FOOD AND AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS
ENVIRONMENTAL RESOURCE ASSESSMENT FOR RURAL LAND USE PLANNING
GCP/YEM/021/NET *Field document 21*

THE SOILS OF THE SOUTH-EASTERN COASTAL AREA

PART 2 THE SOILS OF UPPER HAJAR VALLEY

RENEWABLE NATURAL RESOURCES RESEARCH CENTRE
AGRICULTURAL RESEARCH AND EXTENSION AUTHORITY
MINISTRY OF AGRICULTURE AND IRRIGATION
DHAMAR, REPUBLIC OF YEMEN

1999

FOOD AND AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS
ENVIRONMENTAL RESOURCE ASSESSMENT FOR RURAL LAND USE PLANNING
GCP/YEM/021/NET *Field document 21*

THE SOILS OF THE SOUTH-EASTERN COASTAL AREA

PART 2 THE SOILS OF UPPER HAJAR VALLEY

by

Mohamed Hezam Al-Mashreki

AREA Senior Soil Surveyor

RENEWABLE NATURAL RESOURCES RESEARCH CENTRE
AGRICULTURAL RESEARCH AND EXTENSION AUTHORITY
MINISTRY OF AGRICULTURE AND IRRIGATION
DHAMAR, REPUBLIC OF YEMEN

1999

ABSTRACT

This study deals with the semi-detailed soil survey of the Upper Hajar area. The objective of this activity is to make a comprehensive soil resource inventory of the study area, with particular emphasis on areas with agricultural potential, and advise on suitable management practices, taking into account the climatic conditions as well. The report covers various aspects of the soil resources, including factors related to soil development, methods of field and laboratory study, soil suitabilities for various climatically adapted crops, and associated land husbandry practices.

Many of the soils in the study area have formed under a more or less continuous process of sediment deposition by wadi floods, which has given rise to a stratified surface layer. Such soils have been rated as the most suitable arable soils (unit W). They are deep, have a finer texture than the other soils in the study area, and hence possess a good water holding capacity. Because of their alluvial origin, they are also reasonably fertile. Date-palms dominate these areas.

Most of the soils outside the alluvial system are less suitable for agriculture, being sandy, shallow, rocky, indurated or saline. Soils of the sand plain (unit S) have a too low a water holding capacity to be able to support plant growth, while near the footslopes (unit P) salinity has been recorded at several places, e.g. near the villages Al-Gol, Hasan Ba-Omar and Al Sadarah.

A comprehensive surface irrigation system has been developed in wadi Hajar. It is based on diverting the base flow from the wadi to irrigate the riparian lands. During the rainy season floods are also diverted onto the lands when cereals are being cultivated. Some parcels are being irrigated by water from springs.

بسم الله الرحمن الرحيم

((الخلاصـــــــــة))

تتناول هذه الدراسة مسح وتصنيف التربة وتقييم الأراضي على المستوى الشبة تفصيلي لمنطقة وادي حجر العليا –المكلاء – محافظة حضرموت ، وتهدف إلى عمل حصر شامل لموارد الأراضي في المنطقة . وبنـــاءً على ذلك يوضح هذا التقرير مظاهر التربة المختلفة في منطقة الدراسة ، متضمناً العوامل التي تؤثـــر في عمليـــة تطوير التربة ، صلاحية الأراضي للمحاصيل المختلفة ، المعوقات وكذلك التوصيـــات الخاصـــة بعمليـــة إدارة الأراضي .

وتجدر الإشارة إلى أن ترب منطقة وادي حجر العليا تكونت بواسطة الترسيبات المائية المتراكمة علـــى شكل طبقات متعاقبة نظراً لاختلاف ظروف الترسيب بواسطة الوادي ولذلك اعتـــبرت مدرجـــات للـــوادي وحددت على خريطة التربة كوحدة أرضية منفصلة وأخذت الرمز (W) . وتتميز ترب هذه الوحدة الأرضيـــة بأنها عميقة جداً وذات قوام ناعم ولها مقدرة عالية على الاحتفاظ بالماء . هذه الترب قيمـــت علـــى أنهـــا ذات صلاحية عاليه لانتاج المحاصيل وهي مستغلة للأغراض الزراعية منذ سنين عديدة علماً بأن جزء كبير من هـــذه الأراضي تغطيها أشجار نخيل البلح .

وجد أيضا أن الوحدة الأرضية الثانية التي تسمى (S) وهي عبارة عن قاع مستوى ذات ترب رمليـــة سطحية تكونت من ترسيبات مائية قديمة .

أما الوحدة الأرضية الثالثة (P) المحدودة بين الجبل ومدرجات الوادي تتميز تربها بأنها محلية وتحتـــوي على طبقات الجبس المتصلبة لوحظ أيضا أن معظم القرى والتجمعات السكانية تتركز في هذه الوحـــدة علـــى حواف الجبال بالتحديد . وتحتوي هذه الوحدة الأرضية على بقع أرضية ذات ترب ملحية شديدة الملوحة حيث أن درجة التوصيل الكهربائي لها تبلغ اكثر من ١٤ مللموز بالإضافة إلى أن الترب تحتوي على طبقات جبســيه شديدة التصلب ولذلك صنفت اراضي هذه الوحدة الارضية على أنها ذات صلاحية هامشيـــة للاســـتخدام الزراعي .

ونظراً لان مياه الأمطار قليلة في منطقة وادي حجر العليا بشكل عام ، فان نظام الري السطحي هـــو النظام المتبع حيث يعتمد على المياه المنسابة في الوادي والتي يتم تحويلها عبر قنوات الري إلى داخل الحقول .

ويمكن القول بأنه خلال موسم السيول يتم ري مزارع نخيل التمور والأراضي المزرعة بالذرة الرفيعـــة بطريقة الفيضان ، كما أن بعض مياه العيون تستخدم لأغراض الري والاستهلاك المنزلي وعموما فان صلاحيـــة مياه الري في منطقة حجر العليا تعتبر جيدة ...

TABLE OF CONTENTS

List of tables:

List of figures :

ACKNOWLEDGMENTS

The author would like to express his gratitude to Mr. Omar Bafadel, Director of the Centre, for his administrative and technical support. Much gratitude goes also to Mr. Wen Ting-tiang, Chief Technical Adviser of the FAO project, for the final editing and revision of this document.

Many thanks are extended to Dr. El-Abbas Doka, FAO Land Resources expert, for his continuous guidance and support. From the Mukalla Agricultural Research Station I would also like to thank Dr. Mohammed Ali Hubaishan, Director of the Station, for welcoming the team and introducing them to various Government offices and to the staff of the Upper Hajar project. I appreciate the contribution of Mr. Ali Faraj Bin Nesser, land and water engineer of the Station, for his contribution in the fieldwork.

I wish further to acknowledge with thanks the support received from the following Centre staff : Messrs. Ahmed An-Nasiri and Fuad Al-Kadasi in the cartography section, for drawing the maps, and Mr. Ahmed Al-Dahmashi and his laboratory staff for analyzing the soil samples.

INTRODUCTION

This study is part of the work which has been carried out by AREA's Renewable Natural Resources Research Centre, with support from FAO's Environmental Resource Assessment for Rural Land Use Planning project (GCP\YEM\021\NET), in the second systematic area, located around Mukalla in Hadramout Governorate in the south east of Yemen. This second systematic area runs from Wadi Meifa in the west to Ghail Bawazir in the east, and will be covered by a reconnaissance soil survey. Within the area two pilot areas have been studied in more detail. These are Ghail Bawazir and Upper Hajar, where amongst others semi-detailed soil surveys have been carried out.

The objective of this study is to assess the environmental resources of the study area for their suitability for agricultural development, characterise the soils in terms of physical and chemical properties, identify and locate the main soil types and their distribution, and identify constraints related to resource management, taking into account the agricultural potential of the study area.

This report deals with the soil survey carried out in the Upper Hajar part of Wadi Hajar and covers various aspects of the soil. During fieldwork all relevant soil types were identified, a legend was developed, the boundaries of the mapping units were checked, soil profiles and auger holes were described and soil samples were taken for laboratory analysis.

Seven catenas were constructed in order show the relative positions of the physiographic units and soil units. The catenas run parallel from north to south over the central part of the survey area.

The field study was carried out in two phases:

1) Exploratory study covering all aspect of study (soils, vegetation, land use, and water resources.
2) Semi-detailed for soil survey to identify the main mapping units and describe the properties of their components.

further away from the wadi and is somewhat higher vis-à-vis the wadi bed than the first terrace. It is only occasionally flooded by the stream. It should be noted that due to the semi-detailed scale, of the survey the separation of the first and second terraces not possible. The height of these terraces from the wadi bed is varying between 1-5 m.

1.3 GEOLOGY AND GEOMORPHOLOGY

The majority of the mountain ranges surrounding the valley is of volcanic origin, and subdivided by a dense network of fault lines, but locally sedimentary rocks are also encountered. Volcanic activity continued until early in the Quaternary period, as a result of stresses built up in the earth's crust. The landscape of the whole area was formed under the influence of tectonic movements. This caused the uplifting of the plateau north-east and south-west of Upper Hajar area, which in its turn brought about a deep incision in the plateau by wadi Hajar. Alternating sedimentary and volcanic layers are displayed in the surrounding mountains, which have been folded and subjected to strong faulting.

According to the geological map of Yemen, sheet 14 (Robinson, 1993), the Upper Hajar area is covered by two types of geological structures: Proterozoic (andesitic metavolcanics) and Tertiary (dolomitic limestones). Different materials were deposited at different times as can be clearly observed from deep catenas and wadi cuts in the area.

Deposition of material eroded from the bedrock in the watershed is still the main process in the current development of the valley. Indirectly, such material is brought down by the wadi and deposited in the valley bottom. Coarse material is laid down in the wadi bed itself, while finer material is deposited on top of the wadi terraces when the wadi overflows its banks. Directly, debris from the steep slopes flanking the wadi is brought down, mostly through gravitational action, as scree accumulating at the foot of the slopes. Such material, and in particular its finer components, is being reshifted and reworked by wind and water. This activity is especially pronounced at times of the late spring and mid-summer high floods.

All geomorphological formations in the area are of recent origin, i.e. not older than the Quaternary, and are still undergoing change. The periodically recurring floods of the wadi are the main agent bringing about geomorphological change, through erosion and deposition of sedimentary material (TESCO-VISITERV, 1984).

1.4 CLIMATE

1.4.1 General

Yemen has predominantly a semi-arid climate. The rainy season occurs during the spring and the summer. Three large bodies of water affect the climate of Yemen: the Indian Ocean (including the Gulf of Aden and the Arabian Sea), the Red Sea and the Mediterranean Sea. They are sources of moisture for the passing air masses.

The climate of Yemen is strongly influenced by the mountainous nature of the country. In the west and south the topography is dominated by mountain ranges running parallel to the Red Sea coast, with three ridges interspersed by upland plains. These mountain ranges rise in the north from about 50 km from the Red Sea coast and continue to over 100 km east from the Red Sea. In the southern part of the country these mountain ranges merge with ranges running parallel to the coast of the Gulf of Aden. Although the southern ranges are generally less elevated and steep than the northern ranges, they locally nevertheless reach altitudes of about 2000 m.

No climatic data is available for the Upper Hajar study area since there are no meteorological observation stations. The mean annual rainfall has therefore been estimated at 60 mm by extrapolating the data from a few stations in the region. The bulk of this rainfall occurs during the summer monsoon season. In view of the fact that during the same season a temperature maximum higher than 45 °C is frequently reached, it should be evident that there is a major soil moisture deficit. The potential evapotranspiration in these areas has been estimated at 1800 to 2000 mm per year, which when compared with the rainfall indicates a severe water shortage that necessitates irrigation.

The most important meteorological parameters affecting the soil development processes in this particular area are as follows :

a) The annual mean temperature and the extreme temperature conditions, which control the actual and potential evapotranspiration rates, and make at the same time irrigated farming imperative.
b) The level of the relative moisture content
c) The mean annual precipitation and its seasonal distribution.

1.4.2 Agro-climatic zonation

Agro-climatic zonation is an essential element of agro-ecological zonation. The purpose of zoning, as carried out for rural land use planning, is to separate areas with similar sets of resource potentials and constraints for development. Specific programmes can then be formulated to provide the most effective support to each zone. Zoning divides an area into smaller units based on distribution of soil, land surface and climate. Hence the agro-climate zonation is the subdivision based on climatic criteria. The essential elements in dividing agro-climatic zones are the growing period(s) and the temperature regime.

According to a study carried out by this FAO project (H.Y. Bruggeman, 1997), the Upper Hajar area is located in zone 11. However, Upper Hajar is actually intermediate between zone 11, representing the eastern plateau, and zone 12, covering the coastal area. Although its climate shares many of the characteristics of zone 11, it is clearly hotter than the average for zone 11, and in this respect resembles more zone 12.

1.4.3 Zones 11 and 12

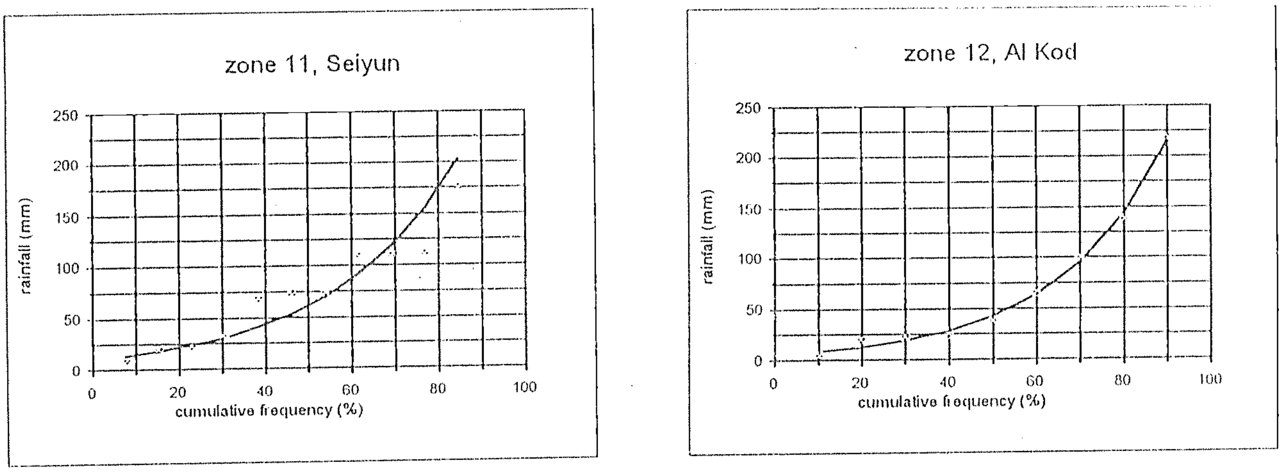
a) *Location*

Zone 11 is located in the eastern part of the country. The extent of the zone is about 186.000 km^2. Zone 12 can be found along the seafront of Yemen. It covers an area of roughly 40.000 km^2. The representative climatic stations for zone 11 are Seiyun (700 m), Marib (1100 m), Beihan (1150 m) and Nuqub (1150 m), while for zone 12 they are (in the southeast) Al-Kod (20 m), Riyan (25 m), Lahej (130 m), Giar (100 m) and Fiyush (65 m). Seiyun and El-Kod are considered to be the most representative stations for these zones, and the details provided below are based on these two stations. It should be borne in mind, however, that the physiographic position of wadi Hajar is different from the environment in which Seiyun and El-Kod are situated. Hence the information given below is not necessarily exactly the same as the prevailing conditions in the study area. See Appendix 6 for a summary of the agro-climatic data.

b) *Rainfall*

In both these zones there is no distinct rainy season. The annual rainfall generally varies between 10 and 200 mm (Figure 2). The months October through January and June are generally dry, although an occasional thunderstorm can bring some rain during these months. Eighty percent of the rains normally falls from January through June. The number of rainy days with rainfall amounts above 5 mm/day varies between 2-10 days.

Figure 2 Cumulative rainfall distribution



c) *Potential evapotranspiration*

The potential evapotranspiration is about 3-4 mm/day during the cool period and 4.5-6 mm/day during the months May-June. The average total amount of evapotranspiration per year is about 1400-1800 mm/year.

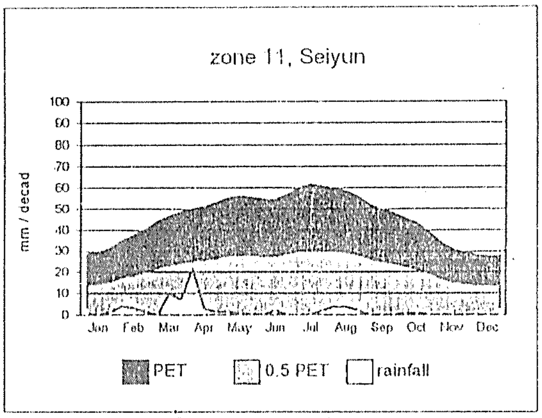
d) *Growing period*

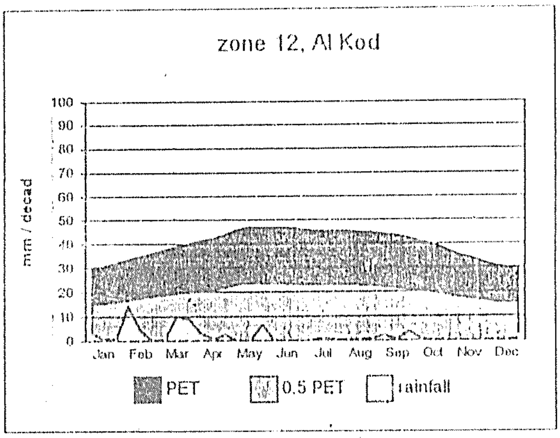
There is no distinct growing period (see figure 3). In fact, virtually all the agriculture in this area depends on spate irrigation, which derives its water from the rainfall that, although of limited depth, falls over large catchments. Upper Hajar is an exception in that it has a perennial stream that provides water for irrigation throughout the year.

e) *Temperature*

Altitude differences in these zones range from 0 m at the coast to 1100 m, and this affects the temperature (Al-Khorasani, 1999). The mean monthly maximum temperature varies between 27-31°C during the cool months of November through January and 34-42°C during the hot months of June-August. The mean monthly minimum temperature varies between 9-11°C

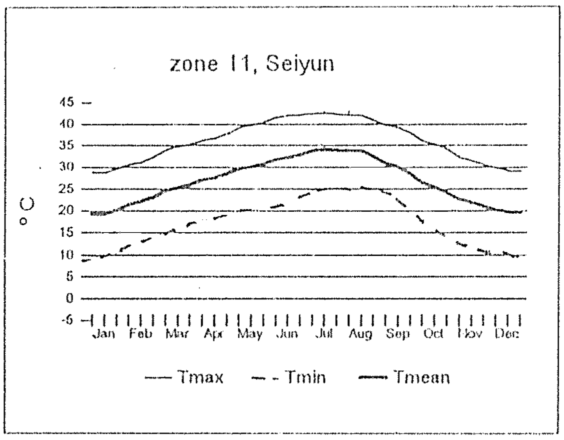
Figure 3 Growing period

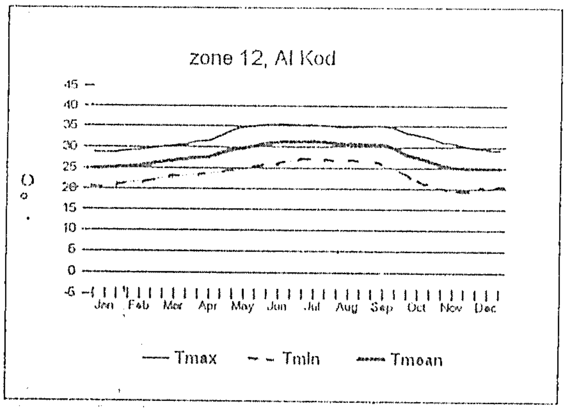




during the cool months and 22-29°C during the hot months of June-August. On the whole, Upper Hajar being situated in a rather sheltered position, temperatures will be nearer to the upper limit of these ranges than around the lower limit.

