145-150 | | | 8.0 | 1.20 | 2.0 | 69 | 13 | 18 | SL | " |
| 170-175 | | | 8.1 | 1.10 | 2.0 | 71 | 15 | 14 | SL | " |

Table I.8 Tube 2S, 3S (Gumeisha)

| | BEFORE FLOODING | | AFTER FLOODING | | |
|---|---|---|---|---|---|
| Sample depth | $EC_{1:1}$ | pH | $EC_{1:1}$ | pH | location |
| 0-20 | 0.30 | 8.6 | 0.38 | 8.4 | tube 2 S |
| -30 | 0.29 | 8.7 | 0.43 | 8.4 | " |
| -40 | 0.29 | 8.9 | 0.365 | 8.6 | " |
| -50 | 0.31 | 8.8 | 0.38 | 8.6 | " |
| -60 | 0.48 | 8.7 | 0.41 | 8.5 | " |
| -70 | 0.40 | 8.6 | 0.40 | 8.5 | " |
| -80 | 0.50 | 8.5 | 0.40 | 8.5 | " |
| -90 | 1.10 | 8.2 | 0.41 | 8.4 | " |
| -100 | 0.80 | 8.3 | 0.43 | 8.4 | " |
| -110 | 0.75 | 8.2 | 0.43 | 8.5 | " |
| -120 | 0.43 | 8.2 | 0.445 | 8.5 | " |
| 0-20 | 1.90 | 8.4 | 0.62 | 8.5 | tube 3 S |
| -30 | 1.49 | 8.5 | 0.55 | 8.5 | " |
| -40 | 1.23 | 8.4 | 0.415 | 8.7 | " |
| -50 | 0.86 | 8.6 | 0.38 | 8.8 | " |
| -60 | 1.01 | 8.4 | 0.38 | 8.8 | " |
| -70 | 1.22 | 8.3 | 0.43 | 8.7 | " |
| -80 | 1.34 | 8.4 | 0.50 | 8.6 | " |
| -90 | 1.89 | 8.5 | 0.54 | 8.6 | " |
| -100 | 1.40 | 8.4 | 0.61 | 8.6 | " |
| -110 | 1.30 | 8.3 | 0.68 | 8.5 | " |
| -120 | 1.28 | 8.3 | 0.89 | 8.3 | " |