FOOD AND AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS
ENVIRONMENTAL RESOURCE ASSESSMENT FOR RURAL LAND USE PLANNING
GCP/YEM/021/NET
Field document 10

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

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SUMMARY

Based on chemical and physical properties, the soils of Al Irrah research farm are moderate to good soils for arable cropping. The soils are all deep to very deep and have fine loamy to clayey textures. At a depth of about 140 cm a sandy loam layer is present. The soils have good water properties, they can store a lot of water and a large part is available for the plants.

Within Al Irrah research farm, a relatively small farm of only 11 ha, three different soil series are present. These three soil series very well represent the deep and very deep soils found in Sana'a basin.

Maris series is a very deep soil that is uniform in colour and texture (dominantly silty clay) throughout the profile, to a depth of 120 cm. Due to the high clay content, soil aggregates can become hard to very hard and the soil develops cracks when it dries out. Deep soil loosening of these soils may improve its physical properties (structure, rootability and infiltration).

Shira series is a deep stratified soil. Its main characteristic is that it contains different layers of different colour and texture. This stratification of soil materials impedes root growth and hampers water movement in the soil. Therefore this soil series is less suitable for most crops than Maris and Gidr soil series. Shallow rooting crops, however, are expected to perform well in these soils. As the top 45 cm of the soil is uniform in texture, structure and colour, shallow rooting crops will not suffer that much from the stratification. It is recommended not to grow fruit trees or other deep rooting crops on these soils.

Gidr series is a very deep soil with a silty clay loam texture in the control section. The soil has a buried dark horizon at a depth of 50 to 80 cm. Starting from a depth of about 100 cm, a calcic horizon can be found. Gidr soil series have good properties for crop growth. It is recommended to test the performance of the fruit trees (now grown mainly on Maris series) also in this soil type.

The main limitations of the soils found in Al Irrah research station are: presence of calcium carbonates (all soils); crust formation (all soils); stratification (one soil unit); a calcic horizon (one soil unit); and problems with soil structure (hard, compact subsoil). Consequently, crops can have problems with nutrient availability (due to high $CaCO_3$ content), rootability and seedling emergence. The way in which crops are affected depends on their sensitivities to these limitations.

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INTRODUCTION

At the request of the management of Al Irrah deciduous horticulture station, a regional research station of AREA (Agricultural Research and Extension Authority of the Ministry of Agriculture and Irrigation), a soil survey was carried out at Al Irrah research station during July and August 1996. In the history of Al Irrah Farm, it actually was the first soil survey describing the soil to a depth of 120 cm. It was also the first time that a detailed soil map for the whole farm was made. In 1984 a soil survey was carried out for the topsoil (0-30cm) only. This survey was meant as a preparation for irrigation experiments on wheat and barley. The conclusion of this survey was that the soils were not very saline, and some had calcareous horizons.

Al Irrah farm was set up in 1983 by an American aid programme, as a research station for fruit trees and annual crops. The main purposes of the farm are (1) to act as a demonstration farm, and (2) to store the genetic resources for fruit trees. In 1990 during the Gulf-war, the American aid programme was suspended and the farm was handed over to the Yemeni government.

Currently, fruit trees (apples, pears, peaches, figs etc), vegetables (tomatoes, potatoes, beans), cereals (sorghum, maize, barley) and fodder crops are grown on the farm. Experiments with varieties, fertilizer applications and irrigation practices are carried out. Results from experiments are likely to be influenced strongly by the different varieties used in the trials and differences in soil characteristics. Thus, for proper experimental designs and a useful interpretation of the results afterwards, it is necessary to know the spatial differences in soil characteristics within the research farm. This need for detailed information on soil characteristics and its relations with land use, was the main reason to carry out his survey.

This survey is supported by the Environmental Resource Assessment for Rural Land Use Planning Project (GCP/YEM/021/NET, FAO). Part of its programme is to conduct detailed soil surveys in different regional agricultural research stations. The objective was to make a comprehensive soil resource inventory, test the representativeness of Al Irrah soils for the regional soils surrounding the station, define the main soil and water constraints in relation to crop production and recommend suitable management and agricultural practices.

The report describes various aspects of the soils of Al Irrah Farm; it includes soil development, soil properties in relation to the landscape, chemical and physical properties and the impact these have on crop performance. Also some recommendations are given on how to improve the soils and crop cultivation practices. It is hoped that this report will contribute positively to the research done at Al Irrah research station and will be helpful for agricultural workers in areas with similar soil characteristics as Al Irrah station.

Chapter 1
BACKGROUND INFORMATION

1.1 LOCATION

Al Irrah Research farm lies in "Bani al Harith" district which is part of Sana'a Governorate. It is situated on toposheet 1544C1, approximately at 412.000m east and 1.710.400m north, and covers an area of about 11 ha (without roads and buildings). The farm is located about 12 km north from Sana'a on the road to Amran. From Gidr village it is a 2 km drive on a dirt road in north-east direction.

The farm is located within Sana'a plain, a flat to almost flat area with elevations ranging between 2100 and 2350 m. Al Irrah lies at an altitude of 2200 m. The plain centre is occupied by Sana'a city.

1.2 GEOMORPHOLOGY

The area around Sana'a, "Sana'a basin", is the central part of the Yemen Highlands (the "Central Highlands"). It consists of high mountain plateau's, mountains, hills and wadis. Numerous wadis with incisions up to 400 meter, break the area into separate massifs. The differences in relief are a major soil forming factor in the region (erosion and deposition).

Sana'a basin is composed of Precambrian, Jurassic, Cretaceous, Tertiary and Quaternary rocks. Precambrian metamorphic formations make the crystalline base and are overlapped by a thick sequence of sedimentary and volcanic younger rocks (basalts, sandstone and limestone) (Mosgiprovodkhoz, 1986). Basalts are rather rich in sodium, resulting in a quite high sodium adsorption rate in some areas. Parent material consists principally of carbonate loams, rarely of carbonate sandy loam and occasionally of carbonate clays (Mosgiprovodkhoz, 1986).

At various places a dark, buried horizon can be found at some depth in the soil profile. This layer, most probably of volcanic origin, is assumed to have been a topsoil some 1500- 2000 years ago when the climatic conditions were much more humid than now. During this wetter climate, marshy areas existed in which humic topsoils were formed and washed topsoil from surrounding areas was deposited, which were later covered by more recently deposited materials (aeolian, colluvial or alluvial materials) (see Acres, 1982; King, 1983 and Gibson and Wilkinson, 1996). This often resulted in a buried soil horizon.

Sana'a plain, part of the Sana'a basin, is about 320 km^2 large and includes the capital city Sana'a. It is an alluvial proluvial plain, i.e. the alluvium was deposited in a former wet period, after a period with volcanism (Mosgiprovodkhoz, 1986). The plain is enclosed by the interior catchment slopes which separate the region from the mountains around. Al Irrah farm lies on a convex slope within Sana'a plain. The landscape is characterized by a broad, gently undulating plain of alluvial material deposited over bedrock.

1.3 CLIMATE

Al Irrah station has its own agro-climatic station which measures temperature, rainfall, windspeed etc. Climatic data for Al Irrah farm are shown in table 1.1. Note that these data are based on only two years (1986 and 1989). Mean summer temperature is 21.4(C and mean winter temperature is 13.3(C. During the months November through February the minimum temperature regularly drops below 0°C.

Average annual precipitation normally is between 200 and 300 mm. Precipitation falls in two rainy seasons, separated by a distinct dry interval (May – mid July). The first rainy period starts in mid March – beginning of April, the second rainy period begins mid July – beginning of August and stops abruptly end of August. Per year there are 10 raindays, i.e. days which receive more than 5 mm of precipitation. The months September through February are generally dry, although occasional thunderstorms may bring some rain during these months (Bruggeman, 1997).

Monthly potential evapotranspiration (PET) figures range from 104 to 185 mm/month, and exceed monthly precipitation in all months. The average total amount of evapotranspiration per year is about 1700 mm/year.

A growing period defines the period of the year when both moisture and temperature conditions are suitable for crop production under rainfed conditions. A period can be considered as a growing period when prevailing temperatures are conducive for crop growth and precipitation plus moisture stored in the soil profile exceed half the potential evapotranspiration (0.5 * PET) (Bruggeman, 1997). Al Irrah has its first marginal growing period of 30 days, in April / May. The second marginal growing period of 20 days starts mid July and ends in August. In 50% of all years there is no growing period at all during this time of the year. In general, rainfed land productivity is low and there will only be a good harvest in very wet years. Therefore, irrigated agriculture plays an important role in agricultural production.

According to the classification made by US Soil Taxonomy, the soil moisture regime is characterised as aridic. An aridic moisture regime means that the moisture control section (normally 25-100 cm depth) is dry in all parts for more than half of the growing season, and is not moist in some parts for more than 90 consecutive days. Normally a crop cannot mature without irrigation. When taking the impact of water harvesting on the soil water content into consideration, the soil moisture regime is still aridic.

Little data about the soil temperature is available. Temperature figures have been gathered for a depth of 20 cm, although officially one should measure the soil temperature at a depth of 50 cm. The soil temperature is lowest during the cold, dry months (18-20(C) and highest in June, when the air temperature is high and the soil is dry (26-30(C).

Mean soil temperatures, at a depth of 20 cm, are 21.6(C (1986) and 21.7(C (1989). According to Bruggeman (1997), yearly average soil temperature at a depth of 50 cm is expected to be about 22.5°C. According to Soil Taxonomy (1994) the soil temperature regime is hyperthermic, (mean annual soil temperature > 22 C) and borders very closely to thermic (mean annual temperature is between 15 and 22 C).

Table 1: Climatic data for Al Irrah farm.

	Tmax (°C)	Tmin (°C)	Tmean (°C)	Relative Humidity (%)	Sunshine (hours)	Solar Radiation (mJ/m²/day)	Wind speed (m/s)	PET (mm/ month)	Precipitation (mm/month)
JAN	25.0	1.4	13.2	38	11	16.7	2.1	114	2
FEB	26.2	4.3	15.2	38	9.3	16.4	2.4	134	5
MAR	27.7	8.9	18.3	46	8.8	17.2	2.5	147	41
APR	27.4	9.4	18.4	50	8.3	17.2	2.2	149	42
MAY	29.5	9.5	19.5	33	10.9	20.2	2.4	175	10
JUNE	30.7	11	20.9	27	10.4	19.3	2.7	185	0
JULY	30.6	13.5	22	36	8.0	16.6	2.1	164	35
AUG	30.1	12.7	21.4	46	8.6	17.4	1.5	149	147
SEP	28.7	9.3	19	32	10.0	18.6	1.9	152	1
OCT	26.2	3.4	14.8	26	12	19.6	2.0	139	0
NOV	26.0	0.6	13.3	29	11.1	17.1	1.8	116	0
DEC	25.0	1.9	13.5	40	8.8	14.0	1.8	104	3
YEAR	27.8	7.1	17.4	37	9.8	6397	2.1	1726	286

1.4 SOIL MANAGEMENT AND LAND USE

1.4.1 Irrigation

As stated before, rainfed agriculture is very marginal in Sana'a basin. For a good and reliable harvest (supplementary) irrigation is necessary. In Al Irrah farm all crops are grown under irrigation. All kinds of irrigation types can be found on the farm: basin, furrow, sprinkler, drip and bubbler. Irrigation water is pumped up and partly stored in a basin. This basin is located somewhat higher than field level thus enabling irrigation water to flow by gravity.

1.4.2 Crops

The following crops are grown:
Vegetables: tomatoes, potatoes, onions
Cereals: sorghum, barley, maize, wheat
Fruit trees: peach, apricot, nectarine, cherries, apple
Miscellaneous: sunflower, broad bean
A rotation scheme for cereals and vegetables exists.

1.4.3 Farm Management

Ploughing

Ploughing is carried out immediately after harvesting, up to a depth of 25 cm deep, using a mouldboard plough and medium power tractor.

Weed control

There are two types of weed control:

1) Mechanical control, using a cultivator that is attached to the rear of a tractor. This is done before planting.

2) Hand weeding is carried out by labourers using different implements such as a pick axe.

Fertilizer application

In general organic manure is used for the nursery house and only leftovers are applied on the fields. The fields get chemical fertilizers.