Figure 4 Temperatures





f) <u>*Relative humidity*</u>

The mean daily relative humidity in zones 11 and 12 varies according to the seasons. During the cool season the mean daily relative humidity varies between 40 and 70 %, while during the hot season the mean daily relative humidity varies between 35 and 60 %.

g) <u>*Sunshine and radiation (Figure 6)*</u>

The average number of sunshine hours varies little over the year (8.5-10.5 hours/day), and is highest during the months May and October/November. This results in a net short-wave solar radiation (Rns) of 16.5-18.5 MJ/m^2/day during May to June, and 12.5-14.5 MJ/m^2/day during December and February.

Figure 5 Relative humidity

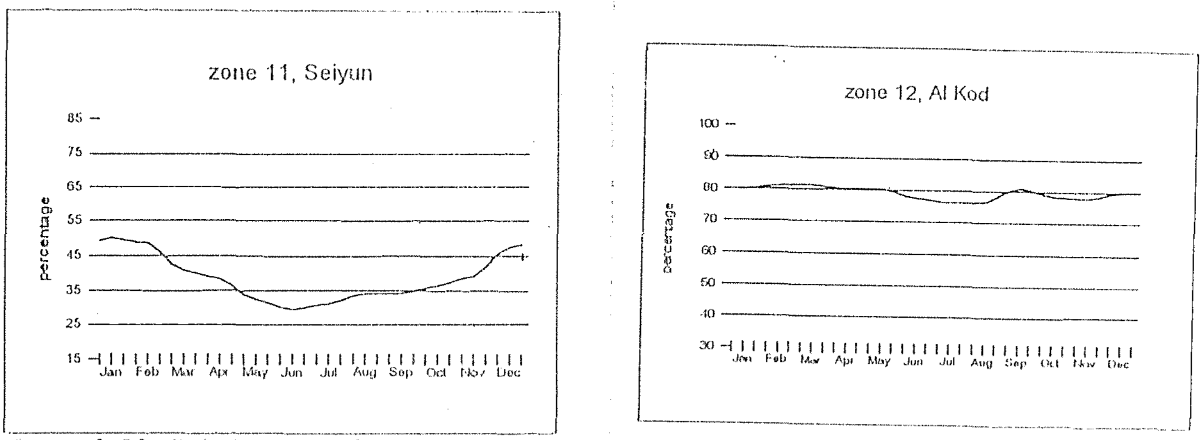
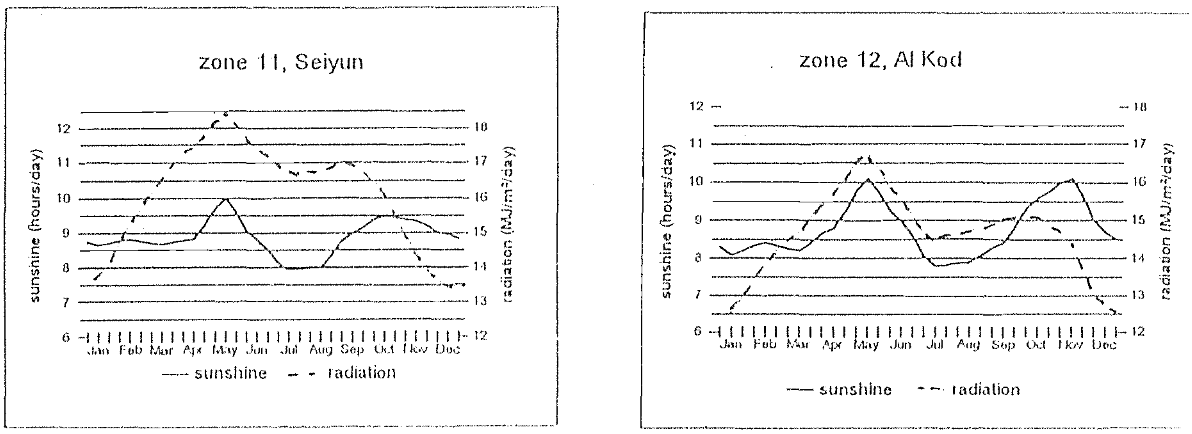


Figure 6 Sunshine and radiation



h) *Soil temperature regime*

No soil temperature data have been recorded for 50 cm depth in both zone s. It is assumed that the soil temperature at 50 cm depth is between the average and the maximum air temperature. The expected lowest soil temperature would then be around 26°C during the cool period, and expected highest 37°C during the month of June. The yearly average soil temperature is expected to be about 33°C. According to Soil Taxonomy (USDA, 1994) the soil temperature would be **Hyperthermic**

i) *Soil moisture regime*

The soil moisture regime for zones 11 and 12 according to Soil Taxonomy (1994) is **aridic**. According to the modifications proposed by Van Wambeke (1982) the soil moisture regime for zone 11 is classified as **typic aridic**. Since no water harvesting is practised in Upper Hajar, on account of the generally low rainfall, the soil moisture regime is not modified. More detail is provided by Bruggeman (1997), who established that the soil moisture regime in zones 11 and 12 is, in all years, typic aridic.

1.5 LAND USE

1.5.1 General

Land use in (semi-) arid areas depends mainly on the availability of irrigation water, coupled with the presence of suitable soils. If enough water is available two or three crops per year are even possible (Belder, 1998). Based on a perennial water availability, wadi Hajar is particularly favourable for intensive agriculture. The wadi terrace area all along the wadi (unit W on the soil map) is covered by permanent agricultural fields that are mostly watered by gravity irrigation. These fields, which consist of fairly rich alluvial soil, are an important date-palm production area and intensively cultivated. This date-palm growing has a several hundred year tradition and is still practised at present in the area.

Date-palm groves can be found mainly in three areas, viz. Jezwill, Al-Gol, and Al-Sadarah. The total numbers of trees in these centres were estimated by Government to be around 600,000 trees. After the Unification of Yemen, the farmers increased the date-palm plantations due to an incentive of YR 1000 provided by the Government for each new palm tree established. Most of the date-palms have been planted on the eastern side of the wadi. On the western side relatively good pieces of land are not used while other parts are mainly used for sorghum, particularly in years when plenty of water is available.

Farmers mentioned that 30 years ago most date-palm groves were established on the western side of the valley. However, floods destroyed these trees and washed a lot of soil away. After this, date-palm plantations were re-established on the eastern side. From the western side soil was taken and brought to the new date plantations. Also clayey soil from this side was used for building houses.

There are some places with salinity problems in Upper Hajar e.g. Al-Sadarah. Close to the wadi bed there are no problems because of light textured material from which salts are easily flushed out. Further away from the river fields have been abandoned because of salinity problems. In these fields there is a need for drainage canals.

The major subsistence crops are millet and sorghum, which are the staple food of the population. Vegetables, bananas and other fruit trees, e.g. papaya and coconut, are grown under date-palm trees. Cereal crops, used both for fodder and grain, are watered by spate and flood irrigation is. This type of agriculture is practised in the main arable farming areas along the wadi length (unit W).

1.5.2 Dominant land utilization types

Land utilization types are a refined kind of land use, with special emphasis on management aspects of the land use, and suitable for land evaluation purposes. The main land utilization types in the study area are described below, as reported by Bahamish (1998).

In Upper Hajar nearly all the land is under private ownership. There are only two types of land use, based on the water management.

a) *Date-palm cultivation under wadi and spring irrigation*

The majority of agricultural land in Al-Gol, Al-Sadarah and Jezwill relies on the perennial baseflow of wadi Hajar. As date-palms are the major cash crop in the area, it is also the principal crop benefiting from this water, which is diverted from the wadi through weirs and led through a system of canals and furrows towards the individual plots. In the study area the farmers practice intercropping under the date-palm trees, generally with food plants which go directly to consumption. Also they grow some fruit trees under or beside date-palm trees (Bahamish 1998).

The date-palm variety Suktry is dominant and cultivated by most farmers, and is very much liked by the market. Recently out of 500,000 palms trees only about 339,500 produced good yields. The annual yield per tree ranges from 22-35 kg. The average age of trees is around 30-40 years, but some are over-aged (above 60 years) and have become unproductive. Palm seedlings (taken from plant shoots) are planted in rows 3-4 meters apart, and start fruiting 5 to 6 years after planting. The irrigation interval differs from one location to another and generally ranges from 30-40 days. Date palm holdings vary from 3-5 feddan per farmer. However, the majority of farmers are working on a crop-sharing basis with landlords. The share of the farmer is around one quarter to one half of the date yield. The share is given to the farmer in return for his agricultural services and maintenance of irrigation canals.

Agricultural practices for date-palm trees start heavily in January and February, mainly cleaning and pollinating female trees. Activities intensify again during June to August for cutting date bunches and drying them. However, work on date-palm trees continues throughout most of the year and decreases during October and November.

Generally sorghum and millet are planted under date-palm trees and can be used as a grain crop or for animal feed. Main planting dates are during October-November (in winter) and during April-May (early summer). As a food crop summer planting is considered more important.

All farmers grow vegetables for home consumption in small areas under date-palm trees, but their production is low. The season for vegetable cultivation is during October-November. Crops grown are tomato, onion, sweet potato, pepper, and melons. Pest attacks, such as white fly, aphids and tomato fruit ball worms, are common. Serious virus diseases are mainly leaf curl on tomato plant.

Fruit trees such as banana, papaya, citrus and mango were introduced recently and they have been planted in small areas beside or under date palm trees. However, landlords oppose growing fruit trees under their palm trees because they believe that this practise adversely affects the quality of date fruits. Farmers, on the other hand, prefer growing some fruit trees as their product adds variety to their diet and may even constitute an alternative source of income

b) *Cereal cultivation based on spate irrigation*

Land not devoted to date-palm cultivation is used for cereal production. The size of the area cultivated with sorghum and millet depends on the quantity of floodwater received. If the amount of water brought by the early spate is large, then wide open areas can be planted, but if the spate is limited then the crop is only planted under date palm trees. Varieties of sorghum and millet used are local once and their seeds are collected from the previous crop. Land preparation is usually carried out about two weeks before planting by hiring tractors for ploughing the soils and using disc harrows, once or twice. After ploughing the soil is a levelled and subdivided into small plots of about 5 x 5 m. The method of planting is by broadcasting, and no fertiliser is used. Harvesting as a fodder crop starts 30-45 days after planting, but if the crop is for human consumption (only possible if there is sufficient floodwater) harvesting is carried out 2-3 months after planting. No yield data are available, but yields are believed to be less than 1 t/ha (grain) on average.

Some tef is also grown, mainly for straw, which is highly valued for use in sun-dried brick making.

1.6 VEGETATION

Under the prevailing environmental conditions, the natural vegetation in the Upper Hajar valley is more a consequence of soil development than a major soil forming factor. This implies that owing to the arid climate, and the occurrence of areas with saline soils, plant species tolerating drought and a high salt concentration predominate. The most frequently occurring natiove trees are xerophytic species such as *Tamarix* and *Salvadora Persica,* spread along the mountainous area, *Acacia Nilotica* occurring on the footslopes and stony terraces, and *Zygophyllum* found in saline areas. Grasses used as pasture appear only after a period of rainfall in winter and spring seasons, and hence their yield is lôw (Kazgiprovodkhoz Institute and Directorate Soviet-Yemen project in Irrigation, 1990). In the Upper Hajar area the most common commercial tree is the date-palm, being grown extensively along the wadi.

1.7 WATER RESOURCES

Of all the wadis in the of south-eastern part of Yemen, wadi Hajar is the only stream that is not ephemeral but carries flow continuously, at variable rates, throughout the year. This is one of the reasons why attention has been focussed on this area, where the water supplies essential for agriculture production in an arid environment is permanently available.

The amount of water flowing through the wadi is directly related to the amount of rainfall in the catchment area on the Jol plateau north of the survey area. Although precipitation is not abundant, the catchment is large and enough water is being stored for the wadi to flow perennially. Sometimes rainfall is, however, torrential and will exceed the storage capacity of the catchment. In 1986 and 1996 such heavy rains gave rise to large floods that damaged irrigation canals, destroyed palm trees and washed away considerable amounts of soil near the banks of the wadi. In an average year six floods, both large and small, pass through the wadi.

There are about 27 main diversion canals in the Al-Gol, Al-Sadarah and Jezwill areas, which draw their water from the wadi. The amount of water at times of flood flowing through the wadi in Upper Hajar is about 340 millions m^3, with a discharge of 1800 l/s. About 40% of the water passes through the wadi as peak flow to the sea, 30% infiltrates into the wadi bed to recharge the underground water, while the remaining 30% makes up the baseflow of the wadi (Tesco, 1990), which is being used for irrigation.

Both areas (Lower and Upper Hajar) are covered by a network of irrigation canals, the total length of which is considerable. These canals convey wadi water by gravity to areas selected for irrigation. Since in the Upper Hajar area the salt content of the soils is in general low, although the groundwater is saline, the chemical composition of irrigation water is considered to be identical in quality with the wadi water.

In view of the fact that at times of high flow the salt content of the water is even lower than as usual, it is concluded that the wadi water is suited not only to irrigation but even for leaching salts that have accumulated in the profile.

In the Upper Hajar area, water for irrigation is obtained not only from the wadi, but also from around 80 springs of presumably volcanic origin. The discharge rate of spring water ranges from 5 to 10 l/s. However, after heavy rains the discharge may increase up to 20 to 40 l/s (Bahamish, 1998). The total salt content in the water of some springs analysed was less than 600 ppm (Tesco, 1984), so that these too are classified as suitable for irrigation. It should be noted, however, that the area irrigated from them is necessarily small. In the Lower Hajar area there are besides the irrigation canals, the two largest being the Bateis and Bahafid canals, several major drainage canals as well, the original function of which was to remove from the irrigated areas the salts accumulated in the course of irrigation. At the present these drainage canals are capable of performing their original function to a limited extent only.

Under the geological and subsurface hydrological conditions prevailing in the Upper Hajar area, the groundwater table is situated at considerable depth, except in the vicinity of the wadi bed. Only in the Lower Hajar area has the influence of groundwater on soil development processes been detected during field surveys. In this area many profiles contain a high salt content due to a shallow and highly saline groundwater table (TESCO-Viziterv, 1984)

Chapter 2 METHODS OF SOIL SURVEY

2.1 GENERAL

A soil survey was carried for the Lower Hajar project (TESCO–Viziterv, 1984), and this included a preliminary study of the Upper Hajar area for the Wadi Hajar Agricultural Rehabilitation Project. The work conducted in Upper Hajar area was limited to the description of some profiles.

Since there was little earlier soil information, it was decided to carry out a standard semi-detailed soil survey on Upper Hajar area. Because of administrative reasons, and also natural, particularly geomorphological conditions, the area can be considered consisting of three clearly distinct regions, namely Al-Sadarah, Al Gol and Jezwill. On the basis of this division the survey catenas were laid out.

The following AREA staff participated in the survey, which took place from 16 to 30 December 1997 :

Mohammed Hezam Al-Mashreki	Teamleader, Senior Soil Surveyor
Marleen Belder	Soil surveyor (FAO)
Ali Bin Nesser	Land and water engineer
Fadl Mutlaq	Soil surveyor
Abdullah Al-Najar	Field assistant (Technician)
Saleh Al-Kobati	Driver

The whole staff came from AREA's Renewable Natural Resources Research Centre in Dhamar, with the exception of Mr. Ali Ben Nesser, who belongs to the AREA office in Mukallah. The staff worked as one party under the supervision of the teamleader.

2.2 BASE MATERIAL

A topographic map (1978) at a scale of 1:100,000 (sheet no. D-39-49) was available during the fieldwork, on which the agricultural areas were accurately indicated. An additional thematic map (irrigation canal design), scale 1: 5000, from a Russian project in Wadi Hajar was also used in order to locate the soil observations accurately and to separate the different soil mapping units.

Aerial photographs were not used, although an intensive effort was made to obtain them from the Military Survey Department in Sana'a and Aden. Eventually it was realised that the aerial photos available had only very limited coverage of the wadi, and mostly covered zones outside the study area. A GPS was used to precisely locate the observation points.

2.3 LEVEL OF SURVEY AND FIELDWORK

As a preliminary step in establishing a working legend, a rapid soil reconnaissance survey was made to identify the main soil types, based on auger hole checking along a number of catenas across the wadi. Subsequently more detailed ground observations were carried out at semi-detailed level to establish the pattern of soil distribution.

The main soil types were represented by profile pits. The described profiles were subsequently used to characterise each of mapping units. Profiles were examined, where possible, to a depth of 120 – 150 cm.

The actual fieldwork was completed within two weeks. The soil survey was carried out at a semi-detailed scale of 1:50,000, and the observation sites were located on a number of catenas, which were situated at right angles (i.e. from north to south) to the general direction of wadi Hajar. This method was in particular useful since aerial photographs were not available. The soils were tested by auger holes and then profile pits were dug to represent the various soil types distinguished.

Most of the observation were made on the cultivated wadi terraces near the river, while fewer were sited near the mountains, but enough information about these shallow and/or stony and cemented soils was gathered to confidently draw soil boundaries.

2.4 SOIL SAMPLING AND LABORATORY ANALYSIS

Soil samples were collected from the observations made (8 profile pits and 30 auger holes) and delivered to the laboratory. In total, about 64 soil samples were analysed at AREA's Soil and Water Laboratory in Dhamar for the following parameters (the laboratory analytical methods used are listed in Appendix 2) :

- pH paste
- EC paste (in saturation extract of soil)
- Available phosphorus
- CEC (cation exchange capacity)
- Exchangeable cations (sodium, calcium, magnesium and potassium)
- $CaCO_3$ content
- Organic carbon content
- Total nitrogen

In case where the EC > 4 mS/cm, then soluble cations (carbonates, bi-carbonates, chlorides, and sulphates) were determined. With regard to the organic carbon determinations, the figures given in the analytical data tables accompanying the profile descriptions appear to be too high, as compared to data from other surveys. These organic carbon figures have therefore not been used for soil classification. The following parameters were obtained by calculation (where possible) :

- C/N ratio
- ESP (Exchangeable Sodium Percentage)
- CEC (clay)
- SAR (Sodium Adsorp. Ratio)

Physical tests included the following two determinations :

- Mechanical analysis (texture)
- Moisture % (air dry soil)

The soils of Upper Hajar were classified according to the Soil Taxonomy of the United States Department of Agriculture (1994), and correlated with the World Reference Base for Soil Resources (FAO, 1998). At national level, the soils were classified to the family level.

Chapter 3 SOILS

3.1 MORPHOLOGICAL AND PHYSICAL CHARACTERISTICS

Soils can differ greatly in their morphological, physio-chemical and mineralogical properties. These differences affect crop responses to management operations. Improper use of soil may adversely affect crop production and lead to soil degradation. It is therefore essential to understand the soil to ensure suitable sustained agricultural use and proper conservation (Mohamed Ali, 1997).