1.4.4 Fertilizer experiments

Fertilizer experiments for sorghum, wheat, onion and potato were carried out in Al Boun, situated north of Al Irrah station. Although Al Boun is another research station probably with other soils some results are presented here.

1) Sorghum. Nine different NP treatments were carried out for sorghum. Highest yield (3.2 ton /ha) was obtained with 100 kg/ha N and 60 kg/ha P. Lowest yield (1.277 ton/ha) was obtained with 0 kg/ha N and 60 kg/ha P.

2) Six NP trials were carried out for wheat (Aziz, Marib and Sunalica varieties). Highest yield (6.67 ton /ha) was obtained with 120 kg/ha N and 80 kg/ha P. Lowest yield (4.83 ton/ha) was obtained in the control plot (no fertilizers).

3) Six NP trials were carried out for onion (Texas early). Highest yield (22.18 ton/ha) was obtained with 80 kg/ha N and 80 kg/ha P. Lowest yield (18.86 ton/ha) was obtained with 0 kg/ha N and 80 kg/ha P.

4) Twelve trials were carried out for potato (Diamont variety). All trials got 100 kg/ha K while N and P gifts differed. Highest yield (35.89 ton/ha) was obtained with 160 kg/ha N and 120 kg/ha P. Lowest yield (20.72 ton/ha) was obtained with 120 kg/ha N and 80 kg/ha P.

Table 2 summarizes the NPK gifts for which highest yields were obtained.

Table 2: Results of fertilizer experiments carried out in Al Boun

Crops	Fertilizer gift resulting in highest yield (kg / ha) N	P	K	Yield (ton / ha)
Sorghum	100	60	0	3.2
Wheat (Aziz)	120	80	0	6.67
Onion (Texas, early)	80	0	0	22.18
Potato (Diamont)	160	120	100	35.89

Chapter 2
SOILS AND MAPPING UNITS

2.1 PREVIOUS WORK

In former years two soil surveys have been carried out in (part of) Sana'a basin. A medium scale soil survey was carried out in 1976 by the FAO/UNDP project in Bani Hushaish. This is a mountainous area with wadi's, different from the relatively flat area in which Al Irrah lies.

The "Mosgiprovodkhoz" -team (Mosgiprovodkhoz, 1986) carried out a broad research for Sana'a basin, including Al Irrah, covering water resources, climate, geology and soils. A small scale soil survey (1: 200.000) was carried out for the whole area and large scale surveys were carried out for key areas representative for the region. In total 290 soil observations ranging from 0.3 to 2 meter depth were made.

Soils were divided into different groups depending on their development (among others soil depth), texture and colour. Seven soil groups were differentiated, and some were subdivided into irrigated and non-irrigated soils. For each soil mapping unit profile descriptions and some chemical data are given. (See also section 3.7).

2.2 METHODOLOGY

For this survey use was made of the following materials:
-Topographic map of Yemen Arab Republic, scale 1:50.000, sheet number 1544 C1
-Geological map (Grolier and Overstreet), scale 1:500,000
-Soil map of Yemen Arab Republic, (Cornell, 1983), scale 1:500.000
-Aerial photographs (1973), run 833, nr.0017 and 0018, scale 1:60.000
-FAO manual "guidelines for soil description"
-Munsell colour chart
-Two types of augers for dry and wet soil
-Measuring wheel
-HCl, 10%

Soil descriptions were carried out conform the FAO guidelines and USDA Soil Taxonomy system.

No physiographic units could be distinguished within the station and also no other surface features, which could assist in differentiating between soils, were present. Therefore it was decided to carry out a grid survey with 2 augers per ha. The total area of the farm, without buildings and roads, was calculated at 10.9 ha. The northern road within the station was taken as a base line. Augers were set along a line perpendicular to this baseline, at 330°, when facing the north or 150° , when facing the south. In total 22 augers were described (see appendix 1). After three days of augering, it was possible to roughly indicate soil differences within the research farm. Based on these differences, five profiles were dug and described. Exact location of profiles and augers are given in Appendix 4.

Augers reached a depth between 100 and 130 cm. For every auger information was gathered about texture, matrix colour, carbonate content, depth of different layers and the presence of mottles, nodules or concretions. For profiles also structure, soil consistence and plasticity, rooting depth, biological features and horizons were described. Also surface features like sealing, crusting and cracks were described.

The information derived from the augers and the profiles, together with the chemical analysis of the samples, form the basis for the final soil classification and soil map.

2.3 SOIL PARENT MATERIAL AND SOIL FORMING FACTORS

2.3.1 Soil parent material

It is difficult to differentiate between the various parent materials. Everything has been thoroughly mixed and reworked and has been deposited as one alluvial sediment. Soil parent material consists of a combination of alluvium, colluvium and loess. The alluvium is a mixture of weathering products of the surrounding mountains and rock outcrops and materials originally deposited by wind. The lowest parts of the plain are assumed to have been lakes or marshy areas during the proluvial period. In these lakes fine textured materials were able to settle at the bottom (bottom lake sediments). In these areas soils are fine textured (clay, silty clay) and buried dark horizons can sometimes be found as well.

2.3.2 Soil forming factors

The soils of Al Irrah as described in this report, have been formed and changed by different factors. The main soil forming factors are:

1) **Parent material**, a mix of alluvium, colluvium and some loess. All parent materials are rich in calcium carbonates.

2) **Climate**
The former wet climate resulted in a dark coloured, buried horizon with a high organic carbon content (see 1.2 and 2.3.1).
Low precipitation and high evaporation have prevented leaching of calcium carbonates, but resulted in an accumulation of calcium carbonates. This process will be explained here in some detail. Parent material is rich in carbonates such as calcite (CaCO3). The weathering of calcite is shown in the following equation:

$$CaCO3\ (s) + CO2\ (g) + H2O\ (l)\ (\ Ca2+ + 2HCO3-$$

The solubility of calcite is highest at high CO_2 pressure and at low temperature. CO_2 is produced by plant roots and by respiration of micro-organisms in the soil.
An excess of evapotranspiration over rainfall as is the case in Al Irrah, means that most rainwater is evaporated or used by plants for respiration. Occasionally, very heavy downpours may cause percolation to below the rooting depth of plants, maybe sufficient to remove easily soluble salts. Removal of less soluble compounds, such as calcium carbonate is insignificant in this climate.

Often calcium carbonate is translocated within the soil profile by processes of dissolution, transporting and precipitation. Calcium carbonate in the surface soil will be dissolved by the CO_2 pressure from the roots and can be moved to a greater depth where it precipitates again (so called secondary $CaCO_3$). The secondary $CaCO_3$ formed first consists of filamentous material in the smaller biopores (pseudomicelia). Later, continued accumulation produces soft or hard nodules.

Soils of Al Irrah are all rich in active calcium carbonates.

3) **Topography**
In depressional sites and places surrounded by mountains, fine textured material eroded from the slopes by water (silt, clay and calcareous loess) was deposited and deep soils could be formed.

4) **Man-made factors**
Crop residues, manure and chemical fertilizer inputs influence the organic carbon content and nutrient status of the soil. The (top)soil is disturbed by ploughing and other management practices.

2.4 SOIL CHARACTERISTICS, MORPHOLOGY

2.4.1 Texture

Texture of all soils is fine loamy to fine clayey up to ± 100/ 140 cm. The texture of the topsoil appears to be uniform anywhere within the farm and ranges between silt loam and silty clay loam. The subsoil shows some increase in clay content and textures are clay loam, silty clay and clay. Textures are good in terms of waterholding capacity and (when not too clayey) also in available moisture for plants. The silt loam topsoil resulted at some places in crust formation.
Profiles that reached a depth of 140-180 cm showed a change in texture to sandy loam. Based on the information in Mosgiprovodkhoz (1986) soil survey report, it is most likely that all soils in Al Irrah farm are underlain at a certain depth by a sandy loam layer.

2.4.2 **Soil colour**

Generally, the colour of the topsoil is brown (10YR 5/3, dry) and dark brown (10YR 3/3) when moist. The colours of the subsoil differ between mapping units. Shira series and Gidr series, have distinct very brown to black subsurface horizons (black, 10YR 2/1, moist) at a depth of ± 80-100 cm. These layers are high in organic carbon content and this could explain the good results farmers in the surrounding area get by turning the first 100 cm of the soil. The subsoil colours of the other mapping units are somewhat darker than the topsoil (dark grayish brown, 10YR 3/2, moist). The sandy loam sublayer at a depth of ± 140/ 180 cm has a very pale brown colour (10YR 7/3 wet). Reddish coloured iron mottles were observed in one profile.

2.4.3 **Soil depth**

Soils in Al Irrah farm are all deep to very deep. No bedrock or cemented layers were encountered. Effective soil depth ranges from ± 100 cm (Shira series) to > 160 cm (Maris series).

2.4.4 **Rootability**

The rootability of the soils is moderate to good. Roots can reach great depths and were found up to 120 / 130 cm. Some factors impede root growth, i.e. stratification of the soil, compaction and swelling and shrinking of the clays. Stratification is a severe limitation in Shira series. Rootability is restricted in these soils clearly illustrated by the horizontal growth of roots at 45 and 95 cm. However, growth of shallow rooting crops will not be seriously restricted by this stratification. In Maris series, variant 1 and 2, root growth might be hampered in the subsurface layers due to compaction and structural problems (platy structure). Most likely these conditions are a result of the high clay content in the subsoil. The soil becomes compact and hard to very hard when dry, impeding root growth.

2.4.5 **Soil structure**

The largest part of the farm consists of soils that have a weak to moderate (sub) angular blocky or platy structure.

The surface soil is more or less the same for all profiles. It has a subangular blocky structure with dominantly fine and moderately fine aggregates. Due to a high silt fraction and a low organic matter content, existing structures can be destroyed easily.
The structure of the upper A horizon (0-20 cm), is loose when dry and wind erosion can easily take place during dry periods. Land management practices like ploughing should not be done when the topsoil is completely dry.
The unstable topsoil structure also rapidly collapses after rains or irrigation. A crust forms readily after rains or irrigation: the original aggregate constituents fall apart and form a dense stratified crust with a poor pore system. This crust formation is mainly due to a high silt content, presence of calcium carbonate and low organic matter content. A sufficient amount of humus would consolidate aggregate

formation and strength. A crushed (and sealed) topsoil leads to an increased soil density, a decreased porosity and infiltration capacity and hampers seed emergence.

Maris series, variant 1 and 2, all have a platy structure at a depth of ± 30 till 85 cm. The sandy loam substratum has a porous massive structure.
Grade of structure is weak (surface layers and deep subsurface layers) to moderate (subsurface layers).

2.4.6 Soil compaction

Soil compaction was observed at some depth in the soils with a high clay content. In downward direction an increase in density and a decrease in porosity was noticed. Mosgiprovodkhoz (1986) also observed soil compaction in subsurface horizons, especially in irrigated soils. Their report gives two causes that can lead to the soil compaction: (1) accumulation of exchange sodium in the soil absorbtion complex. It is known that soils with a high sodium exchange ratio, can become very hard when dry; (2) formation and accumulation of secondary minerals of the montmorillonite group. One might also think of compaction due to machinery use.

2.4.7 Cutans

Cutans are clay skins on ped and pore surfaces, indicating clay illuviation or surface related clay particle reorientations such as pressure faces. During fieldwork, shiny ped faces were observed. Some doubt exists whether they indicate clay skins, pressure faces or something else.

Research in other areas in Yemen concluded that the shiny pedfaces were mainly the result of calcite skins (thin sections from Ausifirah). Examination of thin sections from profiles in the montane plains that looked most likely to have cutans, did not reveal any (Acres, 1982). The same seems to be true for the shiny ped faces observed in Al Irrah. Although they look like clay cutans, most indicate calcite skins while some may indicate pressure faces.