Based on the catenas (see fig. 6) investigated, and taking into account the physiography, altogether 8 soil profiles and 30 augers have been explored and described in the survey area, and from which 64 soil samples were collected for laboratory testing and analyses (see Appendix 2).

3.1.1 Parent material

The Upper Hajar valley is a typical combination of foothill debris and recent alluvial sediments. All geomorphological formations in the area are of recent origin, i.e. not older than the Quaternary, and the soil parent material is dominated by mainly calcareous fluviatile sedimentary material.

a) *Alluvial deposits*

As noted above, nearly all soils have developed in recent alluvial deposits laid down by the wadi. The alluvium is mainly composed of layers of silty loam, silty clay loam, clay loam and sandy loam to loamy sand, with variable thickness. Due to the absence of clear pedogenetic features, soil texture and degree of stratification are the main criteria used to differentiate the soils along the wadi.

b) *Colluvial deposits*

In situ weathered materials, originating from the slopes of the valley, were found in the footslope areas. These soils are characterized by a high gypsum and calcium carbonate content, even to the extent that in places the soil layers have been cemented by the gypsum present and consequently have a massive structure throughout the profile.

3.1.2 Soil texture and stratification

The soil textures in Upper Hajar area are dominantly silty loam, silty clay loam, and sandy loam with a few layers of clay loam and loamy sand. The soil derived from alluvial deposits along the wadi, starting from Al-Sadarah and extending through Al-Gol towards Jizwell, show relatively little variation in texture (soil mapping unit W). The silt + clay fraction is generally higher than 60 % and the sand fraction is predominantly very fine and fine sand (see e.g. soil profile descriptions in Appendix 3).

Most soils in unit W have a clear stratification with different textures throughout their profiles. The stratification in most profiles consists of 3-5 layers. Thickness of layers range from 15-30 cm. Large exposures clearly show the deposition of different layers and the big differences in thickness and depth of these layers over short distances. Profiles 6 and 7 are examples of such stratified soils. Other soils (e.g. profiles 3 and 8 are fairly homogeneous, with a fine loamy texture. It cannot be excluded that such soils are made up of irrigation sediments, as they resemble the Ahwar series soils first recognized in the wadi Ahwar soil survey (Hunting Technical Services, 1967). These deep wadi terrace soils normally are fairly fine textured (clay loam, loam) and therefore could potentially develop salinity problems if not irrigated properly.

3.1.3 Soil colour

Pedogenetic processes, which modify soil colour, are weakly developed in the wadi mapping unit (W) as result of the arid climate and recent deposition of much of the alluvial sediment. All hues were reported as 10YR, with values ranging between 7 and 6 while the chromas vary between 3 and 4. There are some deep alluvial soils (classified as Torrifluvents and Torriorthents) that have darker colour.

The soils of other units (P and S) show relatively dark colours. These are mainly the Typic Haplogypsids, which have values ranging between 7 and 4 while the chromas are between 4 and 2.

3.1.4 Soil structure

Soil structure refers to the nature and the degree of aggregation of soil particles. In these young soils the structure is only little developed and hence often is massive. Occasionally weak or very weak structure grades are encountered. The prevailing arid conditions prevent quick soil developments, which is reflected in the soil structure. Soil rich in gypsum often have has a massive structure throughout the profile, which is caused by gypsum cementation.

Torrifluvents show clear stratification, but the individual layers have either a massive structure or are loose, consisting of single grain particles. Torriorthents are young homogeneous soils, possibly formed in irrigation sediments.

3.1.5 Rootability

Rootability is directly linked with effective soil depth. It is influenced by different factors. The most important ones for the survey area, which limit root penetration or restrict root growth, are:

- Cementation (found in some profiles in soil unit P)
- Stony layers and rocks fragments (found in some profiles in soil units P and S)
- Shallow depth to bedrock (found in soil unit S)

3.2 CHEMICAL CHARACTERISTICS

3.2.1 Soil pH

The soil in the survey area can be characterised by a number of features. The soils are generally alkaline, their pH ranging from 6.5 to 8.5 (see appendix 3). The relatively high pH is due in part to the high colloidally dispersion and calcium carbonate when the soil is diluted for pH measurement. In soils having a considerable salts content the higher pH can be attributed to the hydrolysis of the sodium ions as well.

3.2.2 Soil EC and salinity

The salinity of a soil is measured as the electric conductivity (EC) of a soil-based paste or solution, and expressed in mS/cm. The EC was measured both in the field and in the laboratory. In the field the measurements were made in a 1:5 soil solution, while in the laboratory the soil was diluted with water until it reached saturation, and the EC measured in this saturated paste. The obtained values ranged from 0.5 to 37 mS/cm in the field test and from 0.5-130 mS/cm in the lab. A very general classification of EC and salinity level is given in table 1.

Table 1 Classification of EC and salinity level.

USDA Soil class	Description	EC (mS/cm)	Total salt content (%)	Crop reaction
0	Salt free	0-4	< 0.15	Salinity effects are mostly negligible except for the most sensitive plants
1	Slightly saline	4-8	0.15-0.35	Yields of many crops restricted
2	Moderately saline	8-15	0.35-0.65	Only tolerant crops yield satisfactorily
3	Strongly saline	> 15	> 0.65	Only very tolerant crops yield satisfactorily

(Source: Landon, 1996).

The chemical analysis shows that the soils in unit P are strongly saline (augers: UPH5, 6, 11, 12, 14, and 15). The heavy textured layers always have high concentration of salt. It should be noted that this unit is unused land (bare land) and the soil is characterised by a gypsic horizon as well.

Land use is an important factor in controlling salts as it was reported that abandoned fields tend to become slightly to moderately saline through time. Intensive cropping and elimination of long fallow results in an increased water use, part of which will seep down the soil profile and wash out salts. As a consequence, the salinity level in the root zone will decrease (FAO, 1988).

3.2.3 Calcium carbonate

The soils in the study area contain a high active calcium carbonate component. This high contents of carbonates in the soils of Upper Hajar is evidently due to a high weathering rate of the surrounding sedimentary rocks and the lime contents often layers are deposited in successive layers in the soils. The material (in particular in unit P) is rich in calcium carbonates/gypsum and the accumulation of the carbonates takes place because of low precipitation and high evapotranspiration rates. The laboratory figures show a very sharp increase of $CaCO_3$ content in the calcic horizons. $CaCO_3$ in these horizons is sometimes 20 times higher than in the above lying layers. In general the depth to calcic horizons is determining factor for land use. Cultivation (ploughing) on shallow soils over calcic horizon avoided by farmers.

3.2.4 Organic carbon

Organic matter is an important source and reserve of plant nutrients and soil moisture. It gives an indication of soil fertility. Organic matter figures can be calculated from organic carbon figures by the following formula : Soil organic carbon (%) x 1.72 = organic matter (%).

Organic matter figures are mostly less than 1%. The organic matter content in the calcic and gypsic horizons is between 0.15 and 0.40 % and is lower than in the topsoil. The organic carbon content in these topsoils is lower than the 0.6 % criteria for a mollic horizon. The analytical data indicate in some cases high values of organic carbon, but these are believed to be erroneous results and have been ignored for classification purposes.

3.2.5 Soil fertility

Phosphorus is an important macronutrient influencing crop performance. Figures for the Upper Hajar study area range between 1 and 4 ppm in the topsoil as available phosphorus. These levels indicate a deficiency for almost all crops. This can most probably be attributed to the strongly calcareous nature of the soils of Upper Hajar, which can fix large amounts of phosphorus.

Nitrogen is also extremely low (0.01 to 0.05 %). The potassium content of the soils is considered as moderately well to satisfactory.

3.3 SOIL CLASSIFICATION

The soils have been classified according to the World Reference Base for Soil Resources (FAO, 1998) and correlated with the 1994 Keys of the Soil Taxonomy (Soil Survey Staff). However, the available soil analytical data are insufficient to proper classify the soils down to series level. The very fine sand fraction is essential to determine the textural class correctly (Al-Mashreki, 1997). Therefore, the family level classifications are given. According to the agroclimatic characterization of Yemen (Bruggeman, 1997) the soil temperature regime is hypothermic in zones 11 and 12, while the soil moisture regime is aridic. Table 2 shows the soil mapping units and their classification. Because the scale of the survey, it was not possible to map pure taxonomic units, but associations (unit W) and complexes (units S and P) were mapped instead.

Table 2 Soil mapping units and their classification:

Soil mapping unit	Soil Taxonomy (1994)	World Reference Base (1994)
W	Typic Torrifluvent, fine loamy, mixed, hyperthermic	Calcaric Fluvisol
W and S	Typic Torriorthent, coarse loamy, mixed, hyperthermic	Calcaric Regosol
P	Typic Haplosalid, fine loamy, mixed, hyperthermic	Haplic Solonchak
P and S	Typic Haplogypsid, fine loamy, mixed, hyperthermic	Calcaric Gypsisol
S	Lithic Torriorthent, coarse loamy, mixed, hyperthermic Lithic Torripsamment, fine sandy, mixed, hyperthermic	Eutric Regosol Calcic Arenosol

The soils are assumed to have mixed clay mineralogy as their parent material has washed down by water from different locations underlain by various rock types. Since all soils are calcareous, calcareousness has not been indicated in the family level name. Physiographic position, stratification and irregular decrease of organic carbon with depth are the main criteria to identify these taxonomic units.

The classification system is based on class distinction through defined diagnostic horizons (like gypsic, calcic, salic etc.). In the study area soil are classified as Haplogypsid (i.e. soils with gypsic horizon), Haplosalid (i.e. soils with salic horizon), Torriorthent (i.e. weakly developed stratified alluvial soils) and Torrifluvent (i.e. stratified alluvial soils, receiving seasonal sediments, normally situated close to a wadi, with irregular amounts of organic carbon).

The most common soil orders in the study areas are Entisol and Aridisol. There is some variation, primarily in unit W that covers the area along the wadi (first and second terraces), in soil characteristics such as texture and carbonate content. Each of these predominant soil orders is described below.

3.3.1 Entisol

The majority of these soils have been deposited by water, mostly in recent times, with the result that strongly expressed profile development is rare. They are young undeveloped soils. Entisols in Yemen are strongly influenced by alluvial or loessal, usually calcareous, silty parent material. Two suborders have been distinguished in the survey area, Fluvents and Orthents (both in soil unit W). Fluvents have clear characteristics resulting from their fluvial origin, such as an irregular organic matter content with depth or a clearly distinguishable stratification. Orthents are not linked to a specific depositional or soil forming process.

3.3.2 Aridisol

These are typical soils of the arid zone, as the name implies. In regions characterised by a stable surface, a salic horizon (a soil with a high salinity) has developed and hence these soils are classified as Salids. Gypsic horizons were observed in some soils and these have been classified as Gypsids (units P and S).

3.4 THE SOIL MAP

3.4.1 Soil legend

The soil map legend, which is given in tabular form in table 3, was defined on the basis of soil genesis concepts and field survey principles. The description of each soil mapping unit is given in tables 2 and 3. The structure of the soil legend is hierarchical and can consist in principle of four levels, with the lowest level representing the phase of a series. However, in this survey only a single letter is used which denotes the physiography, and characterizes the soils in the mapping unit at family level. Of the three mapping units, W stands for wadi alluvium (1st and 2nd terraces), P represents the Pediment and S represents the old sandy terraces.

The final soil map scale is 1: 50,000, with the base map having been produced from the topographic base map scale 1: 100,000 (Fig. 7). This map was used to determine the approximate area of the different mapping units. The calculation was made using a planimeter, and the results are shown in table 4. The total survey area amounts to 6000 ha.

3.4.2 Type of mapping units

As can be seen from table 3, two types of soil mapping units were identified during fieldwork, viz. associations and complexes. In an association, delineated areas are dominated by a two or more soils, which, due to the scale of the survey can not be separated on the map, although their relative position can be described (van Wambeke and Forbes, 1986). Unit W is considered an association, as although its soils are more or less homogeneous, it is made up of two fluvial terraces, the lower of which is still regularly flooded, that at the scale of the map cannot be separated.

In a complex it is not possible to describe the position of the component soils. As a rule, the dominant soil in an association or complex provides the name for the mapping unit. Most of the remainder of the delineation consists of taxonomic units so similar to the dominant and co-dominant components that major interpretations are not significantly affected. The total amount of inclusions that are dissimilar to all of the major components does not exceed about 15 % if limiting (e.g. rocky) and 25 % if non-limiting, i.e. they can be cultivated (Mohamed Ali, 1997).

Table 3 Soil legend

Mapping Unit	Land-Form	Relief	Components of main and associated soils	Main characteristics
W	Wadi Terrace	Almost flat	Association of typic Torrifluvent, typic Torriorthent and inclusions	Stratified, dominantly silt loam and silty clay loam soils, very deep, moderately well to well drained, strongly calcareous, massive to very weak structure, slightly saline.
P	Dis-sected plain	Gently sloping	Complex of typic Haplocalcid, gypsic Haplosalid and inclusions	Remnants of sedimentary material, characterised by gypsic horizons and associated with calcium carbonate, strongly cemented layers, dominantly sandy loam and silty clay loam soils, stony to very stony, moderately deep, moderately well drained, strongly calcareous, massive structure, highly saline.
S	Sandy plain	Flat	Complex of lithic Torriorthent, lithic Torrifluvent and inclusions	Shallow and very stony soils, dominantly loamy sand, sandy loam and silty loam soils, over limestone bedrock well drained, strongly calcareous, massive structure, moderately saline.
B	Wadi bed	Flat to sloping	-	Coarse sedimentary materials (gravels, stones and boulders)
M	Mountain slope	Steep to very steep	-	Old basic parent rocks (volcanic and sedimentary)

3.4.3 Mapping unit description

Below the mapping units that were identified in the fieldwork are described in some detail. Table 4 gives the approximate acreage of each unit, and indicates the representative profile pits that were described (see Annex 2).

Table 4 Soil mapping units, area measurements and profiles

Soil Mapping Unit	Area (ha)	%	Profiles
W	4000	67	UPH002, UPH003, UPH006 UPH007, UPH008
P	1300	22	UPH001, UPH004, UPH005
S	700	12	
total	6000	100	

W Soils of the wadi terraces

This mapping unit, an association, is found in flat to slightly undulating (0 to 2% slope) terrain, located on the first and second terraces formed in recent and subrecent alluvial sediments. These terraces are situated 1 to 2 m above the present wadi bed. The most recent parts of the terraces are regularly flooded. The terraces comprise the spate-irrigated areas of wadi Hajar. This unit starts from Al Sadarah and extends all the way via Al Gaol to Jezwill.

The texture of these very deep, well to moderately well drained stratified alluvial soils is fine loamy in the control section (sandy loam, sandy clay loam, silty loam and silty clay loam texture). The organic matter content decreases irregularly with depth (see profiles 2,3,6,7,8). Structurally the soils are weak and liable to compaction. Throughout the profile the soil is calcareous, and at several locations a slight salinity has been noted as well. Due to its recent deposition, these soils are considered Entisols in the Soil Taxonomy classification, and Regosols or Fluvisols in the WRB classification.

In general, fluvial accumulation terraces occur in the central part of the study area between Al Sadarah and Om Al Shatr. Level erosional terraces are found in the footslope area in the north and south of the wadi.

The principle crop growing in this mapping unit is date-palm, with some banana, millet, sorghum, sesame, papaya, onion, tomato, water melon, sweet potato, eggplant, okra, radish, pepper etc., while alfalfa is also cultivated. This mapping unit also found in the wadi bed and flood areas. The main constraints for agriculture of this unit are erosion by exceptional large seasonal floods, and alkalinity.

Classification :
- Typic Torriorthent, coarse loamy, mixed, isohyperthermic, and Typic Torrifluvent, fine loamy, mixed, isohyperthermic (Soil Taxonomy, 1994)
- Calcaric Regosol and Calcaric Fluvisol (WRB, 1998)

Representative profiles : UPH002, UPH003, UPH006, UPH007 and UPH008

P Soils of the pediment

Gently sloping pediments at the foot of the south and north running mountain slopes which flank the valley, and some isolated rock outcrops. These pediments have mainly developed in old basic parent rocks (volcanic and metamorphic), but remnants of some sedimentary materials were also found. The pediments are used for dryland and spring irrigated farming and grazing. Much of this land not used for crop production due to soil salinity and gypsum problems.

The gravely and locally shallow soils of this complex mapping unit are mainly Aridisols, characterised by a gypsic horizon with stony layers. They are moderately deep, moderately well to well drained strongly calcareous fine and coarse loamy (sandy loam to silty clay loam) soils, stony to very stony. They are often highly saline. Colluvial material was observed at the surface. The gypsic horizon is in the parent material in most places under this unit, in particular in the northeast along Al-Sadarah, Hesen Ba Amer and in the Al-Gol footslope line areas. The salinity comes from the spring water, which may be influenced by salty rocks. It was observed that there is not much agricultural activity, apart from grazing, in this unit.

Classification:
- Typic Haplogypsid, fine loamy, mixed, isohyperthermic and Typic Haplosalid, fine loamy, mixed, isohyperthermic (Soil Taxonomy, 1994)
- Calcaric Gypsisol and Haplic Solonchak (WRB, 1998)

Representative profiles: UPH001 and UPHOO5

S Old Sandy Terrace

Flat sand plain with shallow and stony soils. Mainly developed from depositional/alluvial material. This complex mapping unit consists mainly of shallow Aridisols and Entisols, underlain by bedrock. This plain was observed as bare land, without any vegetation cover. The unit can be characterized as having shallow soils, well drained, strongly calcareous, stony to very stony, loamy sand to sandy loam textures.

Classification:
- Lithic Torriorthent, coarse loamy, mixed, isohyperthermic (Soil Taxonomy, 1994)
- Eutric Regosol (WRB, 1998)

B1 Wadi bed

This unit is made up of the channels located at the bottom of the wadi, with its width ranging between 50-200 m. During the dry season most of this wadi bed is exposed, the stream being confined to a flow of about 5-15 m wide. The wadi bed is composed of rounded gravels, stones, boulders, and silt and sandbars. During to the meandering of the wadi, seasonal changes are frequent and in some years the wadi even destroys parts of its embankments.

M1 Mountain slopes

The mountain slopes run parallel to the wadi on both sides of the valley, and are mainly composed of old basic rocks (volcanic, metamorphic and sedimentary formations). They are partly covered by a thin layer of loose rocks.

CHAPTER 4 LAND EVALUATION

4.1 INTRODUCTION

Land evaluation for land use planning are the final stages of this survey. Land suitability evaluation is the process of assessing the suitability of tracts of land for specific kinds of use. Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses.

There may be certain parts of the area considered, for which particular kinds of use are not relevant, e.g. irrigated agriculture beyond a limit of water availability. In these circumstances, suitability need not be assessed. Such parts are shown on maps or tables by the symbol NR (Not Relevant).

4.2 STRUCTURE OF THE SUITABILITY CLASSIFICATION

The framework has the same structure, i.e. it recognises the same categories, in all of the kinds of interpretative classification (see below). Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land use. Four categories of decreasing generalisation are recognised :

- i Land Suitability Orders: reflecting kinds of suitability.
- ii Land Suitability Classes: reflecting degrees of suitability within orders.
- iii Land Suitability Subclasses: reflecting kinds of limitation or main kinds of improvement measures required, within Classes.
- iv. Land Suitability Units: reflecting minor differences in required management within subclasses.

4.2.1 Land suitability orders

Land suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders, which can be shown on maps, tables, etc. by the symbols S and N respectively.

Order S (Suitable) is used for land on which sustained use of the kind under consideration is expected to yield benefits that justify the inputs, without unacceptable risk of damage to land resources.

Order N (Not Suitable) is applied to land which has qualities that appear to preclude sustained use of the kind under consideration. Land may be classed as Not Suitable for a given use for a number of reasons. It may be that the proposed use is technically impracticable, such as the irrigation of rocky steep land, or that it would cause severe environmental degradation, such as the cultivation of steep slopes. Frequently, however, the reason is economic: that the value of the expected benefits does not justify the expected costs of the inputs that would be required.

4.2.2 Land suitability classes

Land suitability classes reflect the degree of suitability. The classes are numbered consecutively, by Arabic numbers, in sequence of a decreasing degree of suitability within the Order. Within the order Suitable the number of classes is not specified. There might, for example, be only two, S1 and S2. The number of classes recognised should be kept to the minimum necessary to meet interpretative aims, five being probably be the most ever required. If three classes are recognised within the order Suitable, as can often be recommended, the following names and definitions may be appropriate in a qualitative classification:

Class S1 Highly Suitable. Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Class S2 Moderately Suitable. Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitation will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.
Class S3 Marginally Suitable. Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

In a quantitative classification, both inputs and benefits must be expressed in common measurable terms, normally economic. In different circumstances different variables may express most clearly the degree of suitability, e.g. the range of expected net income per unit area, or the net return per unit of irrigation water applied to different types of land. Where additional refinement is necessary it is recommended that this should be achieved by adding classes, e.g. S4, and not by subdividing classes, since the latter procedure would contradict the principle that degrees of suitability are represented by only one level of the classification structure, that of the suitability class.

Differences in degrees of suitability are determined mainly by the relationship between benefits and inputs. The benefits may consist of goods, e.g. crops, livestock products or timber, or services, e.g. recreational facilities. The inputs needed to obtain such benefits comprise such things as capital investment, labour, fertilisers and power. Thus an area of land might be classed as Highly Suitable for rainfed agriculture, because the value of crops produced substantially exceeds the costs of farming, but only Marginally Suitable for forestry, on grounds that the value of ' only slightly exceeds the costs of obtaining it. It should be expected that boundaries between suitability classes will need renewal and revision with time in the light of technical development and economic and social change.

Within the order Not Suitable, there are normally two classes :
Class N1 currently Not suitable : Land having limitations which may be surmountable in time but which can not be corrected with existing knowledge or at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in an economic manner.
Class N2 permanently Not Suitable : Land having limitations which appear so severe as to preclude any possibility of successful sustained use of the land under the proposed use.

Quantitative definition of these classes is normally unnecessary, since by definition both are uneconomic for the given use. The upper limit of class N1 is already defined by the lower limit of the least suitable class in Order S.

The boundary of class N2, permanently Not Suitable, is normally physical and permanent. In contrast, the boundary between the two orders, Suitable and Not Suitable is likely to be variable over time through changes in the economic and social context.

4.2.3 Land suitability subclasses

Land suitability subclasses reflect kinds of limitation, e.g. moisture deficiency, erosion hazards. Lower- case letters indicates subclasses with mnemonic significance, e.g. S2m, S2e, and S3me. There are obviously no subclasses in class S1.

The number of subclasses recognised and the limitations chosen to distinguish them will differ according to the purpose of the classification. There are two guidelines. Firstly, the number of subclasses should be kept to a minimum so that it will satisfactorily distinguish lands likely to differ significantly in their management requirements or potential for improvement due to differing limitations. Secondly, as few limitations as possible should be used in the symbol for any subclass. One, rarely two, letters should normally suffice. The dominant symbol (i.e. that which determines the class) should be used alone if possible. If two limitations are equally severe, both may be given.

Land within the Order Not Suitable may be divided into suitability subclasses according to kinds of limitation, e.g. N1m, N1me, N1m, although this is not essential. As this land will not be placed under management for the use concerned it should not be subdivided into suitability units.

The structure of the suitability classification, together with the symbols used, is summarised in table 5. Depending on the purpose, scale and intensity of the study, either the full range of suitability orders, classes, subclasses and units may be distinguished, or the classification may be restricted to the higher two or three categories.

Table 5 Structure of suitability classification

	Category		
Order	**Class**	**Subclass**	**Unit**
S – Suitable	S1	S2m	
	S2	S2e	S2e-1
			S2e-2
	S3	S3me	etc.
		etc.	etc.
N – Not suitable	N1	N1m	
	N2	N1e	
		etc.	

4.2.4 Classification table

On regularly irrigated fields, most of the lands are occupied by date-palm and numerous crops are cultivated, including vegetables and other crops such as banana, papaya, coconut and different local sorghum species.

Table 6 Land suitability for irrigated agriculture.

Mapping unit	Topography	Depth (cm)	Texture	Stoniness	Salinity	Carbonate content	Constraint	Suitability Classification
W	Almost flat	> 100	Silty loam and silty clay loam	Nil	Slightly saline	Strongly calcareous	Nil	S
P	Gently sloping	50-100	Sandy loam And silty clay loam	Many	Highly saline	Strongly calcareous	Topography, stoniness salinity, fertility, moisture	S2t, n, s, f, m
S	Flat	< 50	Loamy sand to sandy loam	Common	Moderately saline	Strongly calcareous	Depth, texture, stoniness, fertility, moisture	N1

t: texture, n: stoniness s: salinity f: fertility m: moisture (Units B1 and M1 are miscellaneous land types, and have not been included in table 6)

Table 7 Land suitability classes for the different mapping units for adapted crops

Mapping Unit	Date-Palm	Papaya	Banana	Sorghum	Millet	Sesame	Alfalfa	Vegetables (water-melon, sweet potato, onions, tomatoes, egg plant, okra, radish etc.)
W	S	S2 f	S2 f	S	S2 f	S2 f	S1	S
P	S2 m, f	S3 s, f, m	S2 s, m, f	S2 m	N1s, m, f	S3 s, f, m	S2 s, m	S3 s, m, f
S	N2	N2	N2	S3 m, d, f	N2	N2	N1	N1

4.2.5 CROP REQUIREMENTS

Crop requirements for some crops, presently grown in the survey area, are listed in Appendix 5. The information is based on Technical note 3, "Crop Requirement Tables for Yemen" (Wen, 1998).

The tables in Technical Note 3 have been largely compiled from international literature data. However, the particular situation in Yemen has been taken into account. Slope criteria have, for instance, not been included, as in Yemen virtually all agriculture takes place on level land (terraces and plains). Where available, information on conditions under which a crop in Yemen grows has been incorporated. For one potato and one sorghum variety sufficient data could be found to compile a complete table for that particular variety, in other cases the information appears in the notes. For several crops, in particular tree crops, not sufficient data could be found to prepare suitability tables, and only the tables with basic climatic and soil requirements could be compiled.

The main important crops, presently grown in the study area are: date-palm, sorghum, millet, banana, papaya, tomato, onion, eggplant, okra, radish, paper, water melons. The crop requirements tables are given in appendix 5.

Chapter 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the results of the survey and investigation described in the foregoing, the following main conclusions may be arrived at.

- The main soils in the Upper Hajar area have formed through accumulation of flood deposits over many years (wadi terraces, W). These stratified and medium textured soils have a good potential for arable cropping due to their inherent fertility.
- The alluvial material generally has a low content of soluble salts and is non-sodic. Calcium carbonate contents are less than 30%. pH values range from 7.5 to 9. Organic matter contents are low, generally less than 1%. Nitrogen contents are very low (0.01-0.5%).
- The soils outside the alluvial system either sandy to loamy or shallow and stony (sand plain S).
- The in-situ developed soils are characterised by a high gypsum and or calcium content. The soil layers are cemented and often have massive structure throughout the profiles (Pediments, P)
- The greatest variation of saline soils was recorded in the footslope area (Pediment, P), around Al-Ghaol, Hesen Ba Omar and Al-Sadarah village, where the soil EC ranges for 14 to 37 mS/cm). The recorded soil salinization peculiarities and variations were considered in the work program and surveys of the study area.
- Large part of the alluvial soils (unit W) are moderately to highly suitable to date-palm plantation, some fruit trees (Bananas and Papayas), arable cropping and vegetables.
- The soils which classified as marginally (unit P) to not suitable (unit S) for agriculture have the following limiting factors:
  - High salinity level of surface and subsurface layers.
  - Coarse gravel and stones situated at sallow depth below the surface.
  - Cementation by gypsum in either surface or subsurface layers.

5.2 RECOMMENDATIONS

From the field observations and inspection, data collected and experience gained, it become evident that the land is suited to expanding agricultural production. Further investigation and surveys are strongly recommended, taking into account the following consideration.

- Monitoring the chemical characteristics, particularly salinity, of the soils and irrigation water every year will enable farmers to take timely measures to avoid salinization of their land.
- Improved management of the land to avoid or minimize erosion by water and wind.
- The possibility of adding organic matter and artificial nutrients, in particular nitrogen, should be investigated. The continuous culture of date-palm and perennial crops, with no replenishment of nutrients, leads inevitably to an impoverishment of the soils.

- The quality of stratified alluvial soils through the measurement of their permeability and infiltration in the field is necessary to determine their behaviour under irrigation conditions.
- Constructing drainage canals along the saline field in order to remove the concentration salts through these canals after leaching the soil periodically.
- Economic analysis of different land utilisation types is important for sustainable production.
- Leaching the salts from saline soils to the desired depth will alone not produce any durable results, unless the salts leached are removed from the land. For this purpose it is considered essential to improve the drainage of the soils by artificial measures. Leaching just as irrigation should be accomplished using water taken from the wadi, the only perennial stream in the region. Leaching and irrigation should be scheduled relative to each other in such manner that excessive salts have been leached from the soil profile before the start of the irrigation season.
- Crop yields can be increased considerably only if an integrated package, that takes into account the peculiarities of the valley, of more advanced irrigation techniques, together with improved land and crop husbandry is introduced in the region.
- Rational land use can be realised by appropriately selected crops.

APPENDIX 1 REFERENCES

Al-Khorasani, Mohamed. 1999. The relationship between elevation and altitude in Yemen. FAO project GCP/YEM/021/NET. Technical Note 7. AREA, Dhamar.

Al-Mashreki, M.H. 1997. Land resource study of Hodeidah Green Belt. FAO project GCP/YEM/021/NET Field Document AREA, Dhamar.

Belder, Marleen. 1998. The soils of the south-eastern coastal area. Part 1. The soils of Ghail Bawazir area. FAO project GCP/YEM/021/NET Field document 20. AREA Dhamar.

Bruggeman H.Y. 1997. Agro-climatic resources of Yemen. Part 1. Agro-climatic inventory. FAO project GCP/YEM/021/NET Field document 11. AREA, Dhamar.

Bahamish H.S 1998, Agriculture in the southeastern coastal area. part 1, cropping system and practices in Upper Hajar and Ghail Bawazir. FAO project GCP/YEM/021/NET Field document 22. Renewable Natural Resources Research Centre. AREA. Dhamar

FAO, ISSS, ISRIC. 1998. World Reference Base for Soil Resources. World Soil Resources Reports 84. FAO, Rome.

FAO - ISRIC. 1990. Guidelines for soil description (3 rd Edition, revised), Soil Resource Management and Conservation Service, Land and Water Development Division. FAO, Rome.

FAO. 1988. Salt-affected soils and their management. FAO Soils Bulletin 39. FAO, Rome.

Hunting Technical Services. 1967. Report on a soil survey and land classification of Ahwar area.

Kazgiprovodkhoz Institute and Directorate Soviet - Yemen Project in Irrigation. 1990. Scheme of groundwater utilization in wadis Rabwa and Ahwar, PDRY. Volume 1. Wadi Rabwa. Appendix 2. Soils. Book 1. Report. Moscow and Aden

Landon, J.R (Editor)1996, Booker Tropical Soil Manual, A handbook for soil survey and agricultural land evaluation in the tropical and subtropics. Longman, Harlow

Mohamed Ali, El-Abbas D. 1997. The soil of El-Kod research farm. FAO project GCP/YEM/021/NET Field Document 11. AREA, Dhamar.

Mohamed Ali, El-Abbas D., and Wen Ting-tiang. A framework for soil series in Yemen. Part 1. Existing soil series. FAO project GCP/YEM/021/NET Field Document 2. AREA, Dhamar.

Robinson

TESCO - Viziterv. 1984. Wadi Hajar Agricultural Rehabilitation Project, PDRY. Final report. Soil survey. Budapest.

USDA. 1994. Keys to Soil Taxonomy, Sixth Edition. Soil Conservation Service, Dept. of Agriculture. Washington D.C.

van Wambeke, A. 1982. Soil moisture and temperature regimes, Africa, Soil Management Support Services Technical Monograph 3, Ithaca.

Wen Ting-Tiang. 1998. Crop requirement tables for Yemen. FAO project GCP/YEM/021/NET Technical note 3. AREA, Dhamar.

APPENDIX 2 METHODS OF ANALYSIS

Soil and water laboratory analysis:

Following is a summary of analytical methods used in AREA Dhamar laboratory to analyze soil and water samples collected from different parts of the country. The summary was prepared by Dr. A.E.Fadl - Soil chemical analysis expert.

Analytical methods used:

Soils analysis:

All results refer to oven dry soil sieved through 2 m/m sieve.

1 Soil Reaction (pH) is determined by pH meter in soil saturation extract. A model WTW pH 422 pH meter is used

2 Total soluble salts (E.C.)
Saturation paste is prepared by adding soil to a known quantity of distilled water to the saturation point. Saturation extract is sucked off using vacuum. E.C. of saturation extract is read off an E.C. model WTW meter and expressed in dS/cm at 25°C.

3 Calcium carbonate : Acid neutralization method is used.

4 Organic carbon : Modified Walkley - Black method is used.

5 Total Nitrogen : Measured according to the standard Kjeldahl method using distillation and titration units as applaud.

6 Available phosphorus : Olsen method (0.5 M sodium bicarbonate extraction).

7 Cation Exchange Capacity : Saturation of the soil colloidal complex is effected with IN sodium acetate at pH 8.2 and excess salt is removed with ethanol. Sodium is then replaced by ammonium, using IN ammonium acetate at pH 7.0 and concentration of sodium is determined in the final solution by flame photometry.

8 Exchangeable cations : Exchangeable Na and K are determined in ammonium acetate leachate. Results are corrected for water soluble Na and K and net exchangeable values are reported. Exchangeable Ca and Mg are determined in the same leachate if soils are non-calcareous, or by difference calculation from CEC in calcareous soils.

9 The following parameters are obtained by direct calculation.
1. ESP
2. SAR

10Mechanical Analysis : A modified hydrometer method is used which involves the following three stages :

a. Removal of soluble salts and complete dispersion in calgon

b. Separation of total sand by wet sieving followed by division into 5 sand components, (USDA) system, by dry sieving.

c. Determination of the clay fraction in the dispersed sample by hydrometer and calculation of silt by difference.

The soils rich in $CaCO_3$ and organic matter will have a special treatment. The fine earth fraction (less than 2 millimeters) is used for the test, and USDA system of the particle size grade is adopted to express results of the different fractions i.e.

very coarse sand	2.0 - 1.0 mm
Coarse sand	1.0 - 0.5 "
Medium sand	0.5 - 0.25 "
Fine sand	0.25 - 0.1 "
V. fine sand	0.1 - 0.05 "
Silt	0.05 - 0.002 "
Clay	< 0.002 "

Water analysis:

The methods used for analysis of water are essentially those used for the analysis of water extracts of soil obtained at saturation. The methods described in FAO Bulletin No.10 "Physical and Chemical Methods of Soil and Water Analysis" 1988

APPENDIX 3

SOIL PROFILE DESCRIPTIONS AND ANALYTICAL DATA

Soil profile 1

GENERAL DESCRIPTION

Profile code :	UPH001	Date :	14/12/97
Authors :	M. Al-Mashreki, F. Mutlaq, Ali Al-Najar		
Soil classification :	Haplic Gypsisol (WRB, 1998)		
	Typic Haplogypsid, fine silty, hyperthermic (USDA 1994)		
Location :	Hesn Ba Amer, Upper Hajar		
Map co-ordinates (UTM)		Longitude :	833958.75 E
Map sheet :	D-39-49	Latitude :	1605911.88 N
Elevation :	372 m a.s.l	Slope :	0-1%
Landform :	dissected plain	Land element :	plain
Topography :	flat	Micro-topography :	ploughing ridges
Land use :	irrigated farming	Human influence :	-
Crops :	-		
Vegetation :	dwarf shrubland (10% cover)		
Parent material :	alluvium/colluvium		
Effective soil depth :	> 1 m	Groundwater depth :	not observed
Erosion :	-	Sealing/crusting :	moderate sealing
Rock outcrops :	-	Surface stones :	nil
Drainage :	moderately well		
Permeability :	-		
Moisture conditions :	0-35 cm dry		
Remarks :			

PROFILE DESCRIPTION

Ap	0 - 5 cm	pale brown (10YR 6/3, moist) and very pale brown (10YR 7/3, dry) silty clay loam; weak fine subangular blocky; hard (dry), friable (moist), sticky and plastic (wet); few very fine channels pores; few very fine roots; strongly calcareous; clear and smooth boundary
AB	5 - 15 cm	brown (10YR 5/4, moist) and very pale brown (10YR 7/4, dry) silty clay loam; very weak fine subangular blocky; slightly hard (dry), friable (moist), sticky and plastic (wet); common fine channels pores; common fine roots; strongly calcareous; clear and smooth boundary
By1	15 - 35 cm	brown (10YR 5/4, moist) and very pale brown (10YR 7/4, dry) silty clay loam; very weak very fine subangular blocky structure; slightly hard (dry), friable (moist), sticky and plastic (wet); many hard gypsum crystals; common fine channels pores; common fine roots; strongly calcareous; clear and smooth boundary
By2	35 - 50 cm	brown (10YR 5/4, moist) silty clay loam; very weak fine subangular blocky structure; slightly hard (dry), friable (moist), sticky and plastic (wet); common hard gypsum crystals; many medium channels pores; many medium roots; strongly calcareous; clear and smooth boundary
C	50 - 110 cm	dark grayish brown (10YR 4/2, moist) silty clay loam; massive structure; few fine vugh pores; strongly calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS Profile UPH001

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/52	0 - 15	-	0	1	1	15	20	47	16	loam
98/53	15 - 35	-	1	2	9	13	17	42	16	loam
98/54	35 - 50	-	3	4	6	0	7	53	27	silt loam
98/55	45 - 60	-	0	2	4	1	0	63	30	silty clay loam
98/56	60 - 110	-	1	2	2	2	4	66	23	silt loam

Lab. No.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/52	0 - 5	7.4	130	370	13	0.03	433	7
98/53	5 - 15	8.0	5.8	410	15	0.03	500	7
98/54	15 - 35	8.0	6.3	390	-	-	-	-
98/55	35 - 50	8.2	2.7	390	-	-	-	-
98/56	50 - 110	8.0	3.6	600	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/52	0 - 5	-	-	8.5	4.3	-	-	-
98/53	5 - 15	-	-	15	3.9	-	-	-
98/54	15 - 35	-	-	5.5	1.8	-	-	-
98/55	35 - 50	-	-	3.0	1.1	-	-	-
98/56	50 - 110	-	-	2.9	0.7	-	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/52	0 - 5	2025	105	54	82	61	0.0	4	2201	145.6
98/53	5 - 15	230	50	54	82	52	0.0	4	360	360
98/54	15 - 35	36.5	3	12	16	15	0.0	4	48.5	48.5
98/55	35 - 50	18.5	0.6	3.3	3.5	13	0.0	2	10.6	10.6
98/56	50 - 110	13.5	0.5	15.3	26.7	4.7	0.0	7	44.3	44.3