2.5 SOIL CHARACTERISTICS, CHEMICAL DATA

2.5.1 Analysis of irrigation water

Irrigation water was taken from the well in Al Irrah and analyzed in the laboratory in AREA, Dhamar. The results are as follows:

E.C (mS/cm at 25° C):	0.49		
pH:	8.4		
Soluble Cations (cmol/L)		Soluble Anions (cmol/L)	
Na:	2.4	CO_3:	0.0
K:	0.1	HCO_3:	3.8
Ca:	1.2	Cl:	1.4
Mg:	2.3	SO_4:	0.8
Sum of Cations	6.0	Sum of Anions	6.0

SAR (Sodium Adsorption Ratio):	1.8
RSC (Residual Sodium Carbonates, i.e. available carbonates, CO_3 and HCO_3^- that are not bound by Ca and Mg cations):	0.0
SSP (Sodium Saturation Percentage):	40.0

Classification (U.S. Salinity Lab): C2-S1 i.e. medium salinity, low sodium water. It can be used for irrigation on almost all soils with most crops. However, moderate leaching is required to control accumulation of salt particularly for crops with sensitive salt tolerance.

2.5.2 Calcium carbonate

The topsoil of all mapping units is moderately to strongly calcareous. Also the subsoil is strongly calcareous everywhere within the research station. An increase in carbonatic concentrations is observed downwards in the soil. The topsoil normally does not show any visible concentrations, while from ± 40 cm to 80 cm downwards few concentrations and below 80 cm common or many concentrations are present. Concentrations are mainly present in the form of soft filaments (pseudomicelia).

A calcic (more than 15% carbonates) horizon was identified during fieldwork in Gidr series, at a depth of 105-135 cm. However, this was not confirmed by laboratory results. In general, laboratory figures for calcium carbonate content in Al Irrah soils, seem to be too low.

The presence of active calcium carbonate influences the pH of the soil and the availability of other nutrients in the soil. It especially decreases available phosphorus, iron and zinc (particularly important for fruit trees).

2.5.3 Soil pH

Together with the organic carbon content, the pH is an important indicator for the fertility status of the soil. In Al irrah, pH values range between 6.6 and 8.2. Normal pH values for the topsoil are around 8.0. For the subsoil normal pH values are between 7.7 and 8.0. These pH values are normal for calcareous, Yemeni soils. Exceptions exist for the dark buried layers with a high organic carbon content. pH values in these layers (50-100cm depth) are considerably lower, between 6.6 and 7.6.

In general a pH between 7.5 and 8.5 affects the availability of several nutrients and therefore deficiencies of phosphorus and micronutrients like iron, manganese and zinc can be expected.

2.5.4 **Organic Carbon**

Organic matter is an important source and reserve of plant nutrient and soil moisture. It also influences the soil structure. High organic matter contents in the topsoil will stabilise the structure and limit the formation of surface crusts after rainfall. Organic matter figures can be calculated from organic carbon figures: Soil organic Carbon (%) x 1.72 = Soil Organic Matter (%)

Organic matter figures for the topsoil range between 0.7 and 2.6 %. The average figure for the topsoil is 1.4 %. There is no significant difference in organic matter content between topsoil and subsoil from the same material.

The organic carbon content in the buried black horizons is sometimes similar to other horizons (Gidr series). In the Shira series however, organic carbon figures in these layers are much higher compared to the overlying and underlying layers. An explanation for this is given in sections 1.2 and 2.3.1.

Compared to other regions in Yemen the organic matter content in Al Irrah is moderate to high. For a good crop performance, figures are moderate and regular application of organic manure is recommended.

2.5.5 **Phosphorus, Nitrogen, Potassium (NPK)**

Phosphorus is an important macronutrient influencing crop performance. Often, figures for Yemen soils are rather low. The average figure for available phosphorus in the topsoil in Al Irrah is 4.6 ppm. Values for the subsoil range between 1 and 8 ppm with an average of 3.6 ppm. These figures indicate a deficiency for almost all crops. An explanation for the low phosphorus availability is that the active calcium carbonate converts phosphate to calcium phosphate that is unavailable for plants. Especially for crops like potatoes, tomatoes and onions P-levels are far too low. Table 3 gives an overview.

Table 3: P-values for different crop requirement levels.

Crop requirement	Deficient P-values (ppm)	Moderate P-values (ppm)	Adequate P-values (ppm)
Low P (grasses, cereals, soybean, maize)	< 4	5-7	>8
Moderate P (cotton, sweetcorn, tomatoes)	< 7	8-13	>14
High P (potatoes, celery, onions)	< 11	12-20	>21

(Source: Landon 1996)

No laboratory data is available for nitrogen, but values are expected to be low. Laboratory values for potassium indicate that values are adequate but not very high. Crops requiring high levels of potassium need additional K-fertilizer on Al Irrah soils.

2.5.6 Micronutrients

Although micronutrients have not been determined some general remarks can be made. Micronutrients (Zn, Cu, Fe) availability is reduced with increasing pH. High calcium carbonate levels reduce availability of copper and iron. Crops sensitive to Fe and Zn deficiencies are: maize, citrus, legumes and cotton.

2.5.7 Soil EC

The EC-soil gives an indication of the total quantities of soluble salts in soils. According to USDA classification, soils with an EC between 0 and 2 are considered salt free. EC values for Al Irrah soils range from 0.4 to 2.4. The EC of the topsoil is low, normally between 0.4 and 0.8. The EC of the subsoil is also low. No salt problems are present in the farm or are expected to develop in recent future. However in two profiles an increase in salts was measured at 30-100 cm. To avoid the salts from coming to the surface, fields should not be abandoned (allowing upward water movement) and regular ploughing should be carried out (breaking of capillaries). In this way capillary rise of salts will be avoided.

Chapter 3
SOIL CLASSIFICATION

3.1 SOIL TAXONOMY

The soils under investigation have been classified according to Soil Taxonomy (1994) and World Reference Base for Soil Resources (FAO, UNESCO, ISRIC, 1994).

Soil Taxonomy is a hierarchical system with different categories. The system is based on class distinction through precisely defined diagnostic horizons, soil moisture regimes and soil temperature regimes. Each category is designed to be useful at an appropriate level of detail. Soil orders, at the highest level are used at small scale (exploratory) surveys. Soil series (or phases of soil series), at the lowest level, are used at detailed level. A soil series has a specific regional name such as "Maris, fine loamy". As explained in section 2.3, the soil moisture regime for Al Irrah is aridic and the soil temperture regime is hyperthermic.

Since Al Irrah research station was surveyed at detailed level, soils are classified up to the series level (see section 3.3). At order level, soils in Al Irrah farm are classified as Aridisols, i.e. soils that have an aridic temperature regime. At lower level the soils are classified as Typic Haplocambids, fine loamy / fine clayey, mixed, hyperthermic. Haplocambids in this survey are soils with a very low rate of transformation due to the lack of soil moisture.

3.2 WORLD REFERENCE BASE FOR SOIL RESOURCES

The World Reference Base for Soil Resources (WRB) (FAO, ISRIC, UNESCO, 1994) classification system has three hierarchical levels of classification. The three levels are used to encompass the major soils of the world. At the highest level 30 Major Soil Groupings are found, subdivided at the second level in more than 200 Soil Units. The third level consists of Soil Subunits. At the first hierarchic level soils are differentiated according to main soil forming processes that produced characteristic soil features. The second hierarchic level takes secondary soil forming processes into account.

The classification system of which the first version was published between 1974 and 1978 has been revised several times since. For this survey the most recent version of 1994, "The World Reference Base for Soils" was used. The main objectives of the 1994 World Reference Base for Soil Resources are among others (FAO, ISRIC, UNESCO, 1994):

-"To develop an internationally acceptable framework for delineating soil resources to which national classifications can be attached and related".

-"To provide this framework with a sound scientific basis".

Presently the system is widely used in both developing and developed countries.

A major difference with Soil Taxonomy is the absence of soil moisture and soil temperature regimes.

Soils in Al Irrah farm are all classified as Calcaric Cambisols. Cambisols are soils that are normally relatively young with beginning soil formation. Cambisols are one of the most common soils in the world and can be found in places were soils are young and soil formation is slow, as is the case in the arid climate of Al Irrah. Calcaric Cambisols are Cambisols having calcaric soil material between 20 and 50 cm from the surface.

3.3 SOIL SERIES

Soil series are defined as "a group of soil horizons similar in differentiating characteristics and arrangement in the soil profile, except for the texture of the surface soil, and developed from a particular type of parent material. The soils within a series are essentially homogeneous in all soil profile characteristics except texture, principally of the surface horizon, and slope, stoniness, degree of erosion, topographic position and depth to bedrock where these features do not modify greatly the kind and arrangement of soil horizons" (Mohammed Ali, 1996). Soil Series were devised as a class of soils that can be recognised at a level where they can be useful for providing management advice to farmers. Soil series can be used to map soils at semi detailed scale, i.e. scales of 1:20,000 to 1:50,000. At detailed level, i.e. scales larger than 1:20,000, phases of soil series are suited to characterize soils (Mohammed Ali, 1996).

Series should be defined in the same way everywhere, regardless of the immediate purpose of the survey. Where detailed interpretations are required, the series can be subdivided into phases according to any characteristic significant to land use, for example depth, surface texture, stoniness, slope or salinity.

The soil series used in this report were partly defined in a previous survey by Acres (1980 and 1982) for the Montane Plains (south of the Yizla pass). Acres gave a very good description of the various soil series (Maris, Shira etc) in the Montane plains. It turned out that soils found in Al Irrah are partly similar to soil series described in the Montane plains report. One new series has been defined in this report, viz. Gidr series.

Acres assumed that most parts of the Montane plains have an ustic moisture regime. However, recent information (Bruggeman, 1997) indicates that the moisture regime in this area is aridic (as it is for Al Irrah as well). This implies that soils described by Acres, which were classified as Ustochrepts, would now, based on more climatic data, classify as Aridisols. So, although the Soil Taxonomy classification in 1982 for the soils in the Montane plains differs from the recent Soil Taxonomy classification for Al Irrah soils, in fact the soils in both places are similar.

Table 4 shows similar soils found in Al Irrah and the Montane plains, indicated by soil series name and by their Soil Taxonomy classification in Acres (1982) and this report (1998). From this table it appears that Acres gave the Maris series two different classifications. This is not correct and has to be rectified (for more information see also Field Document 2, and Field Document (under preparation).

Table 4: Soil series with Soil Taxonomy classification in 1982 and this report.

Soil series	Soil Taxonomy (Acres, 1982)	Soil Taxonomy (this report)
Maris	Vertic Ustochrept / Udic Ustochrept	Typic Haplocambid, fine clayey, mixed, hyperthermic
Shira	Udic Ustochrept	Typic Haplocambid, fine loamy over sandy, mixed, hyperthermic
Gidr	--	Typic Haplocambid, fine loamy, mixed, hyperthermic

Table 5 shows similar soils found in Al Irrah and the Montane plains, indicated by soil series names and by their FAO classification in Acres (1982) and this report (1998).

Table 5: Soil series with FAO classification in 1982 and this report.

Soil series	FAO (Acres, 1980, 1982)	FAO (WRB, this report)
Gidr	--	Calcaric Cambisol
Maris	Calcaric Cambisol Vertic Cambisol	Calcaric Cambisol
Shira	Calcaric Cambisol	Calcaric Cambisol

3.3.1 **Maris series**

Maris series is a deep to very deep, moderately well drained soil. The soil is distinguished by its uniform, moderately fine to fine textures up to about 120 cm depth or more. Subsoil textures are mainly clay to silty clay, and sometimes silty clay loam and clay loam. A number of profiles have cracks and slickenside development below the surface or cracks at the surface that do not extend to the subsoil. Profiles lack a clear buried, dark horizon. Most profiles have forms of visible calcium carbonate concentrations.

WRB classification (1994):	Calcaric Cambisol
Soil Taxonomy classification (1994):	Typic Haplocambid, fine clayey, mixed, hyperthermic

Variant 1 also has a deep profile, uniform in colour, texture and most other properties. The texture is somewhat coarser than in Maris series (clay loam, silty clay loam in the control section) and the soil does not develop cracks.

3.3.2 **Shira series**

This is a deep (< 150 cm), well drained soil that has layers of different texture below 30 cm. Shirah series is formed in stratified alluvial deposits. The texture of the stratified layers in the control section differs between fine clayey and coarse loamy. The surface horizon has a texture of silt loam or silty clay loam that is underlain by alternating layers of silty clay loam, silty clay and sandy loam textures. The depth and thickness of these layers is variable. A total number of 5 to 6 alternating layers can be found in the profile in the first 110 cm. Dark layers with a significantly higher organic carbon content are present in the profile at depth varying between 40 and 110 cm.