Soil profile 2

GENERAL DESCRIPTION

Profile code :	UPH002	Date :	24/12/97
Authors :	M. Al-Mashreki, F. Mutlaq, Ali A. Al-Najar		
Soil classification :	Calcaric Fluvisol (WRB, 1998) Typic Torrifluvent, coarse loamy, hyperthermic (USDA 1994)		
Location :	Al-Sadarah, Upper Hajar		
Map co-ordinates (UTM)		Longitude :	832533.438 E
Map sheet :	D-39-49	Latitude :	1605804.63 N
Elevation :	420 m a.s.l	Slope :	0-1%
Landform :	valley in moun-ainous area	Land element :	alluvial plain
Topography :	flat	Micro-topography:	even
Land use :	irrigated farming	Human influence :	long-continued irrigation
Crops :	mainly date-palm		
Vegetation :	dwarf shrubland (20% cover)		
Parent material :	alluvium		
Effective soil depth :	120 cm	Groundwater depth:	not observed
Erosion :	-	Sealing/crusting :	slight sealing
Rock outcrops :	few rocks	Surface stones :	very few gravel
Drainage :	moderately well		
Permeability :	-		
Moisture conditions :	0-15 cm dry		

PROFILE DESCRIPTION

Ap	0 - 15 cm	very dark grayish brown (10YR 3/2, moist) and grayish brown (10YR 5/2, dry) silty clay loam; very weak fine subangular blocky; slightly hard (dry), friable (moist), sticky and plastic (wet); few distinct pore and void clay cutans; continuous weakly compacted; many coarse channel pores; common medium roots; extremely calcareous; gradual and irregular boundary.
C1	15 - 50 cm	brown (10YR 4/3, moist) and grayish brown (10YR 5/2, dry) silty clay loam; very weak fine subangular blocky structure; slightly hard (dry), very friable (moist), sticky and plastic (wet); few distinct clay cutans in voids; continuous slightly compacted; few fine channel pores; many coarse roots; extremely calcareous; gradual and irregular boundary
C2	50 - 70 cm	brown (10YR 4/3, moist) silty clay loam; massive structure; soft (dry), very friable (moist), sticky and plastic (wet); few faint clay cutans on pedfaces; continuous weakly compacted; few fine channel pores; many coarse roots; extremely calcareous; abrupt and irregular boundary
2C1	70 -120 cm	brown (10YR 4/4, moist) sandy clay loam; massive structure; loose (moist), slightly sticky and slightly plastic (wet); few very fine channels pores; few coarse roots; strongly calcareous; clear and smooth boundary
2C2	120+	brown (10YR 4/3, moist) sandy clay loam; loose (moist), slightly sticky and slightly plastic (wet); few coarse roots; strongly calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS   Profile UPH002

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/57	0 - 15	-	0	0	6	22	18	34	20	loam / clay loam
98/58	15 - 50	-	0	0	14	52	20	6	8	sandy loam
98/59	50 - 70	-	1	2	10	21	23	27	16	sandy loam
98/60	70 - 120	-	6	18	29	13	5	16	13	sandy loam
98/61	120+	-	1	3	11	9	5	40	31	clay loam

Lab. No.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/57	0 - 15	8.3	6.1	440	13	0.03	433	4
98/58	15 - 50	8.4	4.4	560	6	0.01	600	2
98/59	50 - 70	8.1	4.6	540	-	-	-	-
98/60	70 - 120	7.7	7.2	700	-	-	-	-
98/61	120+	7.5	16.1	-	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/57	0 - 15	-	-	2.1	0.6	10.6	-	-
09/58	15 - 50	-	-	1.3	0.2	4.5	-	-
98/59	50 - 70	-	-	2.0	0.5	10.7	-	-
98/60	70 - 120	-	-	8.0	0.4	8.6	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/57	0 - 15	36.5	1	7.3	10.7	39	0.0	3	13.5	12
98/58	15 - 50	33.5	0.7	1.3	12.7	30	0.0	2	16.2	12
98/59	50 - 70	36.5	2.8	6.0	6.7	29	0.0	4	19	15
98/60	70 - 120	850	0.6	106.7	38.6	37	0.0	4	954	100
98/61	120 +	1125	22.7	41.3	88.7	54	0.0	2	1228	139

Soil profile 3

GENERAL DESCRIPTION

Profile code :	UPH003	Date :	24/12/97
Authors :	M. Al-Mashreki, F. Mutlaq, Ali A. Al-Najar		
Soil classification :	Calcaric Regosol (WRB, 1998)		
	Typic Torriorthent, fine loamy, hyperthermic, mixed (USDA, 1994)		
Location :	Om Al-Shatr, Upper Hajar		
Map co-ordinates (UTM)		Longitude :	839711.313 E
Map sheet :	D-39-49	Latitude :	1603080.50 N
Elevation :	390 m a.s.l	Slope :	1-2%
Landform :	valley in mountainous area	Land element :	wadi flood plain (near side slope)
Topography :	almost flat	Micro-topography :	even
Land use :	irrigated farming	Human influence :	-
Crops :	date-palm		
Vegetation :	dwarf shrubland (20% cover)		
Parent material :	alluvium		
Effective soil depth :	> 120 cm	Groundwater depth :	not observed
Erosion :	-	Sealing/crusting :	nil
Rock outcrops :	very few rocks	Surface stones :	very few
Drainage :	well		
Permeability :	-		
Moisture conditions :	0-120 cm dry		
Remarks :			

PROFILE DESCRIPTION

A	0 - 55 cm	dark yellowish brown (10YR 4/4, moist) and very pale brown (10YR 7/4, dry) silty loam; very weak very fine subangular blocky; very hard (dry), friable (moist), slightly sticky and slightly plastic (wet); continuous, weakly cemented; many fine interstitial pores; very few very fine roots; strongly calcareous; clear and smooth boundary
C1	55 - 85 cm	brownish yellow (10YR 6/6, moist) and very pale brown (7/4, dry) loamy sand; massive structure; loose (dry) loose (moist), non sticky and non plastic (wet); common very fine interstitial pores; very few fine roots; strongly calcareous; clear and smooth boundary
C2	85 - 120 cm	light yellowish brown (10YR 6/4, moist) and very pale brown (10YR 8/4, dry) silty loam; massive structure; slightly hard (dry), loose (moist), slightly sticky and slightly plastic (wet); continuous weakly cemented; common very fine interstitial pores; very few fine roots; strongly calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS Profile UPH003

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/62	0 - 55	-	0	1	8	7	5	49	30	clay loam
98/63	55 - 85	-	3	6	11	9	12	31	28	clay loam / loam
98/64	5 - 120	-	3	7	13	7	9	29	32	clay loam

Lab. no.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/62	0 - 55	7.8	14.4	495	18	0.03	600	2
98/63	55 - 85	6.6	43.5	610	17	0.07	243	2
98/64	85 - 120	7.1	29.3	610	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/62	0 - 55	-	-	72	3.4	-	-	-
98/63	55 - 85	-	-	33.5	2.3	-	-	-
98/64	85 - 120	-	-	2.8	2.3	-	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/62	0 - 55	120	20.5	32	37.3	37	0.0	3	170	-
98/63	55 - 85	40	14	23.3	24	10	0.0	3	88	-
98/64	85 - 120	280	10.5	10	10	9	0.0	4	297	-

Soil profile 4

GENERAL DESCRIPTION

Profile code :	UPH004	Date :	24/12/97
Authors :	M. Al-Mashreki, F. Mutlaq, Ali A. Al-Najar		
Soil classification :	Calcaric Gypsisol (WRB, 1998) Typic Haplogypsid, coarse loamy over clayey, mixed (USDA, 1994)		
Location :	Al-Hergah, Upper Hajar		
Map co-ordinates (UTM)		Longitude :	835204.125 E
Map sheet :	D-39-49	Latitude :	1602832 N
Elevation :	390 m a.s.l	Slope :	0-1%
Landform :	valley in mountainous area	Land element :	upper slope
Topography :	flat	Micro-topography :	even
Land use :	grazing	Human influence :	-
Crops :	-		
Vegetation :	dwarf shrubland (20% cover)		
Parent material :	alluvium		
Effective soil depth :	> 1 m	Groundwater depth :	not observed
Erosion :	-	Sealing/crusting :	nil
Rock outcrops :	-	Surface stones :	very few
Drainage :	imperfectly		
Permeability :	-		
Moisture conditions :	0-100 cm dry		
Remarks :			

PROFILE DESCRIPTION

Ap	0 - 8 cm	brown (10YR 5/3, moist) and light gray (10YR 7/3, dry) sandy loam; single grain structure; loose (dry), loose (moist), non sticky and non plastic (wet); many fine flat fresh and slightly weathered rock fragment; many very fine interstitial pores; nil roots; strongly calcareous; clear and smooth boundary
By	8 - 30 cm	brown (10YR 4/3, moist) and brown (10YR 5/3, dry) silty clay loam; massive structure; hard (dry), firm (moist), sticky and plastic (wet); continuous massive weakly cemented; many gypsum crystals and aggregates; many coarse plane pores; nil roots; strongly calcareous; abrupt and irregular boundary
Bw	30 - 45 cm	very dark grayish brown (10YR 3/1, moist) and very dark grayish brown (10YR 3/2, dry) silty clay loam; moderate medium subangular blocky; hard (dry), firm (moist), sticky and plastic (wet); continuous nodular weakly cemented; few gypsum crystals; many medium plane pores; nil roots; strongly calcareous; clear and wavy boundary
C1	45 - 65 cm	dark grayish brown (10YR 4/2, moist) and brown (10YR 5/3, dry) silty clay loam; massive structure; slightly hard (dry), friable (moist), sticky and plastic (wet); continuous massive weakly cemented; common medium plane pores; nil roots; extremely calcareous; gradual and irregular boundary
C2	65 - 100	light brownish gray (10YR 6/1, moist) and light gray (10YR 7/1, moist) silty clay loam; massive structure; hard (dry), firm (moist), sticky and plastic (wet); continuous massive strongly cemented; few fine interstitial pores; nil roots; extremely calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS Profile UPH004

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/65	0 - 8	-	1	0	6	28	24	10	31	sandy clay loam
98/66	8 - 30	-	0	1	22	39	17	9	12	sandy loam
98/67	30 - 45	-	1	1	35	34	11	9	9	loamy sand
98/68	45 - 60	-	3	5	10	12	11	40	19	loam
98/69	60 - 100	-	0	1	1	1	8	51	38	loam

Lab. no.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/65	0 - 8	8.3	1.6	520	16	0.07	229	3
98/66	8 - 30	7	18.5	600	9	0.04	225	1
98/67	30 - 45	8.3	1.3	610	-	-	-	-
98/68	45 - 65	8.1	7.8	640	-	-	-	-
98/69	65 - 100	8.1	4.6	490	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/65	0 - 8	-	-	3	0.3	-	-	-
98/66	8 - 30	-	-	1	0.2	-	-	-
98/67	30 - 45	-	-	-	0.2	-	-	-
98/68	45 - 65	-	-	-	0.8	-	-	-
98/69	65 - 100	-	-	-	1.1	-	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/65	0 - 8	1.5	0.5	5.3	2.7	2	0.0	4	4	5
98/66	8 - 30	112.5	1	18.7	26	9	0.0	3	146	24
98/67	30 - 45	0.7	0.3	18.7	4.6	8	0.0	3	13.3	<1
98/68	45 - 60	43	1.4	38.7	17.3	70	0.0	2	28	8
98/69	65 - 100	27	0.7	37.3	16.7	35	0.0	2	44	5

Soil profile 5

GENERAL DESCRIPTION

Profile code :	UPH005	Date :	24/12/97
Authors :	M. Al-Mashreki, F. Mutlaq, Ali A. Al-Najar		
Soil classification :	Calcaric Regosol (WRB, 1998)		
	Typic Torriorthent, fine loamy, hyperthermic, mixed (USDA, 1994)		
Location :	Manzel Al-Ghamera, Upper Hajar		
Map co-ordinates (UTM)		Longitude :	835692.625 E
Map sheet :	D-39-49	Latitude :	1604373.63 N
Elevation :	420 m.a.s.l	Slope :	0-1%
Landform :	valley in mountainous area	Land element :	wadi floodplain
Topography :	flat	Micro-topography :	ploughing ridges
Land use :	irrigated farming	Human influence :	-
Crops :	-		
Vegetation :	no (semi-) natural vegetation		
Parent material :	alluvium		
Effective soil depth:	> 1 m	Groundwater depth :	not observed
Erosion :	-	Sealing/crusting :	nil
Rock outcrops :	few rocks	Surface stones :	very few
Drainage :	excessive		
Permeability :	-		
Moisture conditions :	0-45 cm dry		
Remarks :			

PROFILE DESCRIPTION

Ap	0 - 15 cm	light yellowish brown (10YR 6/4, moist) and pale brown (10YR 7/3, dry) sandy loam; single grain structure; loose (dry), loose (moist), non sticky and non plastic (wet); common very fine vugh pores; abundant medium roots; non calcareous; clear and smooth boundary
C1	15 - 45 cm	light yellowish brown (10YR 6/4, moist) and very pale brown (10YR 7/4, dry) loamy sand; massive structure; soft (dry), very friable (moist), non sticky and non plastic (wet); common fine interstitial pores; common fine roots; non calcareous; abrupt and wavy boundary
C2	45 - 130 cm	light yellowish brown (10YR 6/4, moist) and very pale brown (10YR 4/4, dry) loamy sand; massive structure; loose (dry), loose (moist), non sticky and non plastic (wet); common very fine interstitial pores; common fine roots; non calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS Profile UPH005

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/70	0 - 15	-	0	0	1	2	5	75	17	silt loam
98/71	15 - 45	-	1	3	5	19	15	36	21	loam
98/72	45 - 130	-	0	0	4	18	25	33	20	loam

Lab. no.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/70	0 - 15	8.2	4.9	420	17	0.04	425	4
98/71	15 - 45	8.2	4.1	560	7	0.03	233	2
98/72	45 - 130	7.9	13.3	570	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/70	0 - 15	-	-	4.8	1.0	-	-	-
98/71	15 - 45	-	-	3.8	0.4	-	-	-
98/72	45 - 130	-	-	5.4	0.4	-	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/70	0 - 15	27	0.5	12.7	10.6	36	0.0	2	11.8	8
98/71	15 - 45	6.3	1.5	54.7	10.6	69	0.0	2	2.1	1
98/72	45 - 130	97	1.1	34.7	17.3	8	0.0	2	148	19

Soil profile 6

GENERAL DESCRIPTION

Profile code :	UPH006	Date :	26/12/97
Authors :	M. Al-Mashreki and Ali A. Al-Najar		
Soil classification :	Calcaric Fluvisol (WRB, 1998) Typic Torrifluvent, fine loamy, hyperthermic, mixed (USDA, 1994)		
Location :	Al-Ghoal, Upper Hajar		
Map co-ordinates (UTM)		Longitude :	836424.875 E
Map sheet :	D-39-49	Latitude :	1603571 N
Elevation :	420 m a.s.l	Slope :	1-2%
Landform :	valley in mountainous area	Land element :	floodplain (near side slope)
Topography :	flat	Micro-topography :	even
Land use :	irrigated farming	Human influence :	-
Crops :	-		
Vegetation :	dwarf shrubland (20% cover)		
Parent material :	colluvium		
Effective soil depth :	> 100 cm	Groundwater depth :	not observed
Erosion :	-	Sealing/crusting :	strong sealing
Rock outcrops :	few rocks	Surface stones :	common gravel
Drainage :	imperfectly		
Permeability :	-		
Moisture conditions :	dry throughout		
Remarks :			

PROFILE DESCRIPTION

Ap	0 - 20 cm	yellowish brown (10YR 5/4, moist) and very pale brown (10YR 7/4, dry) silty clay loam; massive structure; hard (dry), firm (moist), sticky and plastic (wet); many medium subrounded fresh and slightly weathered rock fragments; continuous massive weakly cemented; common fine channel pores; common fine roots; strongly calcareous; clear and smooth boundary
BA	20 - 35 cm	yellowish brown (10YR 5/4, moist) and pale brown (10YR 6/3, dry) silty clay loam; very weak very fine granular structure; hard (dry), firm (moist), sticky and plastic (wet); continuous weakly cemented; common fine channel pores; common fine roots; strongly calcareous; clear and smooth boundary
Bw	35 - 45 cm	yellowish brown (10YR 5/4, moist) and very pale brown (10YR 7/3, dry) silty clay loam; weak fine subangular blocky; hard (dry), firm (moist), sticky and plastic (wet); weakly cemented; few very fine vugh pores; few very fine roots; strongly calcareous; clear and wavy boundary
C	45 - 60 cm	yellowish brown (10YR 5/4, moist) and yellow (10YR 7/6, dry) sandy clay loam; massive structure; soft (dry); friable (moist), sticky and plastic (wet); continuous weakly cemented by carbonates and gypsum; few very fine channel pores; few very fine roots; strongly calcareous; clear and smooth boundary
C2	60 - 100	light yellowish brown (10YR 6/4, moist) and very pale brown (10YR 7/3, dry) sandy loam; massive structure; loose (dry), very friable (moist), non sticky and non plastic (wet); nil pores; nil roots; strongly calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS Profile UPH006

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/73	0 - 20	-	1	3	7	8	12	60	9	silt loam
98/74	20 - 35	-	1	4	7	8	15	43	22	loam
98/75	35 - 45	-	1	3	5	4	12	52	23	silt loam
98/76	45 - 60	-	1	2	6	5	13	63	10	silt loam
98/77	60 - 100	-	3	10	18	11	12	25	21	sandy clay loam

Lab. no.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/73	0 - 20	7.8	16/8	580	6	0.1	60	4
98/74	20 - 35	8.2	24.6	520	13	0.03	433	4
98/75	35 - 45	-	28.9	490	-	-	-	-
98/76	45 - 60	7	16	560	-	-	-	-
98/77	60 - 100	6.9	8.6	423	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/73	0 - 20	-	-	4.2	0.3	-	-	-
98/74	20 - 35	-	-	12.5	1.9	-	-	-
98/75	35 - 45	-	-	11.4	3.2	-	-	-
98/76	45 - 60	-	-	8.1	1.4	-	-	-
98/77	60 - 100	-	-	4.0	1	-	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/73	0 - 20	268	40.5	48.7	314	29	0.0	1	641	20
98/74	20 - 35	14	14	38	46.7	22	0.0	2	88.7	2.0
98/75	35 - 45	123	7.3	58	56	22	0.0	4	107.6	2
98/76	45 - 60	17	0.6	32	40	30	0.0	2	57.6	3
98/77	60 - 100	10.3	3.5	24.7	23.3	50	0.0	3	8.8	2