The stratification of soil materials influences the crop performance and this soil is not as favourable for crop growth as the Maris and Gidr series. Shallow rooting crops however will not be affected as the main textural changes occur below 45 cm.

WRB (1994):	Calcaric Cambisol
Soil Taxonomy classification (1994):	Typic Haplocambid, fine loamy, mixed, hyperthermic

3.3.3 **Gidr series**

Gidr series are very deep soils and well drained. The soil has a fine loamy texture. The topsoil has a loam texture and the subsoil (up to 100 cm) has a silty clay loam texture underlain by a sandy loam texture. Gidr series are characterized by a distinct black, buried horizon at a depth of 50 to 80 cm. Organic carbon content in this horizon is usually not high enough to qualify for a mollic horizon.

The buried dark horizon is underlain by a horizon high in calcium carbonate content, mainly at a depth of 100 cm or more. Calcium carbonate % in this horizon is normally more than 15%. The calcic concentrations mainly consist of soft filaments and hard concretions. The soil does not qualify as Calcisol because the calcic horizon is found at great depth, > 100 cm. Gidr series also has a clear change in texture from (silty) clay loam to sandy loam at about 110 cm depth.

Gidr series are in some aspects similar to Tinnan series, a soil found, among others, in Dhamar research station. Both have the same textures and both have a buried dark horizon in the control section. The main differences between the two series are:
(1) that the calcic horizon in Gidr series is found below the control section while in Tinnan series it is found closer to the surface, in the control section. The depth of the calcic horizon affects crop performance and is important to indicate.
(2) Gidr series has a substratum layer of sandy loam at a depth of about 130 cm, while Tinnan series lacks such a layer.

WRB classification (1994):	Calcaric Cambisol
Soil Taxonomy classification (1994):	Typic Haplocambid, fine loamy, mixed, hyperthermic

Table 6 shows the soil series present in Al Irrah farm with their main characteristics.

Table 6: Differentiating soil characteristics for Soil Series in Al Irrah research farm.

SOIL SERIES	TEXTURE (CONTROL SECTION)	BURIED DARK HORIZON	EFFECTIVE SOIL DEPTH	CALCIUM CARBONATE	REPRESENT. PROFILE
GIDR	SiC, SiCL, C Underlain by SaL	30-50 cm thick 10YR 3/2, moist	Very deep	Calcic horizon, weakly cemented at 100-135 cm depth.	SNI043
MARIS	C, SiC	-	Very deep	Calcaric material	SNI045, SNI046
MARIS, VARIANT 1	SiCL, CL	-	Very deep	Calcaric material	SNI047
SHIRA	SiCL, CL, L, C, SaCL	10-25 cm thick 10YR 2/2, moist	Deep	Calcaric material	SNI044

3.4 SOIL MAPPING UNITS

An important aim of this soil survey is to delineate between soils with different land qualities and crop suitabilities. Therefore, major soil characteristics that influence soil properties, land qualities and consequently crop growth, were selected to delineate between soil mapping units.
Within the mapping unit, soils are as homogeneous as possible. The mapping unit descriptions give an average picture of soils within the unit. Small differences in horizon designation, colour, or chemical values may be present within a unit. One should also take into account that a line on the map, dividing two mapping units, in reality usually represents a gradual boundary in the field.

On the soil map for Al Irrah farm, delineations between mapping units are based on differences in soil morphology, i.e. texture, structure, stratification, presence of a calcic horizon, and presence of a (buried) dark layer. In total four different mapping units have been delineated, which are described hereafter.

Each mapping unit is composed of one major soil series and has inclusions of other series. A dominant series covers more than 50% of the mapping unit. Inclusions are soil series that cover less than 20% of a mapping unit. The composition of mapping units is shown in the soil legend table. A mapping unit is named after the dominant soil series.

3.5 SOIL LEGEND

The soil mapping and the location of observations was done on a sketch map of the farm, scale 1:5000, showing the lay out of the farm with the main roads. An initial legend was prepared from a brief reconnaissance and the relevant available information. During the course of the survey the legend was further corrected and refined. Eventually, and based on the soil information collected, a tentative soil map was drawn and then profile pits were located within each map unit.

Table 7: Legend of Al Irrah soil map

MAPPING UNIT / SYMBOL	SOIL SERIES (representative profile)	COMPOSITION OF MAPPING UNIT	SOIL TAXONOMY (1994)	WRB (1994)	LAND USE	CHARACTERISTICS
SH Shira	Shira, silt loam (SNI044)	90% Shira 5% Gidr 5% Maris	Typic Haplocambid, fine loamy, mixed, hyperthermic	Calcaric Cambisol	bare land, young fruit trees, sorghum, wheat	-Stratification -High active CaCO3 content -Poor rootability below 45 cm
GR Gidr	Gidr, silty clay loam (SNI043)	80% Gidr 20% Maris, variant 1	Typic Haplocambid, fine loamy, mixed, hyperthermic	Calcaric Cambisol	peach trees, maize, vegetables, sunflower	-Calcic horizon (100-135 cm) -Buried dark horizon. -Sandy loam layer at 135 cm -
MR Maris	Maris, silty clay loam (SNI045, SNI046)	85% Maris 15% Maris, variant 1	Typic Haplocambid, fine clayey, mixed, hyperthermic	Calcaric Cambisol	orchard	-Compaction -High active CaCO3 content -Fine texture -Uniform in colour and texture
MR-var1 Maris, variant 1	Maris, variant 1, silty clay loam (SNI047)	70% Maris, variant 1 15% Gidr 15% Maris	Typic Haplocambid, fine clayey, mixed, hyperthermic	Calcaric Cambisol	orchard	-Uniform in colour and texture -Fine texture -High active CaCO3 content

3.6 DESCRIPTION OF MAPPING UNITS

3.6.1 GR, Gidr, silty clay loam

Gidr, silty clay loam soils are well drained, very deep, with a fine loamy textured topsoil and subsoil (till 100 cm from the surface). Soil structure in the first three horizons (till 80 cm) is angular and subangular blocky. The grade of structure is moderate to strong, while sizes are mainly fine and medium with a moderate porosity. Together these characteristics provide a good rootability. The layer at 50-80 cm has a darker colour and has sometimes a higher organic carbon content than the other layers. At a depth of 1 meter, the texture changes to sandy clay loam and sandy loam. In contrast with the overlying soil, the fine sandy loam layer contained water at the date of profile description. This water remained either from irrigation or came from lateral flow from surrounding areas. Soil moisture retention and availability for crop growth is high. Water holding capacity and water retention in this fine textured material is optimal and capillary rise from the sandy loam layer to the overlying layer will take place. In this way the crop (especially deep rooting crops) can survive dry spells without irrigation by using the water from the lower lying sandy loam layer.
Next to a high water holding capacity, the soil also has a good internal drainage system.

Limiting factor for crop growth is a calcic horizon at ± 105-135 cm depth. Effects of a high CaCO3 content and a calcic horizon on crop growth have been described elsewhere in this report.

Soil Taxonomy (1994): Typic Haplocambid, fine loamy, mixed, hyperthermic
World Reference Base (1994): Calcaric Cambisol

3.6.2 SH, Shira, silt loam

Shira, silt loam soils are well drained, deep, with a fine loamy textured topsoil and alternating layers of moderately fine and fine textures in the subsoil. The structure type is subangular blocky. At a depth of 75-95 cm, a layer of silty clay with accumulation of $CaCO_3$ is found. After 95 cm, the soil is underlain by thin, stratified materials, either light coloured sandy loam (110-120 cm), or dark coloured silty clay texture (100-110 cm and 120-140 cm). The light coloured layers are rich in carbonates and the dark coloured layers have a gritty, almost granular structure. The structure type is, depending on the layer, angular blocky (silty clay) or porous massive (sandy loam). The water movement in the profile is strongly influenced by the stratification of the profile. Capillary rise from lower lying layers to the overlying topsoil is negligible. At a depth of 45 cm and 95 cm, many horizontal growing roots were observed, indicating poor rootability further downwards.

Factors limiting crop growth are: (1) stratification of the profile and a poor development of the different deposited layers, (2) accumulation of $CaCO_3$ at 75-95 cm, (3) low water retention deeper than 95 cm due to alternating clayey and sandy layers and (4) poor rootability after 45 cm.

These soils have less qualities for crop growth than other soils in Al Irrah research station. The soil is only marginally suitable for deep rooting crops and fruit trees. Deep ploughing till 60/70 cm, in order to mix layers, may improve the rootability.

Soil Taxonomy (1994): Typic Haplocambid, fine loamy, mixed, hyperthermic
World Reference Base (1994): Calcaric Cambisol

3.6.3 **Maris, silty clay loam**

Maris, silty clay loam soils are moderately well drained and have a fine loamy to clayey texture and a dark brown colour throughout the profile (till 140 cm). Soils have a clayey texture in subsurface layers underlain by a sandy loam substratum. Till 140 cm, the soil is very homogeneous in colour (dark grayish brown when moist) and texture (silty clay loam and clay loam). The structure type is subangular and angular blocky the first 40 cm and after 85 cm. In between a platy structure is present. At 140 cm a yellowish brown (moist), sandy loam layer with accumulation of calcium carbonates is present. Surface cracks (< 5mm wide) starting from the surface were observed. Also at a depth of 50 to 130 cm a lot of cracks were observed (± 5 mm wide) in the dry soil. Continuous planar voids, occurring between platy and blocky structure elements are the main type of pores. Aeration is good when the soil is dry. The hydraulic conductivity is high in dry soil because water can be drained quickly through the cracks. After rainfall or irrigation, the soil will swell and hydraulic conductivity and aeration will be low.

Within the first 125 from the surface no profile development other than a structural B-horizon was observed. No diagnostic horizons other than a cambic (structure B) horizon can be distinguished. The soil showed signs of compaction and this soil also had large cracks at some depth. Although the soils in this unit show signs of vertic properties they do not qualify for them. The limitations of these soils are compaction, a platy structure that inhibits root growth and swelling and shrinking properties which also impair root growth.

Soil Taxonomy (1994): Typic Haplocambid, clayey, mixed, hyperthermic
World Reference Base (1994): Calcaric Cambisol

3.6.4 **Maris, variant 1, silty clay loam**

Maris, variant 1, silty clay loam soils, are well drained, very deep, with a fine loamy texture throughout the profile. Soil colour (dark brown and dark grayish brown when moist) is also almost uniform throughout the profile. Structure elements have a blocky or platy shape. In the first two horizons (0-50 cm), small vertical cracks were observed. A compacted soil structure, causing poor aeration and rootability, is the main limitation for plant growth.

Soil Taxonomy (1994): Typic Haplocambid, clayey, mixed, hyperthermic
World Reference Base (1994): Calcaric Cambisol

3.7 REPRESENTATIVE AREA

A map in Appendix 4 gives an indication which areas in the same climatic zone have soils similar to Al Irrah soils. These areas are similar in climate and soils and form one agro-ecological zone. The research results of Al Irrah farm can confidently be extrapolated to these areas. The agro-ecological zonation is based on: (1) climatic data derived from Bruggeman (1997) and (2) soil data derived from Mosgiprovodkhoz soil survey of Sana'a basin (1986).

In the soil report of Mosgiprovodkhoz, a description is given of the mapping units found in Sana'a basin. One of the mapping units contains the three soil series present in Al Irrah research station, i.e. Maris, Shira and Gidr series. The soil series names and concepts are not used in Mosgiprovodkhoz's report but the description of the three soil types complies exactly with the three above mentioned soil series. The mapping unit in which the three soil series are found, covers the soils found on the Highland Plains around Sana'a (altitudes between 2100-2300 m).

In Mosgiprovodkhoz's survey the mapping unit is described as follows:

> "Mountain grey-cinnamon light carbonate cultivated slightly eroded, predominantly slightly solonetzic, sporadically slightly saline, light and medium loamy, rarely sandy loam".The soils are widespread in the area, covering 241 km2. They occur principally in the Sana'a Plain with absolute elevations varying from 2100 to 2350, mainly in a large intermontane depression. The soils are subject to wind erosion. The calcium carbonate content in the first 100 cm varies from 1-17%.

This mapping unit can be divided into four "soil types" which can be described as: (1) deep soils with a buried dark horizon (like Gidr series); (2) deep soils with some compaction in the deeper layers (like Maris series; (3) deep soils with a change in texture at about 80 cm depth (like Shira series); and (4) deep soils which are weakly solonetzic (high sodium adsorption ratio over other cations) and slightly saline (not confirmed by the survey done in Al Irrah).
From the description of the soils found in Al Irrah it can be concluded that at least Mosgiprovodkhoz's "soil types" (1), (2) and (3) comply with soils in Al Irrah.

4.1 INTRODUCTION

Land evaluation and recommendation for land use and soil management are the final stages of this survey. Land evaluation is carried out according to the FAO system (see among others Sys et al, 1991). The evaluation procedure consists of three phases:

(1) The description of the soil/ land and climatological characteristics and limitations.

(2) The determination of the requirements for a certain land use (crop).

(3) Comparison of characteristics with the requirements and classify the suitability of the land for a certain crop/ land use type.

4.2 LAND SUITABILITY CLASSIFICATION SYSTEM

Land suitability evaluation is the process of assessing the suitability of land for specific kinds of use. These may be major kinds of land use, such as rainfed agriculture, irrigated agriculture, livestock production, etc.; or land utilization types described in more detail, for example irrigated arable farming based on apple and peach, or rainfed arable farming based on sorghum.

There are three categories of classification: Land suitability orders, classes and subclasses. These suitability categories are assessed separately for each kind of land use under consideration, with respect to each soil mapping unit in the survey area.
Suitability orders separate land assessed as 'suitable' (S) from that which is 'not suitable' (N) for the use under consideration. The three main reasons why land may be classed as not suitable are that the proposed use is either technically impracticable (e.g. very thin or rocky soils); environmentally undesirable (would lead to severe soil erosion) or economically unprofitable.
Suitability classes indicate degrees of suitability. S1, 'highly'; S2 'moderately' and S3 'marginally' suitable. Of the two classes within the order 'not suitable', N1, indicating 'currently not suitable', refers to the land on which the use under consideration is technically possible but not economic; at present prices the cost of inputs needed to overcome the limitations would exceed the returns. Changes in the relative prices of the product and inputs , or advances in technology, e.g. new drought resistant crop varieties, can result in upgrading of N1 land. N2, indicating 'permanently not suitable', is applied to land on which it is unlikely that any foreseeable change in technical or economic conditions would render it viable for the use under consideration.
Suitability subclasses indicate kinds of limitations, e.g. moisture deficiency, erosion hazard. They are indicated by lower case letters placed after the class symbol, e.g. S2m, S2e (Dent, D. and Young, A. 1981). In this report the following symbols are used to indicate kinds of limitations.

y = Soil fertility (accumulation of calcium carbonates)

c = Soil structure (rootability, compaction)
st = Stratification
h = soil texture, very fine textures (clay)

Table 8: Categories of land suitability classification

ORDER	CLASS	SUBCLASS (EXAMPLES)
S, suitable	S1 S2 S3	S2y S2st S2y,st
N, not suitable	N1 N2	N1st

y = fertility
st = stratification

4.3 SOIL LIMITATIONS AND LAND SUITABILITY CLASSIFICATION

Crop growth in the Al Irrah farm is to a large extend constrained by climaticl conditions like amount of rainfall, evapotranspiration and temperature. Without (supplementary) irrigation the range of crops that can be grown is small: sorghum, wheat and barley. Most crops are grown with supplementary irrigation (like alfalfa, maize and potatoes).

Limitations directly related to the soil are:
-Depth of rooting
-Presence of free calcium carbonates throughout the profile and/or a calcic horizon
-Stratification
-Compaction/ high clay content
-Crusting

In the suitability classification basic requirements for fertilizers (N and P) are not taken into account. Thus if a crop has been classified as S1 it is assumed that regular fertilizer is applied. Extra fertility limitations, caused by high active calcium carbonate contents in the soil, are indicated with the suffix y.
Table 9 gives the requirements for some crops grown in Al Irrah farm. Tables 10 and 11 show a land suitability classification for Al Irrah soils and their major crops.

Table 9: Climatic and soil requirements for some selected crops

Crop	Total Growing Period (days)	Temperature Requirements for growth(0C) optimum(range)	Specific climatic constraints and/or requirements	pH ranges	Texture, drainage	Sensitivity to salinity	Soil depth	Soil fertility
Alfalfa	100 - 365	24-26(10-30)	sensitive to frost;cutting related to temp.;requires low humidity in warm climates.	6.5 – 7.5 (O) 5.5 – 8.0 (R)	Light to medium textured, (O + R), well drained.	Moderately sensitive	Deep (O) Medium (R)	Moderate(O) Low (R)
Sorghum	100 – 140+	24-30(15-35)	sensitive to frost; for germination temp.>10oC;cool temp. causes head sterility	6.0 – 7.0 (O) 5.0 – 8.5 (R)	Medium to heavy textures (O), Wide range of textures (R), relatively tolerant to periodic waterlogging,	Moderately tolerant	Medium (O + R)	Moderate (O) Low (R)
Maize	100 – 140+	24-30(15-35)	sensitive to frost; for germination temp. >10oC; cool temp. causes problem for ripening.	5.0 – 7.0 (O) 4.5 – 8.5 (R)	Medium textures (O), wide range of textures (R). Well drained and aerated soils with deep water table and without waterlogging.	Moderately sensitive	Medium (O) Shallow (R)	High (O) Low (R)
Barley	100 – 130	15-20(10-15)	sensitive to frost; dry period required for ripening	6.5 – 7.5 (O) 6.0 – 8.0 (R)	Medium textured is preferred;relatively tolerant to high water table	Moderately tolerant	Deep (O) Medium (R)	Moderate (O) Low (R)
Wheat	100 – 140	15-20(10-15)	spring wheat: sensitive to frost;dry period required for ripening.	6.0 – 7.0 (O) 5.5 – 8.5 (R)	Medium textures (O), medium and heavy textures (R), relatively tolerant to high water table;	Moderately tolerant	Medium (O) Shallow (R)	High (O) Moderate (R)
Apple	Perennial	10-30 (6-35)	Requires period of winter dormancy	6.2 – 7.0 (O) 4.5 – 8.2 (R)	Light to medium textures (O), wide range of textures (R)	Moderately sensitive	Deep (O) Medium (R)	Moderate (O+ R)
Peach	Perennial	20-33 (7-35)	Requires period of winter dormancy. Needs continuous soil moisture during the growing season.	5.5 – 6.3 (O) 4.5 – 7.5 (R)	Light to medium textures (O) Wide range of textures (R)	Moderately sensitive	Deep (O) Medium (R)	High (O) Moderate (R)
Lentil	70-90	15-29 (5-32)	Sensitive to frost	5.5 –7.5 (O) 4.5 – 8.2 (R)	Medium to heavy textures (O) Wide range of textures (R)	Moderately sensitive (O), moderately tolerant (R)	Medium (O) Shalllow (R)	Moderate (O) Low (R)
Potato	100-150	15-20(10-25)	sensitive to frost; night temp.<15oC required for good tuber initiation	5.0 – 6.2 (O) 4.2 – 8.5 (R)	well drained ; aerated and porous soils. Medium textures (O), wide range of textures (R)	Moderately sensitive	Medium (O) Shallow (R)	Moderate (O) Low (R)
Onion	100-140	15-20(10-25)	tolerant to frost; low temp.(<14-16oC)required for flower initiation; no extreme temp. or excessive rain	6.0 – 7.0 (O) 4.3 – 8.3 (R)	medium textures (O), wide range of textures (R)	Sensitive	Medium (O) Shallow (R)	Moderate (O) Low (R)

Crop	Total Growing Period (days)	Temperature Requirements for growth(0C) optimum(range)	Specific climatic constraints and/or requirements	pH ranges	Texture, drainage	Sensitivity to salinity	Soil depth	Soil fertility
Bean, common	*fresh 60- 90;* dry 90-120	15-20(10-27)	*sensitive* to frost, excessive rain,hot weather	5.5 – 7.5 (O) 4.0 - 9.0 (R)	Medium textures (O), wide range of textures (R). Friable soil, well drained and aerated.	Sensitive	Medium (O) Shallow (R)	Moderate (O) Low (R)
Tomato	100-140	15-20(10-25)	sensitive to frost	5.5 – 6.8 (O) 5.0 – 7.5 (R)	medium textures (O), wide range of textures (R).	Moderately sensitive	Shallow (O) Shallow (R)	High (O) Medium (R)
Cucumber	90-120	18-32(10-35)	*sensitive* to frost	6.0 – 7.5 (O) 4.5 – 8.7 (R)	medium textures, wide range of textures (R).	Sensitive	Medium (O) Shallow (R)	High (O) Medium (R)
Carrot	90-120	15-25(10-30)	tolerant to frost	5.8 – 6.8 (O) 4.2 – 8.7 (R)	medium textures (O), wide range of textures (R)	Sensitive	Medium (O + R)	Moderate (O + R)

O= Optimum

R= Range

Table 10: Suitability classification indicating the major limitations for each mapping unit.

MAPPING UNITS	LIMITING FACTORS							
	Effective soil depth	Calcium carbonate content	Calcic horizon	Soil structure	rootability	Available water	Texture	SUITABILITY CLASSIFICATION[1]
GIDR	very deep	strongly calc. 0-100 extremely calc. + soft concentrations 100-160	105-135	good throughout	good 0-80 moderately 80-160	Good	silty clay loam (topsoil) clay loam / silty clay (35-105) sandy (clay) loam (105-160)	Shallow rooting crops S1 Deep rooting crops S2c Fruit trees S1/ S2y Potato S1
SHIRA	Deep	Strongly calc. 0 - 75 Common soft concentrations, 75 - 140	-	good 0-45 moderate 45-140	good 0-45 low 45-95	Moderate	silt loam (topsoil) silty clay loam (20-95) sandy loam / silty clay (>95) Stratification	Shallow rooting crops S1 Deep rooting crops S2c,st Fruit trees S3st,c Potato S2c
MARIS , variant 1	very deep	Strongly calc. throughout > 50, few soft concentrations	-	good 0-50; >80 moderate 50-80	good 0-50; >80 moderate 50-80	Good	silty clay loam (topsoil) clay loam / silty clay (subsoil)	Shallow rooting crops S1 Deep rooting crops S2c Fruit trees S2c Potato S2c
MARIS,	very deep	strongly calc. throughout 85-130 common concentrations	-	good 0-30; >85 moderate 30-85	good 0-30 moderate 30-130	Good	Silty clay loam (topsoil) clay loam / silty clay (subsoil)	Shallow rooting crops S1 Deep rooting crops S2c Fruit trees S2h,c Potato S2c

y= Soil fertility (accumulation of calcium carbonates)
c= Soil structure (rootability, compaction)
st= Stratification
h= soil texture, very fine textures (clay)

Table 11: Soil suitability classification for each soil mapping unit for some selected crops

Mapping Unit (symbol)	Wheat, Barley	Maize	Alfalfa	Carrot	Potato	Tomato	Onion	Apple	Peach
GIDR	S1	S2y	S1	S1	S1	S1	S1	S2y	S2y
SHIRA	S1	S2y	S2,st	S2st	S2st,c	S1	S1	S3,y,st,c	S3y,st,c
MARIS, variant 1	S1	S2y	S2g	S1	S1	S1	S1	S2c	S2c
MARIS,	S1	S2,y	S2g	S2c	S2c	S1	S2c	S2c	S2c

4.4 CONCLUSIONS AND RECOMMENDATIONS

1. Fruit trees and other deep rooting crops should not be grown on Shira soils. It is recommended to plant new fruit trees on Gidr soils instead of Shira soils.

2. Select shallow rooting crops for Shira soils.

3. Improve the structure of the topsoil in order to decrease crust formation and sealing.
   - Mulch can be used to decrease the impact of raindrops on the bare soil.
   - An increase in organic matter content will improve soil structure and soil fertility and reduce risks for sealing/ crusting.

   A study by Massoud (in FAO, 1973) showed the relation between moisture content of the crust and seed emergence for different crops. To get best results, moisture tension during seed emergence should be kept low (below 0.33 atm). Regular irrigation with short intervals gave the best results.

4. Maris soil series are heavy textured and no soil tillage should be carried out when the soil is too moist because of risks of smearing and compaction.