Soil profile 7

GENERAL DESCRIPTION

Profile code :	UPH007	Date :	25/12/97
Authors :	M. Al-Mashreki, F. Mutlaq and Ali A. Al-Najar		
Soil classification :	Calcaric Regosol (WRB, 1998)		
	Typic Torriorthent, fine loamy, hyperthermic, mixed (USDA, 1994)		
Location :	Al-Hotah, Upper Hajar	Longitude :	846129.938 E
Map co-ordinates (UTM)		Latitude :	1602886.50 N
Elevation :	370 m a.s.l.	Slope :	0-1%
Landform :	valley in mountainous area	Land element :	floodplain
Topography :	flat	Micro-topography :	even
Land use :	irrigated farming	Human influence :	long-continued irrigation
Crops :	date-palm		
Vegetation :	no (semi-) natural vegetation		
Parent material :	alluvium	Moisture conditions :	0 - 30 cm dry
Effective soil depth:	> 1 m	Groundwater depth :	not observed
Erosion :	-	Sealing/crusting :	moderate sealing
Rock outcrops :	nil	Surface stones :	nil
Drainage :	moderately well	Permeability :	-

PROFILE DESCRIPTION

Ap	0 - 7 cm	brown (10YR 5/3, moist) and light gray (10YR 4/3, dry) silty clay loam; very weak fine subangular blocky; soft (dry), very friable (moist), sticky and plastic (wet); common fine channel pores; few fine roots; strongly calcareous; clear and smooth boundary
B1	7 - 30 cm	brown (10YR 4/3, moist) and yellowish brown (10YR 5/4, dry) silty clay loam; weak fine to medium subangular blocky; hard (dry), friable (moist), sticky and plastic (wet); continuous weakly cemented; common medium channel pores; common fine roots; moderately calcareous; clear and smooth boundary
B2	30 - 42 cm	brown (10YR 5/3, moist) silty clay loam; very weak fine subangular blocky; slightly hard (dry), friable (moist), sticky and plastic (wet); continuous weakly cemented; few fine channel pores; many medium roots; moderately calcareous; clear and smooth boundary
B3	42 - 55 cm	yellowish brown (10YR 5/4, moist) silty clay loam; very weak fine subangular blocky; slightly hard (dry), friable (moist), sticky and plastic (wet); continuous platy weakly cemented; few fine channel pores; common medium roots; moderately calcareous; clear and smooth boundary
B4	55 - 83 cm	light yellowish brown (10YR 6/1, moist) and light gray (10YR 7/1, dry) silty clay loam; weak fine subangular blocky; hard (dry), firm (moist), sticky and plastic (wet); continuous platy weakly cemented; few fine interstitial pores; nil roots; extremely calcareous; clear and smooth boundary
B5	83 - 110 cm	dark grayish brown (10YR 4/2, moist) silty clay loam; very weak very fine subangular blocky; slightly hard (dry), friable (moist), sticky and plastic (wet); continuous strongly cemented; few very fine interstitial pores; nil roots;

strongly calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS Profile UPH007

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/78	0 - 7	-	3	8	12	7	5	22	43	clay
98/79	7 - 30	-	5	16	24	11	8	13	23	sandy clay loam
98/80	30 - 42	-	0	1	5	12	13	42	27	loam / clay loam
98/81	42 - 55	-	0	1	3	6	7	44	39	clay loam
98/82	55 - 83	-	0	1	4	8	21	46	20	loam
98/83	83 - 110	-	1	0	1	1	6	68	23	silt loam

Lab. no.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/78	0 - 7	7.1	6.2	850	16	0.07	229	2
98/79	7 - 30	7.2	4.6	783	13	0.04	325	1
98/80	30 - 42	7.0	2.8	480	-	-	-	-
98/81	42 - 55	7.5	1.9	490	-	-	-	-
98/82	55 - 83	7.0	2.5	480	-	-	-	-
98/83	83 - 110	7.1	7.7	620	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/78	0 - 7	-	-	2.9	0.4	-	-	-
98/79	7 - 30	-	-	1.3	0.17	-	-	-
98/80	30 - 42	-	-	1.5	0.78	-	-	-
98/81	42 - 55	-	-	1.7	0.86	-	-	-
98/82	55 - 83	-	-	1.7	0.78	-	-	-
98/83	83 - 110	-	-	4.9	0.77	-	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/78	0 - 7	4.8	1.8	15.3	15.4	44	0.0	3	-	1
98/79	7 - 30	1.5	1.3	17.3	11.4	27	0.0	3	1.5	1
98/80	30 - 42	9.5	0.8	6.7	4.6	19	0.0	2	0.6	4
98/81	42 - 55	12.0	0.1	4.7	2.6	12	0.0	7	0.4	6
98/82	55 - 83	10.0	0.2	5.3	6.0	15	0.0	2	4.5	2
98/83	83 - 110	6.3	0.9	8	8	74	0.0	3	-	2

Soil profile 8

GENERAL DESCRIPTION

Profile code :	UPH008	Date :	26/12/97
Authors :	M. Al-Mashreki, F. Mutlaq and Ali A. Al-Najar		
Soil classification :	Calcaric Regosol (WRB, 1998)		
	Typic Torriorthent, fine loamy, hyperthermic, mixed (USDA, 1994)		
Location :	Jizwell, Upper Hajar		
Map co-ordinates (UTM)		Longitude :	846129.938 E
Map sheet :	D-39-49	Latitude :	1602886.50 N
Elevation :	220 m a.s.l.	Slope :	0-1%
Landform :	valley in mountainous area	Land element :	alluvial plain
Topography :	almost flat	Micro-topography :	even
Land use :	irrigated farming	Human influence	long-continued irrigation
Crops :	date-palm, sorghum, millet, vegetables		
Vegetation :	no (semi-) natural vegetation		
Parent material :	alluvium		
Effective soil depth :	> 1 m	Groundwater depth :	not observed
Erosion :	-	Sealing/crusting :	moderate sealing
Rock outcrops :	no rocks	Surface stones :	very few gravel
Drainage :	moderately well		
Permeability :	-		
Moisture conditions :	0 - 100 cm dry		
Remarks :			

PROFILE DESCRIPTION

Ap	0 - 55 cm	dark yellowish brown (10YR 4/4, moist) and yellowish brown (10YR 5/4, dry) sandy clay loam; moderate, fine to medium subangular blocky; slightly hard (dry), friable (moist), sticky and plastic (wet); very few fine sub-rounded weathered rock fragments; continuous compaction; many medium vugh pores; many fine roots; moderately calcareous; clear and irregular boundary
BA	55 - 80 cm	yellowish brown (10YR 5/4, moist) and yellowish brown (10YR 5/6, dry) silty clay loam; weak fine subangular blocky; slightly hard (dry), friable (moist), sticky and plastic (wet); very few fine subrounded weathered rock fragments; continuous compaction; common fine channel pores; few medium roots; moderately calcareous; abrupt and irregular boundary
Bw	80 - 100 cm	yellowish brown (10YR 4/6, moist) and yellowish brown (10YR 5/6, dry) silty clay loam; weak and moderate fine subangular blocky structure; slightly hard (dry), friable (moist), sticky and plastic (wet); common medium faint clear mottles; few coarse subrounded weathered rock fragment; continuous compaction; few very fine interstitial pores; very few medium roots; moderately calcareous

SOIL PHYSICAL AND CHEMICAL ANALYSIS Profile UPH008

Lab. no.	Depth (cm)	Particle size distribution (%)								Texture class
		>2 mm	VCS	CS	MS	FS	VFS	silt	clay	
98/84	0 – 55	-	3	8	15	11	7	29	27	loam
98/85	55 – 80	-	5	11	15	9	7	37	16	sandy loam / loam
98/86	80 – 110	-	2	5	11	22	14	34	12	sandy loam

Lab. no.	Depth (cm)	pH H_2O (1:1)	EC (dS/m)	$CaCO_3$ (g/kg)	Org. C (g/kg)	Total N (g/kg)	C/N ratio	Avail. P (mg/kg)
98/84	0 - 55	7.1	2.9	740	16	0.04	400	4
98/85	55 - 80	7.0	10.0	690	17	0.03	567	2
98/86	80 - 110	7.0	19.1	530	-	-	-	-

Lab. no.	Depth (cm)	CEC (cmol/kg)		Exch. bases (cmol/kg)				BS (%)
		soil	clay	Na	K	Ca	Mg	
98/84	0 - 55	-	-	2.6	0.45	-	-	-
98/85	55 - 80	-	-	4.6	0.47	-	-	-
98/86	80 - 100	-	-	5.0	0.96	-	-	-

Lab. no.	Depth (cm)	Soluble cations and anions (cmol/l)								SAR
		Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	
98/84	0 - 55	2.2	1.3	10	11.4	20	0.0	4	0.9	-
98/85	55 - 80	17.5	1.4	30	11.3	22	0.0	3	35.9	-
98/86	80 - 100	12.5	2.3	68	18.7	20	0.0	4	77.5	-

APPENDIX 4 AUGER DESCRIPTIONS

Auger no.	Soil depth	Texture	Landform/ land element	Land use	Location	Carbonates	Soil Tax. Classification WRB classification
UPH1	0-5 5-20 20-40	SiL SiCL SiCL	Dissected alluvial plain	Idle	Sombok Ba Kashim	Strongly calcareous	Lithic Torriorthent Eutric Regosol
UPH2	0-5 5-15 15-35	LS SL SL	Alluvial plain	Idle		Strongly calcareous	Lithic Torriorthent Eutric Regosol
UPH3	0-15 15-40 40-55 55-75 75-100	SiL SiCL SiL SiL L	Alluvial plain	Irrigated farming	Om Al-Shatr	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH4	0-30 30-50 50-80 80-100	L SL LS SL	Alluvial plain	Irrigated farming	Om Al-Shatr	Strongly calcareous	Typic Torrifluvent Calcaric Regosol
UPH5	0-10 10-20 20-50	SiL SiCL SiCL	Side slope	Irrigated farming	S.W. Hesen Ba Omar	Strongly calcareous	Typic Haplogypsid Calcaric Gypsisol
UPH6	0-20 20-40 40-50 50-70	SCL SiCL SiCL SCL	Alluvial fan	Irrigated farming	Hesen Ba Omar village	Strongly calcareous	Typic Haplosalid Haplic Solonchak
UPH7	0-10 10-40 40-80	SL SL SL	Fluviatile terrace	Irrigated farming	30 m from wadi bed, East of Al-Sadarah	Strongly calcareous	Typic Torriorthent Calcaric Regosol
UPH8	0-20 20-40 40-70 70-90	SiCL SiCL SiCL	Fluviatile terrace	Irrigated farming	S.E. Al-Sadarah	Strongly calcareous	Typic Torriorthent Calcaric Regosol
UPH9	0-20 20-40 40-70 70-100	SiCL SiCL SiCL SiCL	Fluviatile terrace	Irrigated farming	Al-Sadarah village	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH 10	0-20 20-65 65-95 95 +	SiCL SiCL SiCL	Alluvial fan	Irrigated farming	West of Al-Sadarah village	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH 11	0-50 50-75 75-100	SiCL SiCL SCL	Alluvial plain	Grazing	Manzel Al-Ghamerah village	Extremely calcareous	Typic Haplosalid Haplic Solonchak

Auger no.	Soil depth	Texture	Landform/ land element	Land use	Location	Carbonates	Soil Tax. Classification WRB classification
UPH 12	0-10 10-30 30-60 60-90 90-100	SL LS S LS LS	Fluviatile terrace	Irrigated farming	South of M Al-Ghamerah village	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH 14	0-20 20-45 45-80 80-100	SL SL SCL SiCL	Alluvial plain	Irrigated farming (Spring)	North of Al-Hergah village	Strongly calcareous	Typic Torriorthent Calcaric Regosol
UPH 15	0-15 15-50 50-80	SL SCL SiCL	Alluvial plain	Idle	N. E. Ba Musaibili village	Strongly calcareous	Typic Haplogypsid Calcaric Gypsisol
UPH 16	0-20 20-30 30+ stones	SiCL SiCL	Fluviatile terrace	Irrigated farming	100 m southern of Al-Gaol village	Strongly calcareous	Typic Torriorthent Calcaric Regosol
UPH 17	0-10 10-55 55-90 90-100	LS SL SCL SL	Fluviatile terrace	Irrigated farming	300 m south of Al-Gaol village	Strongly calcareous	Typic Torriorthent Calcaric Regosol
UPH 18 A	0-15 15-55 55-100	SiCL SiL CL	Levee	Irrigated farming	500 m south of Al-Gaol village	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH 18 B	0-15 15-45 45-50 50+stone	SiCL SiCL SCL	Fluviatile terrace	Irrigated farming	Southwest Al-Gaol village.	Extremely calcareous	Typic Torriorthent Calcaric Regosol
UPH 19	0-15 15-35 35-55 55-80 80-100	SiC SiC SCL SCL SCL	Alluvial plain	Irrigated farming	Al-Reyad village.	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH 20	0-15 15-30 30-45 45-80	SiCL SiCL CL SCL	Alluvial plain	Irrigated farming	South of Al-Reyad village	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH 21	0-40 40+ stones	SiCL SiCL	Alluvial plain	Grazing and irrig. farming	Al-Gaymah village	Strongly calcareous	Lithic Torrifluvent Calcaric Fluvisol
UPH 22	0-20 20-60 60-100	SL SL SCL	Alluvial plain	Irrigated farming	South of Al-Haimah village	Strongly calcareous	Typic Torriorthent Calcaric Regosol
UPH 23	0-20 20-70 70-80 80+stone	SiCL SiCL SiCL	Alluvial plain	Irrigated farming	Al-Sabahiah village	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol
	0-25 25-40 40-65 65-100	SiCL SiCL SiCL SiCL	Alluvial plain	Irrigated farming	Al-Houtah village	Strongly calcareous	Typic Torrifluvent Calcaric Fluvisol

Auger no.	Soil depth	Texture	Landform/ land element	Land use	Location	Carbonates	Soil Tax. Classification WRB classification
UPH 25	0-10 10-70 70-100	SiCL SiCL SiCL	Alluvial plain	Irrigated farming		Extremely calcareous	Typic Torrifluvent Calcaric Fluvisol
UPH 26	0-25 25-50 50-90 90-120	SiCL SCL SL SiCL	Alluvial plain	Irrigated farming	Goal Al-Somor	Moderately calcareous	Typic Torriorthent Calcaric Regosol
UPH 27	0-20 20-50 50-85 85-100	SiCL SL LS SL	Alluvial plain	Irrigated farming	500m south of Al-Somor village	Moderately calcareous	Typic Torriorthent Calcaric Regosol
UPH 28	0-20 20-40 40-60 60-90 90-100	SiCL SiCL SiCL SiCL SiCL	Alluvial plain	Irrigated farming	After Jizwell towards Al-Somor	Strongly calcareous.	Typic Torriorthent Calcaric Regosol
UPH 29	0-5	SiL	Alluvial plain	Irrigated farming	Jizwell	Strongly calcareous.	Typic Torrifluvent Calcaric Fluvisol

APPENDIX 5 CROP REQUIREMENT TABLES

Table 8 Crop requirements for date-palm (Phoenix dactylifera)

Main environmental and crop requirements		
characteristic	optimum	range
length of growing period (days)	215-365	
rainfall (mm)	200-300	100-400
mean temperature (°C)	25-45	10-52
relative humidity (%)	35-50	any
drainage	well	well to excessively
depth	very deep	mod.d-very deep
texture	light to medium	light to heavy
pH (H2O)	6.5-8.0	6.0-8.5
Ece (dS/m)	0-5	0- > 10
rooting depth (m)	up to 6 m	
water requirement (under irrigation)	1500-5000 mm (150-300 m3 per tree)	
average farmer's yield (t/ha)	8-30 kg/tree (1-4.5 t/ha), 25 kg/tree (Southern Coastal area); national average 15.2 kg/tree	

Table 9 Crop requirements for sorghum, general (Sorghum bicolor)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	500-700	400-500 700-900	300-400 >900	150-300	-	< 150
mean temperature(°C)	24-26	21-24 26-32	18-21 >32	15-18	-	< 15
relative humidity (%)	0-50	0-50	-	> 85	-	-
Soil requirements						
drainage	well	m. well	Imperf.	poorly	poorly	poorly
depth (cm)	50-150	50-150	25-50	< 25		< 10
texture	medium	heavy	-	-	-	-
coarse fragments (%)	0-3	3-15	15-35	35-50	-	> 50
pH (H20)	6.0-7.0	7.0-8.2	8.2-8.3	8.3-8.5	-	> 8.5
CEC (cool/kg)	> 24	16-24	< 16	-	-	-
OC (%)	> 0.8	0.4-0.8	< 0.4	-	-	-
Eke (Ds/m)	0-4	4-8	8-12	12-26	16-20	> 20
ESP	0-10	10-20	20-28	28-35	-	> 35
CaCO3	3-20	20-30	30-45	45-75	-	> 75
gypsum (%)	0-3	3-5	5-10	10-20	-	> 20

Table 10 Crop requirements for millet (Pennisetum amricanum)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	400-500	300-400	200-300	150-200	-	< 150
mean temperature(°C)	22-26	20-22 26-28	18-20 28-30	16-18 30-32	-	< 16 >32
relative humidity (%)	35-65	35-65	-	-	-	> 85
Soil requirements						
drainage	well	m. well	imperf.	poorly	poorly	poorly
depth (cm)	> 50	> 50	25-50	0-25	-	< 10
texture	medium	heavy	light	-	-	-
coarse fragments (%)	0-3	3-15	15-35	35-50	-	> 50
pH (H20)	6.0-7.0	7.0-7.6	7.6-8.0	8.0-8.2	-	> 8.2
CEC (cmol/kg)	> 16	-	< 16	-	-	-
OC (%)	> 1.5	0.8-1.5	0.4-0.8	< 0.4	-	-
ECe (dS/m)	0-2	2-4	4-6	6-8	8-12	> 12
ESP	0-10	10-25	25-35	35-45	-	> 45
CaCO3	0-10	10-25	25-35	35-55	-	> 55
gypsum (%)	0-3	3-6	6-10	10-20	-	> 20

Table 11 Crop requirements for banana (Musa spp.)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements						
rainfall (mm)	>1800	1500180 0-	1250- 1500	1000- 1250	-	< 1000
mean temperature(°C)	> 22	18-22	16-18	14-16	-	< 14
relative humidity (%)	> 65	> 65	35-50	20-35	-	< 20
Soil requirements						
drainage	well	m. well	imperf.	poorly	poorly	poorly
depth (cm)	> 75	> 75	50-75	25-50	-	0-25
texture	medium	-	heavy	light	-	-
coarse fragments (%)	0-3	3-15	15-35	35-50	-	> 50
pH (H20)	5.8-7.0	7.0-7.5	7.8-8	8.0-8.2	-	> 8.2
CEC (cmol/kg)	> 24	16-24	< 16	-	-	-
OC (%)	> 2.4	1.5-2.4	0.8-1.5	<0.8	-	-
ECe (dS/m)	0-1	1-2	2-4	4-6	6-8	> 8
ESP	0-2	0-4	4-8	8-12	12-16	> 16
CaCO3	0	< 5	5-10	10-15	-	> 15
gypsum (%)	0	< 1	1-4	4-10	-	> 10