5. Deep soil loosening of Maris soils may improve physical properties (infiltration, water availability, rootability).

6. Al Irrah research station represents quite well the different soils present around Sana'a.

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SOIL AUGER DESCRIPTIONS AND ANALYTICAL DATA

NR.	HORIZONS top- bottom	TEXTURE	CARBONATES	COLOUR moist	dry	REMARKS
1.	0- 30 30- 60 60-100 100-130	silty clay loam silty clay loam silty clay loam silty clay loam	strongly extremely strongly strongly	10YR3/2 10YR3/3 10YR3/1 10YR4/4	10YR5/3 10YR4/3 - 10YR5/4	60-100 cm: buried, dark horizon 100-130 cm iron mottles + filaments
2.	0- 60 60-110 110-120	silt loam silty clay loam silty clay loam	extremely strongly extremely	10YR3/2 10YR2/2 10YR5/4	10YR5/3 - 10YR6/4	60-110 cm: buried dark horizon 110-120 cm iron mottles + filaments + concretions
3.	0- 30 30- 60 60-110 110-115	silty clay silty clay loam silty clay loam silty clay	strongly strongly strongly strongly	10YR3/3 10YR3/3 10YR3/2 10YR5/3	10YR5/3 10YR5/4 10YR4/2 10YR6/3	> 110 cm iron mottles and filaments + concretions
4.	0- 15 15- 45 45- 85 85-115	silty clay loam silty clay loam silty clay loam clay loam	strongly strongly moderately moderately	10YR3/3 10YR4/2 10YR3/3 10YR3/2	10YR4/3 - - -	
5.	0- 30 30- 55 55-100	silty clay loam silty clay loam silty clay loam	strongly strongly strongly	10YR3/2 10YR3/2 10YR3/2	10YR5/3 10YR4/2 10YR4/2	
6.	0- 40 40-100	silty clay loam silty clay loam	extremely strongly	10YR3/3 10YR2/2	10YR5/3 -	40-100 cm: some filaments and dark stripes of decayed roots
7.	0-100	silty clay loam	strongly	10YR3/2	-	Homogeneous brown soil. > 70 cm: filaments.
8.	0- 35 35- 75 75-100	silty clay silty clay silty clay	moderately strongly strongly	10YR3/2 10YR3/2 10YR3/2	10YR4/3 10YR4/3 10YR3/3	Homogeneous brown soil. Tough augering in deeper layers. >75 cm filaments.
9.	0- 40 40- 70 70- 90 90-100 100-120	clay loam clay loam sandy clay sandy clay sandy loam	strongly strongly moderately extremely slightly	10YR3/3 10YR4/2 10YR2/1 10YR3/2 10YR3/1	10YR5/3 10YR6/2 7.5YR4/0 10YR6/2 10YR4/1	70-120: soil very loose.
10.	0- 35 35-100	silty clay loam silty clay	strongly strongly	10YR3/3 10YR3/2	- -	35-100 cm: few filaments
11.	0- 35 35-100	silty clay loam silt loam	strongly strongly	10YR3/2 10YR2/2	10YR4/3 10YR3/2	
12.	0- 50 50-100	silty clay loam silty clay loam	strongly strongly	10YR3/2 10YR3/2	10YR5/3 10YR3/3	50-100 cm: dark stripes from decayed roots.
13.	0- 35 35- 80 80-100 100-115	silty clay silty clay sandy clay loam sandy clay loam	strongly strongly slightly slightly	10YR2/2 10YR2/1 7.5YR5/4 10YR2/1	- - - -	80-100 cm, gravely texture, filaments.
14.	0- 40 40-100	clay loam clay loam	strongly strongly	10YR3/3 10YR3/2	- -	Tough augering in deeper layers.
15.	0- 35 35- 60 60- 70 70- 80 80- 100	silt loam silt loam sandy loam sand sandy loam	strongly strongly moderately strongly strongly	10YR3/2 10YR3/2 7.5YR2/0 10YR5/4 10YR2/1	10YR6/3 10YR5/2 7.5YR6/3 10YR6/3 10YR 2/1	

NR.	HORIZONS top- bottom	TEXTURE	CARBONATES	COLOUR moist	dry	REMARKS
16.	0- 30	loam	strongly	10YR3/2	-	At 30 cm, many filaments. 60- 100 cm: gravely texture. 100-110 cm dark and reddish colours.
	30- 75	silt loam	extremely	10YR4/2	-	
	75- 85	loamy sand	extremely	10YR3/1	-	
	85-100	loamy sand	slightly	7.5YR5/4	7.5YR7/6	
	100-110	loamy sand	slightly	10YR3/1	10YR6/1	
17.	0- 50	loam	strongly	10YR3/2	-	> 70 cm, tough augering
	50- 70	silty clay loam	strongly	10YR3/3	10YR5/3	
	70-100	clay loam	strongly	10YR3/2	-	
18.	0- 45	clay loam	strongly	10YR3/3	10YR5/3	70-100 cm: layer very loose and dry, gravely, many concretions.
	45- 70	silty clay loam	extremely	10YR3/2	10YR6/2	
	70-100	loamy sand	extremely	7.5YR2/0	7.5YR3/0	
19.	0- 25	clay loam	strongly	10YR3/3	10YR5/3	55-100 cm: common, soft calcium segregations. Homogeneous soil.
	25- 55	clay loam	strongly	10YR4/2	-	
	55-100	silty clay loam	strongly	10YR3/2	-	
	100+	clay loam		10YR3/2	-	
20.	0- 40	clay loam		10YR4/2	10YR6/3	
	40-100	clay loam		10YR2/2	-	
21.	0- 20	silty clay loam	strongly	10YR4/3	10YR6/3	Same as profile SNI044. 90-100 cm: orange colour mottles, horizon contains mixed whitish, orange and black material.
	20- 40	clay loam	strongly	10YR3/2	-	
	40- 80	silty clay loam	extremely	10YR2/2	-	
	80- 90	sandy clay loam	extremely	10YR3/2	-	
	90-100	sandy clay	extremely	10YR2/1	-	
22.	0- 30	silty clay loam	strongly	10YR3/2	10YR6/3	Same as profile SNI044
	30- 50	clay loam	strongly	10YR4/2	-	
	50- 90	silty clay	strongly	10YR3/2	-	
	90-100	sandy clay loam	slightly	2.5Y2/0	-	
	100-110	loamy sand	slightly	10YR6/6	10YR7/4	
	110-120	sandy clay loam		10YR2/1	10YR2/1	

Analytical data augers

AUGER NO. AND DEPTH	Sand	Silt	Clay	Texture class	Available water (cm)	pH	EC (mS/cm)	$CaCO_3$ (%)	Organic Carbon (%)	Organic Matter (%)	Avail. P (mg/kg)	Exch. Na (cmol/kg)	Exch. K (cmol/kg)	Soluble Na (meq/l)	Soluble K (meq/l)
SNI11 / 0-30	25	52	23	Silt loam	5.1	7.9	0.47	7.5	0.1	0.17	6	1.2	1.1	4.8	2.15
30-60	28	51	21	Silt loam	4.5	8.0	0.52	2.5	1.3	2.3	4	1.2	1.3	3.1	15.5
60-100	13	41	46	Silty clay	7.4	8.0	0.59	2.5	1.5	2.6	2	1.4	0.8	5.2	2.6
100-130	45	28	27	Clay loam	5	7.7	0.87	10	0.7	1.2	3	3	0.8	4.6	2.3
SNI15 / 0-32	16	44	40	Silty clay loam	6.3	7.8	0.55	10	0.9	1.6	7	1.2	1.6	2.2	1.1
32-56	14	37	49	Clay	4.8	7.9	0.7	12.5	1.1	1.9	3	1.2	1	2.7	1.35
56-106	11	35	54	Clay	10.5	7.8	0.93	7.5	1.3	2.3	3	1.2	1	2.5	1.25
SNI13 / 0-35	23	45	32	Clay loam	6.7	8.1	0.76	10	1.5	2.6	8	1.2	0.9	3.2	1.6
35-80	-	-	-	-	9	8.0	0.5	12.5	1.3	2.3	2	1.2	0.8	2.9	1.45
80-100	32	36	32	Clay loam	4	8.1	0.43	5	1.1	1.9	1	1.8	0.25	3.2	1.6
SNI19 / 0-27	19	43	38	Silty clay loam	5.6	8.1	0.45	7.5	1.1	1.9	5	1.6	0.3	3.1	1.55
27-55	13	36	51	Clay	6	8.0	0.49	10	1.1	1.9	3	1.4	1.6	-	-
55-100	11	40	49	Silty clay	9.5	7.4	2.23	12.5	1.1	1.9	3	1.6	1	8.4	4.2
SNI20 / 0-40	17	40	43	Silty clay	-	7.9	0.59	7.5	0.9	1.6	2	1.6	1.1	7.1	3.55
40-100	12	33	55	Clay	-	7.7	1.88	1.25	1.9	3.3	3	3.6	0.46	9.4	4.7
SNI21 / 0-20	25	51	24	Silt loam	-	8.2	0.44	7.5	1.1	1.9	5	1.2	1.1	4.6	2.3
20-40	30	43	27	Loam	-	7.9	0.55	5	0.9	1.6	8	1.4	0.8	3.1	1.55
40-80	-	-	-	-	-	6.8	1.24	10	1.3	2.3	5	1.6	0.45	3.8	1.9
80-90	-	-	-	-	-	7.6	1.62	12.5	1.1	1.9	6	1.4	0.37	6.5	3.25
90-100	21	36	43	Clay	-	7.8	0.47	5	1.5	2.6	7	1.4	0.8	5.6	2.8
SNI22 / 0-30	20	54	26	Silt loam	-	8.1	0.42	5	0.9	1.6	6	1.4	1.1	3	0.55
30-50	21	52	27	Silt loam	-	6.8	1.68	7.5	-	-	5	1.2	0.45	-	-
50-90	28	56	16	Silt loam	-	6.6	1.37	5	0.9	1.6	5	0.6	0.41	2.5	1.25
90-100	37	41	22	Loam	-	7.9	0.38	2.5	1.5	2.6	4	0.6	0.47	-	-
100-110	65	15	20	Sandy clay loam	-	8.0	0.33	4.3	0.4	0.7	6	0.5	0.25	1.5	1.5
110-120	21	37	42	Clay	-	7.9	0.25	1.8	1.5	2.6	5	0.1	0.9	-	-

Soil profile description (SNI043)

Soil Series: Gidr
Profile code: SNI043
Report/ Survey: Al Irrah, research farm
Elevation 2190
Coordinates: 412,000 mE; 1,710,400 mN
Location: Al Irrah research farm, see map
Topography: flat
Position of the site on almost flat terrain: higher part
Landform: intermontane basin
Land element: plain
Slope gradient: 0-0.1%
Slope from: convex
Microtopography: even
Water table: not observed
Effective soil depth: > 150 cm deep

Soil Taxonomy (1994): Typic Haplocambid fine loamy, mixed. hyperhtermic
FAO/ ISRIC/UNESCO (1994): Calcaric Cambisol
Land use: irrigated farming, maize, sorghum, beans, tomatoes
Irrigation type: furrow
Irrigation source: pump
Parent material: alluvium
Rock type: basic igneous rocks
Surface stones: very few, (fine) gravel
Soil moisture regime: aridic
Soil temperature regime: isohyperthermic
Sealing / crusting: crusting
Drainage: moderately well
Internal drainage: moderate
Moisture conditions: dry 0-135 cm; moist 135-160 cm
Remarks: Decaying roots at 135-160 cm, biological activity at 105-135 cm.

Soil profile description (SNI043)

0- 35	Ap	Silty clay loam, brown (10YR 5/3, dry) and dark brown (10YR 3/3, wet); moderate and strong, fine and medium, subangular blocky; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); common, very fine pores; few, fine and medium, subrounded, slightly weathered rock fragments; abundant, very fine and fine roots; strongly calcareous; gradual and smooth boundary.
35- 50	Bw	Silty clay loam, brown (10YR 5/3, dry) and dark brown (10YR 3/3, moist); moderate, fine to coarse, subangular blocky; soft (dry), very friable (moist), slightly sticky, slightly plastic (wet); few, very fine pores; few, fine and medium, subrounded, slightly weathered rock fragments; common, very fine and fine roots; strongly calcareous; clear and smooth boundary.
50- 80	2Ab	Clay loam, dark grayish brown (10YR 4/2, dry) and dark brown (10YR 3/3, moist); moderate, medium and coarse, subangular and angular blocky; slightly hard (dry) and friable (moist), sticky and plastic (wet); few, faint clay cutans on vertical pedfaces; few, very fine pores; very few, fine, irregular, soft carbonate concentrations (filaments); strongly calcareous; gradual, wavy boundary.
80-105	2Bw	Clay loam, dark gray (10YR 4/1, dry) and very dark brown (10YR 2/2, moist); weak, fine and medium, subangular and angular blocky; hard (dry) and friable (moist), sticky and plastic (wet); few, faint clay cutans, on vertical pedfaces; few, very fine pores; very few, fine, irregular, soft carbonate concentrations (filaments); strongly calcareous; few, very fine roots; clear, smooth boundary.
105-135	3Ck	Sandy clay loam, pale brown (10YR 6/3, dry) and brown (10YR 4/3, moist); weak, coarse and very coarse, subangular blocky; hard (dry) and friable (moist), slightly sticky and slightly plastic; few, very fine pores; common, fine to coarse, subrounded, slightly weathered rock fragments; dominant, fine, irregular, soft carbonate concentrations (filaments); extremely calcareous; very few, very fine roots; few biological features; clear, wavy boundary.
135-160	3C	Sandy loam, very pale brown (10YR 7/4, dry) and yellowish brown (10YR 5/6, moist), yellowish red (5YR 5/6) and reddish yellow (7.5YR 8/6) mottles; massive; hard (dry), very friable (moist), slightly sticky and slightly plastic (wet); common, very fine and fine pores; common, fine, irregular, soft carbonate concentrations (filaments); extremely calcareous.

Analytical data SNI043

Depth	Sand	Silt	Clay	Texture class	pH	EC (mS/cm)	CEC	$CaCO_3$ (%)
0-35	22	53	25	Loam	7.9	1.18	24	5
35-50	18	55	27	Silty clay loam	7.8	0.9	31.5	3.8
50-80	14	56	30	Silty clay loam	7.7	0.67	35	2.5
80-105	14	52	34	Silty clay loam	7.9	0.72	37	5.3
105-135	46	41	13	Loam	8.0	0.43	24	7.5
135-160	55	29	16	Sandy loam	8.0	0.52	23	2.5

Depth	Organic Carbon (%)	Organic Matter (%)	Available P (mg/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Na (cmol/l sat. extract)	Soluble K (cmol/l sat. extract)
0-35	0.7	1.2	5	1.4	1.4	5	0.2
35-50	0.7	1.2	5	1.4	1.3	4.6	0.2
50-80	0.7	1.2	1	1.4	0.8	3.4	0.1
80-105	0.7	1.2	7	2	0.9	4.6	0.1
105-135	0.4	0.7	5	1.6	0.3	5.3	0.2
135-160	0.4	0.7	5	1.6	0.2	4	0.2

Soil profile description (SNI044)

Soil Series: Shira
Profile code: SNI044
Report/ Survey: Al Irrah, research farm
Elevation: 2190
Coordinates: 412,000 mE; 1,710,000 mN
Location: Al Irrah research farm
Topography: flat
Position of the site on almost flat terrain: higher part
Landform: intermontane basin
Land element: plain
Slope gradient: 0-0.1%
Slope from: convex
Microtopography: even
Water table: not observed
Effective soil depth: > 120 cm

Soil Taxonomy (1994): Typic Haplocambids, fine loamy, mixed, hyperhtermic
FAO/ ISRIC/UNESCO (1994): Calcic Cambisol
Land use: irrigated, wheat, barley, young fruit trees
Irrigation type: basin, sprinkler
Irrigation source: pump
Parent material: alluvium
Rock type: basic igneous rocks
Surface stones: very few gravel
Soil moisture regime: aridic
Soil temperature regime: isohyperthermic
Sealing / crusting: crusting
Drainage: moderately
Internal drainage: moderately
Moisture conditions: dry 0-140 cm.

Remarks: After 45 cm and 95 cm, many horizontally growing roots. After 75 cm decaying roots were found.

0- 20	Ap	Silt loam, grayish brown (10YR 5/2, dry) and very dark grayish brown (10YR 3/2, moist); weak, very coarse, subangular blocky structure; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common, very fine pores; few, fine roots; gradual, wavy boundary.
20- 45	B	Silty clay loam, brown (10YR 5/3, dry) and dark brown (10YR 3/3, moist); weak, very coarse, subangular blocky structure; soft (dry), friable (moist), sticky and plastic; common, very fine pores; few, fine roots; few biological features; clear, smooth boundary.
45- 75	2A	Silty clay loam, dark grayish brown (10YR 3/2, dry) and very dark brown (10YR 2/2, moist); moderate, medium, subangular blocky structure; slightly hard (dry), friable (moist), sticky and plastic (wet); very few, faint, cutans on pedfaces; few, fine pores; few, fine. irregular, soft, carbonate concentrations (filaments); few, very fine roots; common biological features (infilled burrows); gradual, wavy boundary.
75- 95	2Bw	Silty clay, very dark gray (10YR 3/1, dry) and light gray (10YR 7/1, dry) and black (10YR 2/1, moist) and light brownish gray (10YR 6/2, moist); moderate, fine and medium, subangular and angular blocky structure; slightly hard (dry), friable (moist), very sticky and very plastic (wet); few, faint, clay cutans on pedfaces; few, fine pores; common, fine and medium, irregular, soft, carbonate concentrations (filaments and soft segregations); few, very fine roots; common biological features (infilled burrows); abrupt, smooth boundary.
95-100	3C	Sandy loam, dark yellowish brown (10YR 4/4, dry) and dark yellowish brown (10YR 4/3, moist); massive; soft (dry) and friable (moist); slightly sticky and slightly plastic (wet); common, very fine pores; dominant, fine and medium, irregular, soft, carbonate concentrations (filaments and soft segregations); very few, very fine roots; abrupt, smooth boundary.
100-110	4C	Silty clay gravely, very dark gray (10YR 3/1, dry) and black (10YR 2/1, moist); moderate, fine, angular blocky structure; slightly hard (dry), firm (moist), very sticky and very plastic (wet); few, very fine pores; common, fine and medium, irregular, soft, carbonate concentrations (filaments); very few, very fine roots; abrupt, smooth boundary.
110-120	5C	Sandy loam, very pale brown (10YR 7/3, moist); massive; very few, faint clay cutans on pedfaces; common, very fine and fine pores; common, fine and medium, irregular, soft, carbonate concentrations; very few roots; abrupt, smooth boundary.
120-140	6C	Silty clay gravely, black (10YR 2/1, moist); moderate, fine to coarse, angular blocky structure; hard (dry), friable (moist); very few, faint cutans and pressure faces on pedfaces; few, very fine pores; common, fine and medium, irregular, soft, carbonate concentrations (filaments).

Analytical data SNI044

Depth	Sand	Silt	Clay	Texture class	pH (paste)	EC (mS/cm)	CEC	$CaCO_3$ (%)
0-20	18	53	29	Silty clay loam	8	0.6	33	6.5
20-45	19	52	29	Silty clay loam	8	0.54	35	5.8
45-75	15	54	31	Silty clay loam	8	0.52	56	3
75-95	29	43	28	Clay loam	7.6	0.73	59	8.8
95-110	30	35	35	Clay loam	7.3	2.1	64	5.5
110-120	43	31	26	Loam	7.4	2.4	58	4.3
120-140	6	59	35	Silty clay loam	8.0	1.3	-	10.5

Depth	Organic Carbon (%)	Organic Matter (%)	Available P (mg/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Na (cmol/l sat. extract)	Soluble K (cmol/l sat. extract)
0-20	0.9	1.5	3	2	1	3.9	0.15
20-45	0.9	1.5	4	2.4	0.44	4.0	0.15
45-75	1.1	1.9	2	2	0.42	-	-
75-95	1.3	2.3	1	1.8	0.29	3.6	0.1
95-110	1.3	2.3	1	0.85	0.4	3.4	0.15
110-120	0.9	1.5	4	2	0.18	3.2	0.15
120-140	0.7	1.2	2	1.6	0.9	2.7	0.15

Profile description (SNI045)

Soil Series: Maris
Profile code: SNI045
Report/ Survey: Al Irrah, research farm
Elevation: 2190
Coordinates: 412,000 mE; 1,710,400 mN
Location: Al Irrah research farm
Topography: almost flat
Position of the site on almost flat terrain: higher part
Landform: dissected plain
Land element: plain
Slope gradient:
Slope from: convex
Microtopography: even
Water table: not observed
Effective soil depth: > 150 cm
Remarks: cracks about 5mm wide at 50-130 cm, decayed roots at 85 to 130 cm.

Soil Taxonomy (1994): Typic Haplocambid, clayey, mixed. hyperhtermic
FAO/ ISRIC/UNESCO (1994): Calcaric Cambisol
Land use: irrigated farming, fruit trees
Irrigation type: basin, bubbler, drip
Irrigation source: pump
Parent material: alluvium, loess
Rock type: basic igneous rocks
Surface stones: few, gravel and stones
Soil moisture regime: aridic
Soil temperature regime: isohyperthermic
Sealing / crusting: crusting
Drainage: moderate
Internal drainage: moderate
Moisture conditions: dry 0-130 cm.

0- 30	Ap	Silty clay loam, brown (10YR 5/3, dry) and dark brown (10YR 3/3, moist); moderate, coarse and very coarse, subangular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); few, very fine pores; very few, fine, rounded rock fragments; few, fine, irregular, soft, carbonate concentrations (filaments); strongly calcareous; many, fine and medium roots; diffuse and wavy boundary.
30- 85	Bw1	Silty clay, dark grayish brown (10YR 4/2, dry) and dark brown (10YR 3/3, moist); weak, medium and coarse, platy structure; hard (dry), friable (moist), sticky and plastic (wet); very few, distinct pressure faces on pedfaces; continuous platy compaction; common, fine pores; few, fine, irregular, soft, carbonate concentrations (filaments); strongly calcareous; very few, fine and very fine roots; diffuse and irregular boundary.
85-130	Bw2	Clay loam, very dark grayish brown (10YR 3/2, dry) and very dark grayish brown (10YR 3/2, moist); weak, coarse and very coarse, subangular and angular blocky structure; hard (dry) and firm (moist), sticky and plastic; common, distinct pressure faces on pedfaces; discontinuous platy compaction; many, medium pores; common, fine, irregular, soft, carbonate concentrations (filaments); strongly calcareous; few, very fine roots; few biological features.

Analytical data SNI045

Depth	Sand	Silt	Clay	Texture class	pH	EC (mS/cm)	CEC	$CaCO_3$ (%)
0-30	16	48	36	Silty clay loam	8.0	0.87	31.5	7.8
30-85	11	39	55	Clay	7.9	0.87	42.0	4
85-130	-	-	-	-	-	-	-	-

Depth	Organic Carbon (%)	Organic Matter (%)	Available P (mg/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Na (cmol/l sat. extract)	Soluble K (cmol/l sat.extract)
0-30	0.7	1.2	5	2.6	1.4	5.3	0.2
30-85	0.6	1.0	2	1.8	0.8	2.9	0.1
85-130	-			-	-	-	-

Profile description (SNI046)

Soil Series: Maris
Profile code: SNI046
Report/ Survey: Al Irrah, research farm
Elevation: 2190
Coordinates: 412,000 mE; 1,710,000 mN
Location: Al Irrah, research farm
Topography: flat
Position of the site on almost flat terrain: higher part
Landform: intermontane basin
Land element: plain
Slope gradient: 0-0.1%
Slope from: convex
Microtopography: even
Water table: not observed
Effective soil depth: > 150 cm
Remarks: Decayed roots at 85-140 cm. This soil seems lighter textured than SNI045. Cracks were observed but are smaller and less dense than in profile SNI045.