Table 12 Crop requirements for papaya (Caricca papaya)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	1400-1500	1000-1400	800-1000	600-800	-	< 600
mean temperature(°C)	24-26	20-24 26-28	15-20 28-34	8-15 34-38	-	< 8 > 38 >32
relative humidity (%)	35-65	35-65	65-85	> 85, < 20	-	-
Soil requirements						
drainage	well	-	m. well	imperf.	poorly	poorly
depth (cm)	> 75	> 75	50-75	0-25	-	< 10
texture	medium	light	-	heavy	-	-
coarse fragments (%)	0-3	3-15	15-35	35-50	-	> 50
pH (H20)	6.2-6.4	6.5-7.0	7.1-7.5	7.6-8.0	-	> 8.0
CEC (cmol/kg)	> 24	16-24	< 16	-	-	-
OC (%)	> 2.0	1.2-2.0	0.8-1.2	< 0.8	-	-
ECe (dS/m)	0.1	1-2	2-3	3-4	-	> 4
ESP	0-8	8-15	15-20	20-25	-	> 25
CaCO3					-	
gypsum (%)					-	

Table 13 Crop requirements for tomato (Asolanum lycopersicum)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	500-600	400-500	300-400	200-300	-	< 200
mean temperature(°C)	20-24	18-20 24-26	16-18 26-30	13-16 30-35	-	< 13 >35
relative humidity (%)	35-85	35-85	20-35, >85	<20	-	0
Soil requirements						
drainage	well to imperf.	m. well	imperf. to well	poorly	poorly	poorly
depth (cm)	> 100	> 100	75-100	50-75	-	0-50
texture	medium	heavy	light	-	-	-
coarse fragments (%)	0-3	3-15	15-35	35-50	-	> 50
pH (H20)	6.2-7.0	7.0-7.5	7.8-8.0	8.0-8.2	-	> 8.2
CEC (cmol/kg)	> 24	16-24	< 16	-	-	-
OC (%)	2	1.2-2.0	0.8-1.2	< 0.8	-	-
ECe (dS/m)	0-3	3-5	5-8	8-10	-	> 10
ESP	0-8	8-15	15-25	25-35	-	> 35
CaCO3	0-3	3-5	5-10	10-25	-	> 25
gypsum (%)	0-1	1-2	2-3	3-5	-	> 5

Table 14 Crop requirements for onion (Allium cepa)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	400-500	350-400 500-600	300-350 600-800	250-300 n/a	-	< 250
mean temperature(°C)	18-20	16-18 20-22	13-16 22-23	10-13 23-25	-	< 10 >25
relative humidity (%)					-	
Soil requirements						
drainage	well to imperf.	m. well	imperf. to well	poorly	poorly	poorly
depth (cm)	75-100	75-100	50-75	25-50	-	< 25
texture	medium	-	light	heavy	-	-
coarse fragments (%)	0-3	3-15	15-35	35-50	-	> 50
pH (H20)	6.2-7.2	7.2-7.8	7.8-8.0	8.0-8.2	-	> 8.2
CEC (cmol/kg)	> 24	16-24	< 16	-	-	-
OC (%)	> 2	1.2-2.0	0.8-1.2	< 0.8	-	-
ECe (dS/m)	0-1	1-2	2-3	3-5	-	> 5
ESP	0-10	10-20	20-35	35-50	-	> 35
CaCO3	0-3	3-5	5-10	10-25	-	> 20
gypsum (%)	0-1	1-2	2-3	3-5	-	> 5

Table 15 Crop requirements for watermelon (Colocynthis citrulls)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	500-600	400-500	300-400	200-300	-	< 200
mean temperature(°C)	24-28	22-24 28-30	20-22 30-32	18-20 32-35	-	< 18 >35
relative humidity (%)	MM	LL, HH	-	VL,VH	-	-
Soil requirements						
drainage	well to imperf.	m. well	imperf. to well	poorly	poorly	poorly
depth	VD	DD	MD	MS	-	SS, VS
texture	medium	light	heavy	-	-	-
coarse fragments (%)	0-3	2-15	15-35	35-50	-	> 50
pH (H20)	6.0-7.0	7.0-7.6	7.6-8.0	8.0-8.2	-	> 8.2
CEC (cmol/kg)	> 24	16-24	< 16	-	-	-
OC (%)	> 2	1.2-2.0	0.8-1.2	< 0.8	-	-
ECe (dS/m)	0-3	3-4	4-6	6-8	-	> 8
ESP	0-8	8-15	15-20	20-25	-	> 35
CaCO3					-	> 25
gypsum (%)					-	

Table 16 Crop requirements for alfalfa (Medicago sativa)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	1000-1200	800-1000	600-800	400-600	-	< 400
mean temperature(°C)	24-26	20-24 26-28	15-20 28-32	10-15	-	< 10 > 40
relative humidity (%)	MM	LL	HH	VL, VH	-	
Soil requirements						
drainage	well	m. well	imperf.	poorly a	poorly d	poorly n
depth	VD DD	- -	DD MD MS	MD MS SS	-	SS VS
texture	medium	heavy	-	light	-	-
coarse fragments (%)	0-3	3-10	10-25	25-50	-	> 50
pH (H20)	7.0-7.8	7.9-8.0	8.0-8.2	8.2-8.5	-	> 8.5
CEC (cmol/kg)	> 24	16-24	< 16	-	-	-
OC (%)	> 2.0	1.2-2.0	0.8-1.2	< 0.8	-	-
ECe (dS/m)	0-3	3-5	5-9	9-12	-	> 12
ESP	0-8	8-20	20-35	35-50	-	> 50
CaCO3					-	
gypsum (%)					-	

Table 17 Crop requirements for Sesame (Sesamum indicum)

	CLASSES AND DEGREES OF LIMITATIONS					
	S1		S2	S3	N	
RATING SCALE	100 95	95 85	85 60	60 40	40 25	25 0
Climatic requirements (during growing season)						
rainfall (mm)	400-500	350-400	250-350	175-250	-	< 175
mean temperature(°C)	24-27	20-24 27-28	18-20 28-30	16-18 30-38	-	< 16 > 38
relative humidity (%)	VL, LL MM	-	HH	-	-	VH
Soil requirements						
drainage	well	m. well	-	imperfectly- poorly	poorly d	poorly n
depth	DD	MD	MS	SS	-	VS
texture	medium	-	light	heavy	-	-
coarse fragments (%)	0-3	3-15	15-35	35-50	-	> 50
pH (H20)	6.2-6.5	6.5-7.0	7.0-7.5	7.5-8.2	-	> 8.2
CEC (cmol/kg)	> 24	16-24	< 16	-	-	-
OC (%)	0-2	2-4	4-6	6-8	-	>8
ECe (dS/m)					-	
ESP					-	
CaCO3				?	-	
gypsum (%)					-	

Table 18 Crop requirements for sweet potato (Ipomoea batatas)

Main environmental and crop requirements		
characteristic	optimum	range
length of growing period (days)	80-360	-
rainfall (mm)	750-1250	500-5000
mean temperature (°C)	22-26	10-40
relative humidity (%)	LL (at maturity)	
drainage	well	well
depth	DD	MS-VD
texture	medium	light to heavy
pH (H2O)	5.6-6.6	4.2-7.7
Ece (dS/m)	0-2.5	0-6.0 (50 % yield reduction)
average rooting depth (m)	1.25 (0.8)	
water requirement (under irrigation)	1100-1500 mm (4-8 applications)	
average farmer's yield (t/ha)	5-10 t/ha (rainfed), 12-18 t/ha (irrigated)	

station: Seiyun '(agro-)meteorological
latitude: 15°56' average 1983-1993
longitude: 48°45'
altitude: 700 m

		Temperature (°C)			RH	sun	radiation	winds	PET		rainfall (mm)											
		max	min	mean	%	h/d	MJ/m²/d	m/s	mm/d	mm/dec	average	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
	dec-1	28.9	9.6	19.3	49	8.8	13.5	0.8	2.8	28	0.5	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jan	dec-2	28.8	9.4	19.1	50	8.7	13.7	0.8	2.9	29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-3	29.6	10.6	20.1	49	8.7	14.2	0.9	3.2	32	1.4	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.5
	dec-4	30.7	12.1	21.4	49	8.8	14.7	0.9	3.5	35	3.8	0.0	0.0	0.0	4.1	0.0	0.0	0.0	38.0	0.0	0.0	0.0
Feb	dec-5	31.2	12.9	22.0	49	8.8	15.3	1.0	3.7	37	2.9	11.5	0.0	11.5	7.4	0.0	0.0	0.0	1.9	0.0	0.0	0.0
	dec-6	32.4	13.9	23.1	46	8.8	15.7	1.0	4.1	41	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5	0.0	0.0	0.0
	dec-7	33.9	15.2	24.5	43	8.7	16.1	1.1	4.4	44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mar	dec-8	34.7	15.8	25.2	41	8.7	16.5	1.1	4.7	47	9.8	0.0	0.0	0.0	0.0	34.0	0.0	74.1	0.0	0.0	0.0	0.0
	dec-9	35.4	16.7	26.0	40	8.7	16.9	1.1	4.8	48	6.9	0.3	0.0	0.0	0.0	26.5	0.0	37.4	0.0	12.2	0.0	0.0
	dec-10	36.3	17.8	27.1	39	8.8	17.3	1.1	5.0	50	21.6	58.3	0.0	0.0	9.1	13.6	0.0	51.2	4.1	58.3	43.0	0.5
Apr	dec-11	36.8	18.4	27.6	39	8.8	17.5	1.1	5.1	51	2.8	2.3	0.0	0.0	9.4	9.9	0.0	0.0	0.0	2.3	0.0	6.7
	dec-12	37.8	19.0	28.4	37	9.2	17.9	1.1	5.3	53	1.6	0.8	0.0	0.2	0.0	0.0	0.5	8.5	0.0	0.8	0.0	6.9
	dec-13	39.2	19.7	29.5	34	9.7	18.3	1.1	5.5	55	1.8	0.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
May	dec-14	39.9	20.1	30.0	33	10.0	18.4	1.1	5.6	56	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.0
	dec-15	40.6	20.8	30.7	32	9.6	18.1	1.1	5.6	56	0.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
	dec-16	41.6	21.7	31.6	30	9.1	17.6	1.0	5.5	55	0.2	0.0	0.0	0.0	0.0	1.5	0.0	1.0	0.0	0.0	0.0	0.0
Jun	dec-17	42.1	22.1	32.1	29	8.8	17.4	1.0	5.4	54	2.1	0.0	0.0	0.0	23.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-18	42.3	23.2	32.7	30	8.5	17.1	1.1	5.7	57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-19	42.5	24.6	33.6	31	8.1	16.9	1.3	6.0	60	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	1.0	0.0
Jul	dec-20	42.6	25.3	34.0	31	7.9	16.7	1.4	6.2	62	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.7	1.0	0.0	2.2
	dec-21	42.4	25.3	33.9	32	8.0	16.8	1.3	6.1	61	2.0	0.0	1.1	0.0	1.8	0.0	5.7	1.0	10.0	0.0	0.0	2.2
	dec-22	42.2	25.2	33.7	33	8.0	16.8	1.2	5.9	59	3.7	0.0	0.0	1.6	5.1	17.2	1.5	0.8	0.5	8.1	6.2	0.0
Aug	dec-23	42.0	25.2	33.6	34	8.0	16.7	1.2	5.9	59	3.6	29.5	0.0	0.0	0.0	1.0	0.0	0.4	0.0	7.0	1.0	1.2
	dec-24	41.1	23.7	32.4	34	8.3	16.9	1.1	5.6	56	2.0	0.0	0.0	1.0	8.0	4.1	0.0	0.0	0.0	8.5	0.0	0.0
	dec-25	39.8	21.8	30.8	34	8.8	17.0	1.0	5.2	52	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep	dec-26	39.1	20.9	30.0	34	9.0	16.9	0.9	5.0	50	0.2	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	1.5	0.0
	dec-27	37.9	19.1	28.5	35	9.2	16.7	1.0	4.8	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-28	36.2	16.7	26.4	36	9.4	16.5	1.0	4.5	45	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0
Oct	dec-29	35.3	15.5	25.4	37	9.5	16.1	1.1	4.3	43	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8	0.0	0.0
	dec-30	34.0	14.4	24.2	38	9.4	15.5	0.9	3.9	39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-31	32.3	12.8	22.6	39	9.4	14.9	0.8	3.4	34	0.4	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov	dec-32	31.4	12.1	21.7	39	9.4	14.5	0.7	3.1	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-33	30.7	11.4	21.0	42	9.2	14.0	0.7	3.0	30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
	dec-34	29.7	10.5	20.1	46	9.0	13.6	0.7	2.8	28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec	dec-35	29.2	10.0	19.6	48	9.0	13.5	0.7	2.7	27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-36	29.1	9.8	19.5	48	8.9	13.4	0.7	2.8	28	0.2	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0
Year		36.1	17.3	26.7	39	8.9	5797	1.0	4.6	1643	73	109	22	21	68	110	8	176	73	112	73	33
										P/PET	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0

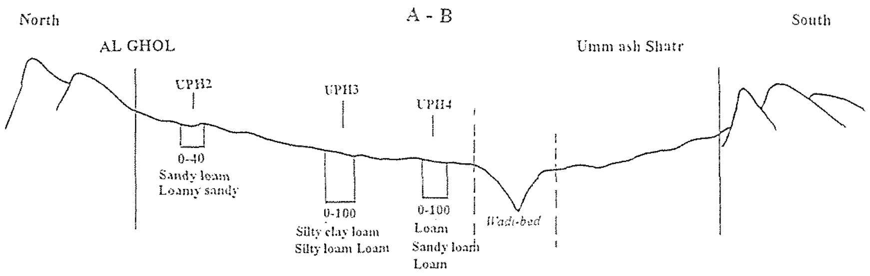
Appendix 6 Climatic data

station: Al Kod
latitude: 13°06'
longitude: 45°21'
altitude: 20 m

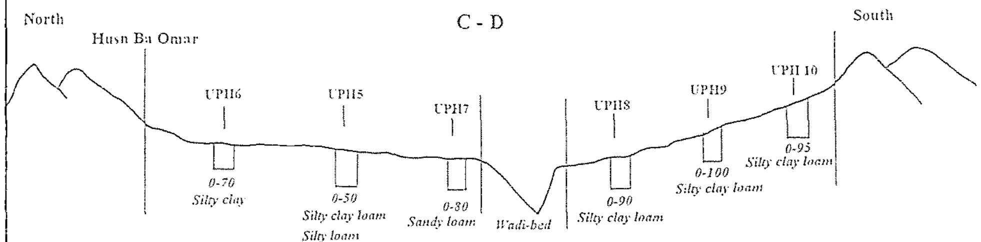
(agro-)meteorological
average 1981-1983, 1986-1991

		Temperature (°C)			RH	sun	radiation	winds	PET		rainfall (mm)									
		max	min	mean	%	h/d	MJ/m²/d	m/s	mm/d	mm/dec	average	1981	1982	1983	1986	1987	1988	1989	1990	1991
	dec-1	29.0	20.9	24.9	80	8.3	12.5	1.3	3.1	31	2.8	0.0	0.0	0.0	0.0	11.5	11.2	0.2	2.0	0.5
Jan	dec-2	28.7	21.2	25.0	80	8.1	12.6	1.3	3.1	31	1.2	0.0	10.0	0.4	0.0	0.0	0.0	0.5	0.0	0.0
	dec-3	28.9	21.4	25.2	80	8.2	12.9	1.3	3.2	32	0.8	0.0	0.0	3.0	0.0	0.0	0.0	4.0	0.0	0.0
	dec-4	29.1	21.6	25.4	81	8.3	13.4	1.4	3.4	34	14.2	0.0	0.0	108.5	3.8	0.0	0.0	14.8	1.0	0.0
Feb	dec-5	29.3	21.8	25.5	81	8.4	13.9	1.4	3.5	35	4.5	0.0	0.0	36.5	0.7	0.0	0.0	0.0	0.0	3.5
	dec-6	29.7	22.1	25.9	81	8.3	14.2	1.4	3.6	36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-7	30.2	22.6	26.4	81	8.2	14.5	1.5	3.8	38	0.8	0.0	0.0	0.0	0.0	0.0	1.2	0.0	5.7	0.0
Mar	dec-8	30.5	22.9	26.7	81	8.2	14.7	1.5	3.9	39	10.2	7.0	0.0	0.0	0.2	84.3	0.0	0.5	0.0	0.0
	dec-9	30.9	23.2	27.0	81	8.4	15.1	1.4	4.0	40	9.0	0.0	0.0	0.0	0.0	0.0	0.0	79.7	1.0	0.0
	dec-10	31.4	23.5	27.5	81	8.7	15.5	1.3	4.2	42	3.0	0.0	0.0	0.0	0.0	1.0	0.0	26.3	0.0	0.0
Apr	dec-11	31.7	23.7	27.7	80	8.8	15.7	1.3	4.3	43	0.8	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-12	32.7	24.0	28.4	80	9.2	16.1	1.3	4.4	44	2.6	0.0	0.0	0.0	0.0	0.0	0.0	2.0	21.0	0.0
	dec-13	34.0	24.5	29.3	81	9.8	16.6	1.2	4.6	46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May	dec-14	34.7	24.7	29.7	81	10.1	16.8	1.2	4.7	47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-15	35.0	25.3	30.2	80	9.7	16.3	1.2	4.7	47	6.7	10.5	0.0	50.2	0.0	0.0	0.0	0.0	0.0	0.0
	dec-16	35.5	26.2	30.8	78	9.2	15.8	1.3	4.7	47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	dec-17	35.7	26.6	31.1	77	9.0	15.5	1.3	4.7	47	0.4	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0
	dec-18	35.6	26.8	31.2	77	8.6	15.1	1.4	4.6	46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-19	35.4	27.1	31.3	76	8.1	14.7	1.5	4.6	46	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2
Jul	dec-20	35.3	27.2	31.3	76	7.8	14.5	1.5	4.6	46	1.2	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0
	dec-21	35.2	27.0	31.1	76	7.8	14.5	1.5	4.6	46	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-22	34.9	26.8	30.9	76	7.9	14.7	1.5	4.5	45	0.8	2.0	0.0	1.0	1.3	0.0	2.3	0.0	0.0	1.0
Aug	dec-23	34.8	26.7	30.7	76	7.9	14.7	1.5	4.5	45	0.7	0.0	0.0	4.9	0.0	0.0	0.0	0.0	0.0	1.0
	dec-24	34.9	26.5	30.7	78	8.1	14.9	1.4	4.5	45	1.2	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	8.0
	dec-25	35.0	26.2	30.6	80	8.3	15.0	1.3	4.4	44	2.2	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0
Sep	dec-26	35.1	26.0	30.5	81	8.4	14.9	1.2	4.4	44	0.6	3.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
	dec-27	34.4	24.6	29.5	80	8.8	15.1	1.2	4.3	43	3.9	0.0	1.0	0.0	0.0	0.0	0.0	0.0	34.0	0.0
	dec-28	33.4	22.8	28.1	79	9.3	15.3	1.2	4.1	41	0.7	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	4.5
Oct	dec-29	32.9	21.8	27.4	79	9.6	15.2	1.2	4.0	40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-30	32.3	21.0	26.6	78	9.8	14.9	1.1	3.8	38	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
	dec-31	31.4	19.8	25.6	78	10.0	14.7	1.1	3.6	36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov	dec-32	30.9	19.2	25.1	78	10.1	14.4	1.1	3.4	34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-33	30.4	19.6	25.0	79	9.6	13.7	1.1	3.3	33	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	dec-34	29.8	20.0	24.9	79	9.0	13.0	1.2	3.1	31	0.4	0.0	0.0	1.1	0.0	2.3	0.0	0.0	0.0	0.0
Dec	dec-35	29.4	20.2	24.8	80	8.7	12.7	1.2	3.0	30	0.1	0.0	0.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	dec-36	29.2	20.6	24.9	80	8.5	12.5	1.2	3.0	30	1.0	0.4	8.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Year		32.4	23.5	28.0	79	8.8	5266	1.3	4.0	1441	70	23	20	219	6	100	39	139	65	22
										P/PET	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.0