Soil Taxonomy (1994): Typic haplocambid, fine loamy, mixed, hyperthermic
FAO/ ISRIC/UNESCO (1994): Calcaric Cambisol
Land use: irrigated farming, fruit trees
Irrigation type: basin, sprinkler
Irrigation source: pump
Parent material: alluvium
Rock type: basic igneous rocks
Surface stones: very few, gravel
Soil moisture regime: aridic
Soil temperature regime: isohyperthermic
Sealing / crusting: -
Drainage: moderate
Internal drainage: moderate
Moisture conditions: dry, 0-180 cm

0- 15	Ap	Silty clay loam, dark grayish brown (10YR 4.5/2, dry) and dark grayish brown (10YR 4/2, moist); moderate, very fine and fine, subangular and angular blocky structure; slightly hard (dry), friable (moist) consistence, sticky and plastic (wet); many, very fine pores; moderately calcareous; common, medium sized roots; clear and smooth boundary.
15- 40	Bw1	Silty clay loam or clay loam, grayish brown (10YR 5/2, dry) and dark grayish brown (10YR 4/2, moist); moderate, medium, subangular and angular blocky structure; slightly hard (dry), friable (moist) consistence, sticky and plastic (wet); many, very fine pores; moderately calcareous; common, medium sized roots; diffuse and irregular boundary.
40- 85	Bw2	Clay loam, dark grayish brown (10YR 4/2, dry) and very dark grayish brown (10YR 3/2, moist); moderate, medium, platy structure; hard (dry), friable (moist) consistence, sticky and plastic (wet); very few, faint cutans on pedfaces; few, fine and medium pores; common biological features; few, fine, subrounded rock fragments; fine, soft, irregular carbonate concentrations (filaments); moderately calcareous; diffuse and irregular boundary.
85-140	Bw3	(Silty) clay loam, dark gray (10YR 4/1, dry) and very dark grayish brown (10YR 3/2, moist); very weak, medium and coarse, subangular and angular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); very few, faint clay cutans on pedfaces; fine, soft, irregular carbonate concentrations (filaments); moderately calcareous; few, very fine roots; common biological activity.
140-180	(auger)	Sandy loam, very pale brown (10YR 7/4, dry) and yellowish brown (10YR 5/4, moist); many carbonate concentrations (soft segregations and filaments).

Analytical data SNI046

Depth	Sand	Silt	Clay	Texture class	pH	EC (mS/cm)	CEC	$CaCO_3$ (%)
0-15	15	44	41	Silty clay	8.1	0.84	35	10
15-40	15	38	47	Clay	7.9	0.39	37	3.5
40-85	14	35	51	Clay	7.8	0.49	28	5.8
85-140	11	36	53	Clay	7.9	0.9	33	3.8
140-180	28	30	42	clay	8.0	1	20	26

Depth	Organic Carbon (%)	Organic matter (%)	Available P	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)
0-15	0.4	0.7	3	2.6	1.4
15-40	0.4	0.7	4	2.2	1.1
40-85	0.4	0.7	3	2.6	1
85-140	0.6	1.0	2	3	0.9
140-180	0.2	0.3	3	6	0.9

Profile description (SNI047)

Soil Series: Maris
Profile code: SNI047
Report/ Survey: Al Irrah, research farm
Elevation: 2190
Coordinates: 412,000 mE; 1,710,000 mN
Location: Al Irrah, research farm
Topography: flat
Position of the site on almost flat terrain: higher part
Landform: intermontane basin
Land element: plain
Slope gradient: 0-0.1%
Slope form: convex
Microtopography: even
Water table: not observed
Effective soil depth: > 150cm
Remarks:

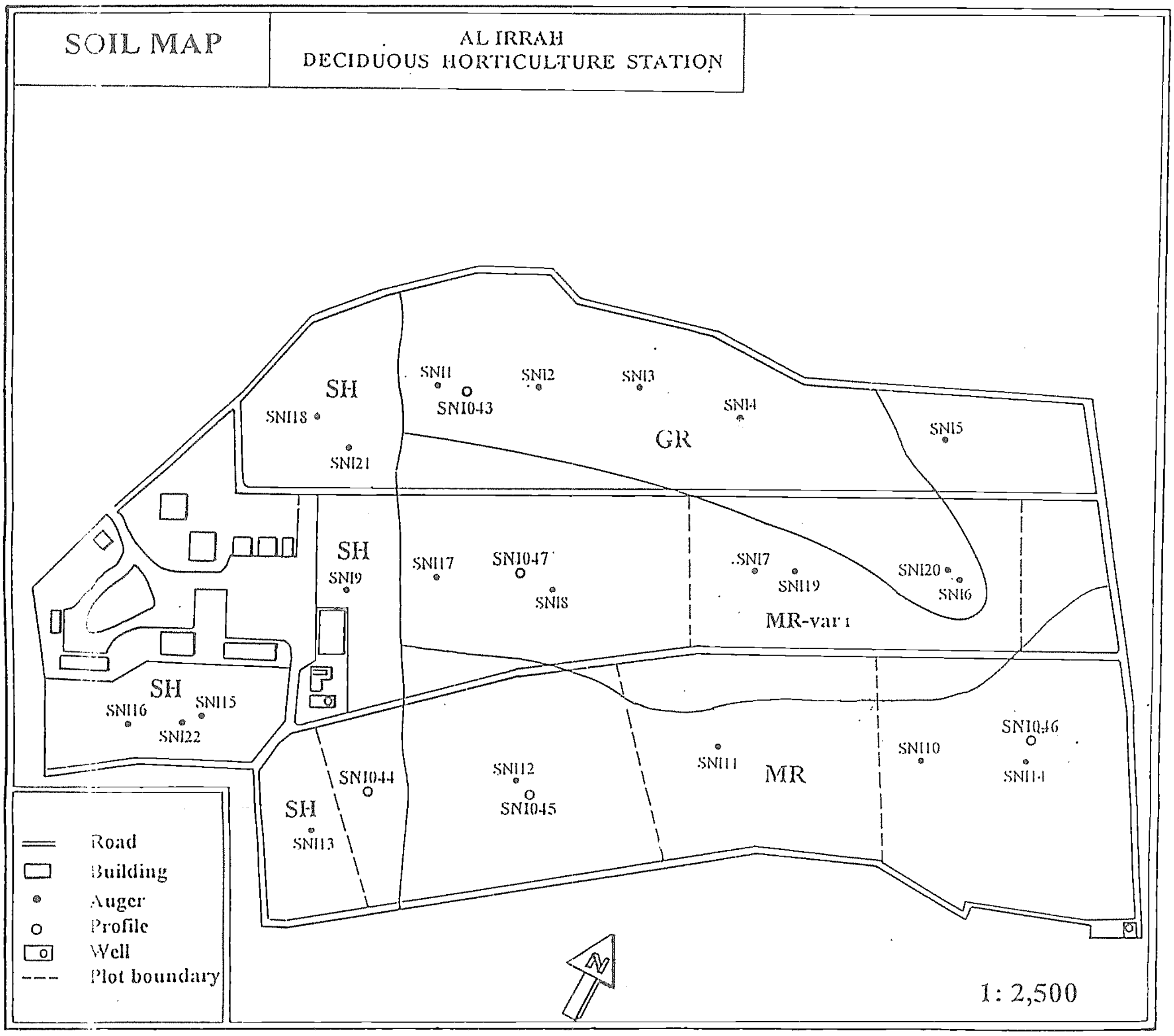
Soil Taxonomy (1994): Typic Haplocambid, fine loamy, mixed, hyperhtermic
FAO/ ISRIC/UNESCO (1994): Calcaric Cambisol
Land use: irrigated farming, beans, sunflower
Irrigation type: basin, furrow
Irrigation source: pump
Parent material: alluvium, loess
Rock type: basic igneous rocks
Surface stones: very few, gravel
Soil moisture regime: aridic
Soil temperature regime: isohyperthermic
Sealing / crusting: nil
Drainage: moderate
Internal drainage: moderate
Moisture conditions: dry 0-155

0- 30	Ap	Silty clay loam, dark grayish brown (10YR 4.5/2, dry) and dark brown (10YR 3/3, moist); moderate, fine, subangular blocky; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); common, very fine pores; very few, fine, subrounded, slightly weathered rockfragments; strongly calcareous; very few roots; smooth boundary.
30- 50	Bw1	Silty clay loam, dark grayish brown (10YR 4.5/2, dry) and dark brown (10YR 3/3, moist); moderate, fine and medium, subangular blocky; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); common, very fine pores; very few, fine, subrounded, slightly weathered rockfragments; strongly calcareous; very few roots; few biological features, infilled burrows; clear and smooth boundary.
50- 80	Bw2	Clay loam, dark grayish brown (10YR 4/2, dry) and very dark grayish brown (10YR 3/2, moist); moderate to strong, medium and coarse, platy; hard (dry), firm (moist), sticky and plastic (wet); few clay cutans on pedfaces; common, fine pores; very few, fine, rounded, slightly weathered rock fragments; few, soft, fine, irregular, carbonatic concentrations; strongly calcareous; very few, very fine roots; few biological features, infilled burrows and crotovinas; diffuse, broken boundary.
80-120	Bw3	Clay loam, dark grayish brown (10YR 4/2, dry) and very dark grayish brown (10YR 3/2, moist); red (2.5YR 5/6) colour mottles; moderate, fine and medium angular and subangular blocky; hard (dry), friable (moist), sticky and plastic (wet); few clay cutans on pedfaces; common, medium pores; very few, soft, fine, irregular, carbonatic concentrations; very few, very fine roots; diffuse, broken boundary.
120-155	BC	Silty clay, dark grayish brown (10YR 4/2, dry) and very dark grayish brown (10YR 3/2, moist); weak, medium angular and subangular blocky; hard (dry), firm (moist), sticky and plastic (wet); few clay cutans on pedfaces; continuous clay compaction; common, fine pores; few, soft, fine, irregular, carbonatic concentrations (filaments and soft segregations); strongly calcareous.

Analytical data SNI047

Depth	Sand	Silt	Clay	Texture class	pH	EC (mS/cm)	CEC	$CaCO_3$ (%)
0-30	18	51	31	Silty clay loam	8.0	0.44	32	10.5
30-50	17	47	36	Silty clay loam	7.5	2.34	33	7.0
50-80					7.6	2.33	36	4.5
80-120					7.5	0.96	39.5	5.5
120-155					7.7	0.87	39.5	9.3

Depth	Organic Carbon (%)	Organic matter (%)	Available P (mg/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)
0-30	0.6		1	2.2	1.5
30-50	0.6		1	2.4	1.4
50-80	0.6		1	1.6	1.1
80-120	0.6		3	1.4	1.0
120-155	0.6		6	1.4	0.9



SOIL MAP LEGEND

MAPPING UNIT / SYMBOL	SOIL SERIES (representative profile)	COMPOSITION OF MAPPING UNIT	SOIL TAXONOMY (1994)	WRB (1994)	LAND USE	CHARACTERISTICS
SH Shira	Shira, silt loam (SNI044)	90% Shira 5% Gidr 5% Maris	Typic Haplocambid, fine loamy, mixed, hyperthermic	Calcaric Cambisol	bare land, young fruit trees, sorghum, wheat	-Stratification -High active $CaCO_3$ content -Poor rootability below 45 cm
GR Gidr	Gidr, silty clay loam (SNI043)	80% Gidr 20% Maris, variant 1	Typic Haplocambid, fine loamy, mixed, hyperthermic	Calcaric Cambisol	peach trees, maize, vegetables, sunflower	-Calcic horizon (100-135 cm) -Buried dark horizon, -Sandy loam layer at 135 cm -
MR Maris	Maris, silty clay loam (SNI045, SNI046)	85% Maris 15% Maris, variant 1	Typic Haplocambid, fine clayey, mixed, hyperthermic	Calcaric Cambisol	orchard	-Compaction -High active $CaCO_3$ content -Fine texture -Uniform in colour and texture
MR-var1 Maris, variant 1	Maris, variant 1, silty clay loam (SNI047)	70% Maris, variant 1 15% Gidr 15% Maris	Typic Haplocambid, fine clayey, mixed, hyperthermic	Calcaric Cambisol	orchard	-Uniform in colour and texture -Fine texture -High active $CaCO_3$ content

Base information derived from :
Topographic maps of the area scale 1 : 50,000, published by Survey Authority San a 1985/1986

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Agricultural Research & Extension Authority,
FAO project GCP/YEM/021/NET Environmental Resources Assessment for Rural Land Use Planning.

SOIL TYPE SIMILAR TO AL IRRAH
(IN ṢAN'Ā' BASIN)