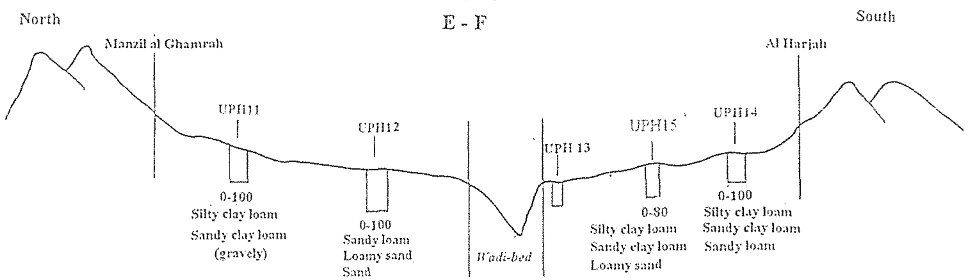
Catena 1



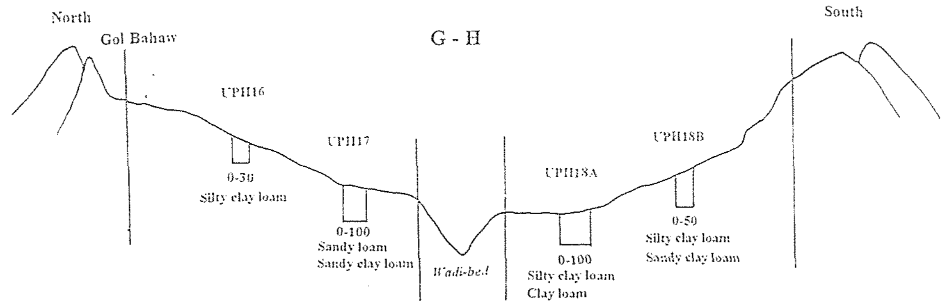
Catena 2



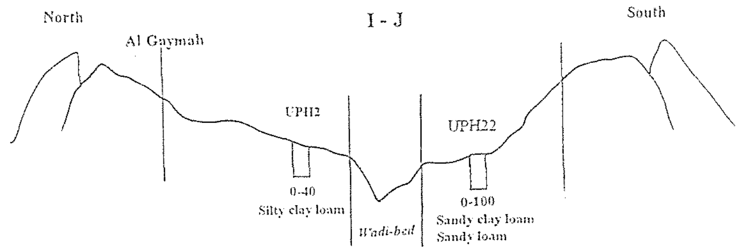
Catena 3



Catena 4



Catena 5



Catena 6

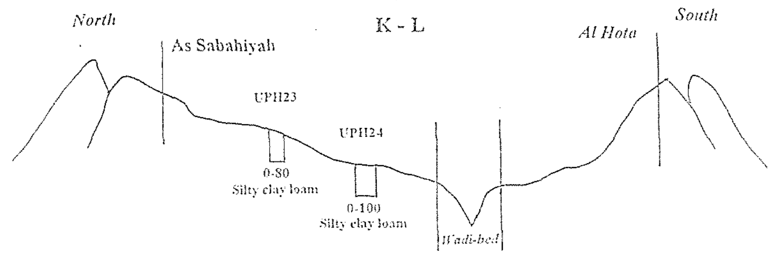
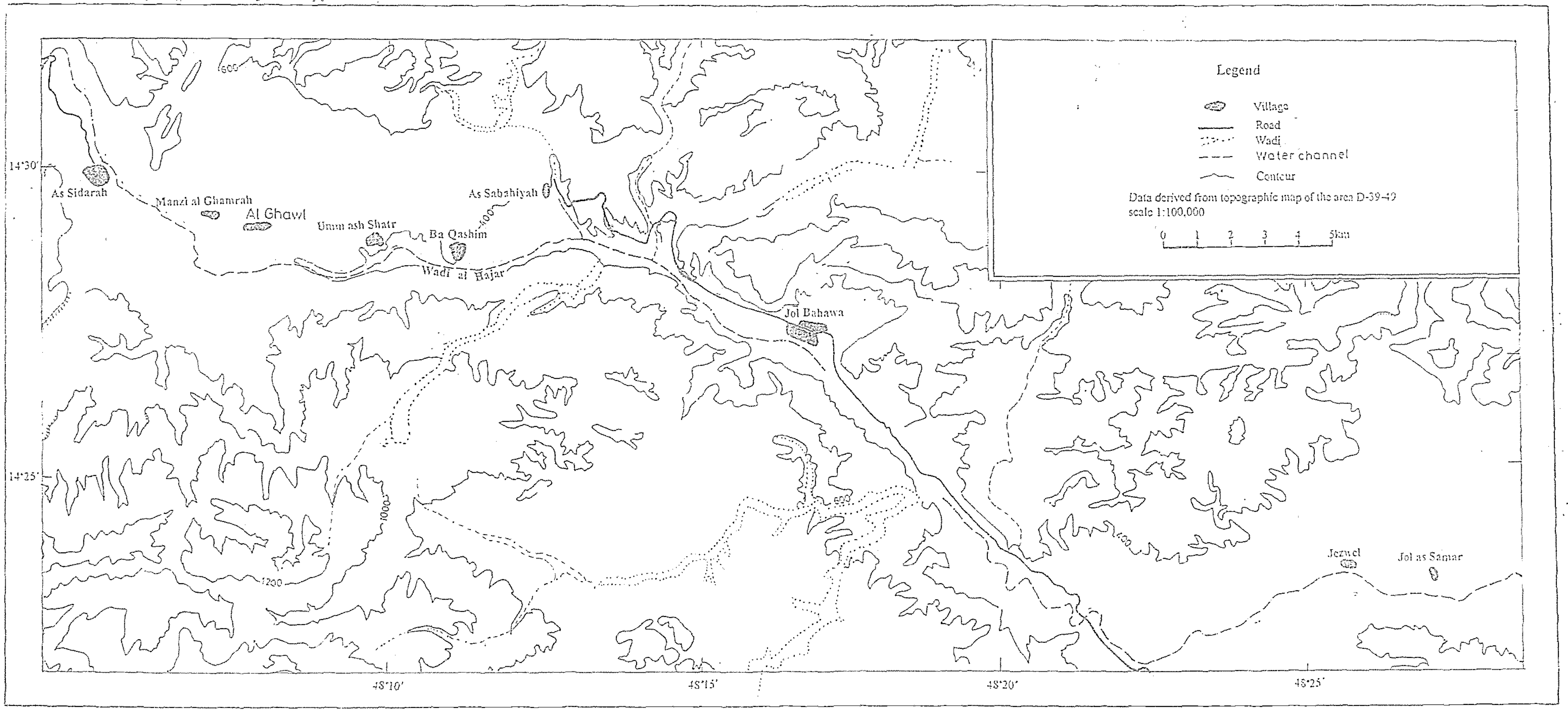


Fig. 2 Location map



CHAPTER 1 GEOGRAPHIC SETTING

1.1 LOCATION

The area is situated in the catchment of Wadi Hajar, Hadramout Governorate, between latitudes 14° 22′ and 14°32′ N and longitudes 48° 04′ and 48°29′ E. This area is covered by topographic sheet no. D-39-49 (1:250,000).

The Upper Hajar survey area, covering a surface of about 6000 ha, is situated around 60 km upstream from the coastal road to Mukalla, and includes the villages of Sadarah, Al-Gol and Jezwill (see the fig.1 for a location map). The total length of the wadi from Al-Sadarah to Jezwill is about 50 km. It should be noted that the area between Al-Gol and Jezwill is not being cultivated because rock outcrops dominate it. Near the mouth of the Hajar river, Lower Hajar is situated, another important agricultural area depending on the waters of the wadi. Its soils were surveyed in 1984 by Tesco-Viziterv

1.2 PHYSIOGRAPHY AND RELIEF

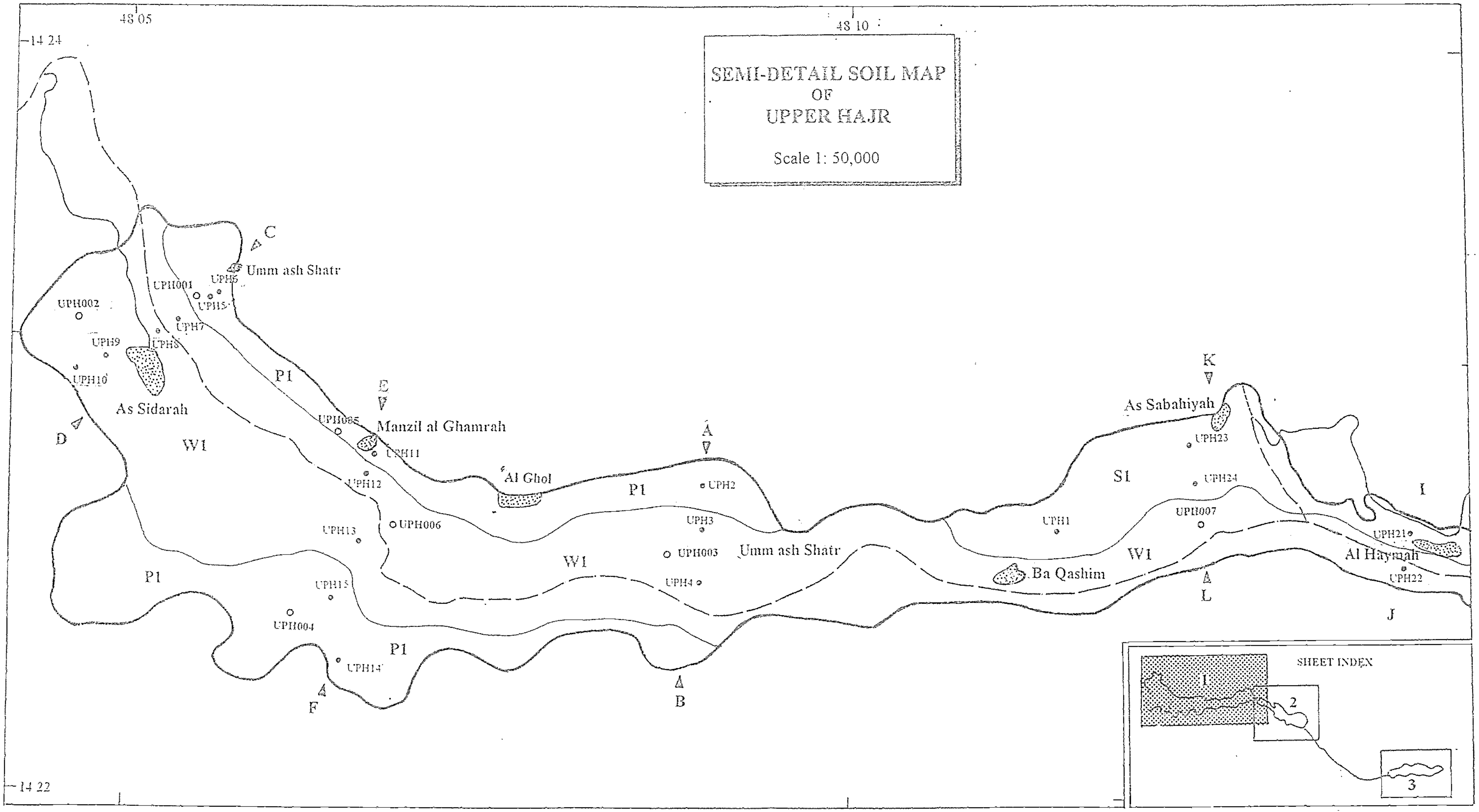
Wadi Hajar flows through a long and gently sloping alluvial valley floor, which is seasonally affected by floods, to the Arabian sea. This wadi is bounded in the southeast and northwest by high mountain ranges with elevations from 1000 to over 2000 m above sea level (a.s.l.).

The major relief features of the study area were formed under neotectonic movements that dissected the platform, separating geostructural forms, which afterwards due to volcanic and. exogenic processes were reshaped into the present landforms. Current elevations in the valley are 250, 380 and 420 m a.s.l. for Jezwill, Al-Gol and Al-Sadarah villages respectively.

The area surveyed is situated along the upper and middle sections of the perennial wadi Hajar. The bed of this stream is cut deeply into the earlier mentioned mountain ranges, which are mainly of volcanic origin. The valley is relatively narrow. The alluvial valley floor is dissected by the stream, which sometimes flows though the centre of the valley, thus dividing the alluvial plain into two parts, and elsewhere runs close besides the mountain slopes (see figure 1). At times of high water, the wadi still erodes the banks violently, scoring both sides.

The study area can be divided into 4 main physiographic units. The first one is formed by an almost flat to undulating area, mainly located in between Al-Gol and Al-Sadarah and around Jizwell. This units borders the mountain slopes and the wadi and contains wadi terraces, sand plains, depressions and some rock outcrops. Most of the (potential) agricultural area situated in this part. The second unit is the wadi bed, which is dominated by stones, gravels and boulders. This unit runs SE to NW, and is approximately 50 km long. The third unit is a dissected rocky area concentrated between Al-Gol and Jizwell. It is unsuitable for agriculture. The fourth unit consists of steep mountains slopes located on both side of the wadi.

The wadi terrace area consists of alluvial terraces. A lower terrace runs on both sides along the wadi bed for most of its length, except where there are rocky areas. This first terrace is subjected to flooding by the stream during periods of high water. The second terrace lies

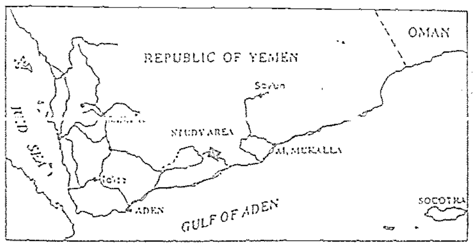


Prepared by :

Ministry of Agriculture & Irrigation.
Agricultural Research & Extension Authority.
Renewable Natural Resource Research Centre.
FAO-Project GCP/YEM/021/NET -
Environmental Resources Assessment for Rural Land Use Planning.

DHAMAR JUNE, 1998

LOCATION DIAGRAM



Settlement
Water channel
Road
Study area boundary
Soil boundary
Profile
Auger

Topographic data derived from :

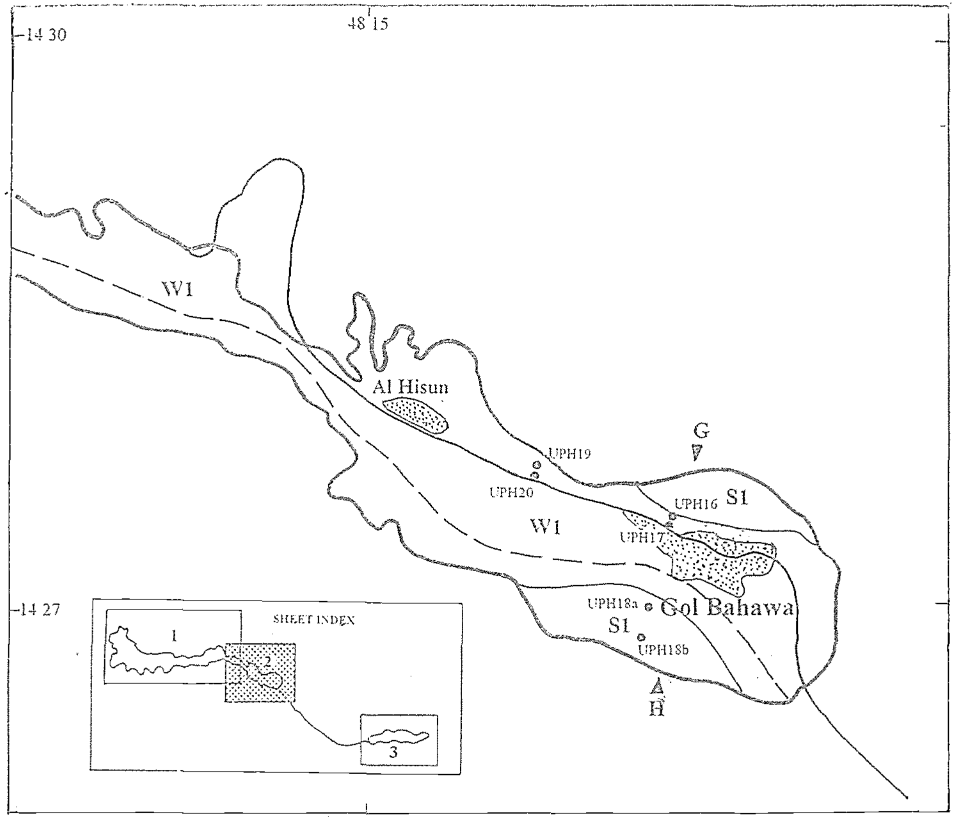
Aerial photographs and topographic maps of the area scale 1:100,000, sheet no. D-39-17 and D-39-49, 1978.

Surveyed by :

Mohammed Hizam al Mashriqi

Cartography by :

Ahmad R. An Nasiri



SEMI-DETAIL SOIL MAP
OF
UPPER HAJR

Scale 1: 50,000

SOIL LEGEND

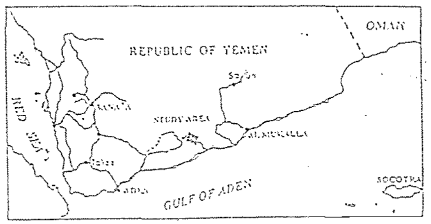
Mapping unit	Landform	Relief	Type of mapping unit	Components of main and associated soils	%	Main characteristics
W1	Wadi alluvial terraces	Almost flat	Consociation	Tyoic Torrifluvents Typic Torriorthents Inclusion	50 40 10	Stratified, dominantly silt loam and silty clay loamsoils, very deep, moderately well to well drained, strongly calcareous, massive to very weak structure, slightly saline.
P1	Dessicted plain	Gently sloping	Complex	Typic Haplocalsids Gypsic Haplosalids Inclusion	60 30 10	Remnants of some sedimentary materials, dominantly sand loam and silty clay loam soils stony to very stony, moderately deep, moderately well drained, strongly calcareous, massive structure, high saline.
S1	Sand Plain	Flat	Complex	Lithic Torriorthents Lithic Torrifluvents Inclusion	70 20 10	Shallow and very stony soils, dominantly loamy sand sand loam and silty loam soils, well drained, strongly calcareous, massive structure, moderatly saline.
B1	Wadi bed	Flat to sloping terrain	-	-	-	Coarse sedimentary materials (gravels, stones and bolders)
M1	Mountain	Steep to very steep	-	-		Old basic parent rocks (volcanic and metamorphic)

Prepared by :

Ministry of Agriculture & Irrigation,
Agricultural Research & Extension Authority,
Renewable Natural Resource Research Centre,
FAO-Project GCP/YEM/021/NET -
Environmental Resources Assessment for Rural Land Use Planning

DHAMAR JUNE, 1998

LOCATION DIAGRAM



Settlement
Water channel
Road
Study area boundary
Soil boundary
Profile
Auger