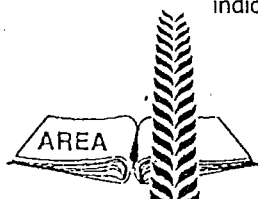


THE SOILS OF THE CENTRAL HIGHLANDS

AGRICULTURAL RESEARCH STATION

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AGRICULTURAL RESEARCH AND EXTENSION AUTHORITY
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**THE SOILS OF THE CENTRAL HIGHLANDS
AGRICULTURAL RESEARCH STATION**

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PREFACE

This study was carried out by the Land Resource Section of FAO project GCP/YEM/021/NET, AREA Dhamar. The field staff consist of dr. El Abbas Doka Mohammed Ali a (FAO land resource expert), Marleen Belder (APO soil surveyor), Lotfi Kasim Al Asbahi (soil surveyor) and Ahmed Saleh Salam (land evaluator). Work for the eastern farm was done by Lotfi Kasim Al Asbahi, Ahmed Saleh Salam and dr. El Abbas Doka Mohammed Ali. Work for the western farm was carried out by Lotfi Al Asbahi and Marleen Belder and supervised by dr. Abbas Doka. Ahmed Saleh Salam also assisted in writing the paragraphs about land use and soil management as well as land evaluation.

The authors would like to thank the following persons:

The laboratory staff headed by dr. A.E. Fadl for analysing all soil samples;
The cartography section under Ahmed Rizq, for drawing the different maps;
Mr. T.T. Wen, CTA, for his comments on the draft version and for editing this report;
The management of AREA, western and eastern farm, for providing us with relevant information and for their co-operation; Ahmed Ghani for his assistance in soil augering and for digging all soil profiles.

It is hoped that this report will contribute positively to the research done at Dhamar Farm and will also be helpful for agricultural workers in areas with similar soil characteristics.

INTRODUCTION

This report is one of a series of reports prepared by the Land Resource Section of FAO's "Environmental Resource Assessment for Rural Land Use Planning Project" (ERARLUP). Part of the Land Resource Section's programme is to conduct detailed soil surveys of the different regional agricultural research stations of AREA¹, distributed all over Yemen. The objectives are to make a comprehensive soil resource inventory, test the representativeness of the soils identified at the research station vis-à-vis the soils found in the region, define the main soil and water constraints in relation to crop production, and recommend suitable management and agricultural practices in relation to soil and water.

This report describes various aspects of the soils of the Central Highlands Agriculture Research Station (CHARS). It covers the development of the soils, their properties in relation to the landscape, their chemical and physical properties and the impact these have on crop performance. In addition, some recommendations are given on how to improve the soils and/or crop growth.

The Dhamar research station is divided into a western and an eastern farm, separated by the Sana'a - Dhamar road. Soil survey for each part has been carried out by different teams and at different periods. The eastern farm was surveyed from January till March 1996 by dr. El Abbas Doka Mohammed Ali, Ahmed Saleh Salam and Lotfi Kasim Al Asbahi. During the months September, October and November 1996, fieldwork and soil map preparation for the eastern farm was carried out by Lotfi Kasim Al-Asbahi and Marleen Belder. A soil boundary verification for the two surveys was carried out jointly in November 1996 and a joint soil map was then prepared. In December 1996 a draft report was written. At that time the chemical data of the soil samples was not yet available. The final version, incorporating the analytical data, and adjusting text and conclusions, was completed in 1997.

Information about the soils has partly been derived from fieldwork and partly from existing studies about soils in the Central Highlands.

¹ AREA stands for Agricultural Research and Extension Authority and is part of the Ministry of Agriculture and Irrigation.

CHAPTER 1 ENVIRONMENT

1.1 LOCATION

The Dhamar research station belongs to the Central Highlands Agricultural Research Station. It is divided into two parts: a western and an eastern part, separated by the Sana'a - Dhamar road. The eastern farm covers an area of 24.4 ha of arable land while buildings and fallow land cover 3.5 ha. The western farm covers an area of 146.9 ha of which a major part is used as rangeland for sheep. Dhamar Research Farm is located about 10 km north of the town of Dhamar. The area can be found on topographic sheet 1444A4. Coordinates for the farm range from: 429.325 mE to 431.000 mE and 1617.000 mN to 1618.625 mN. Its elevation ranges from about 2385 to 2400 m above sea level.

1.2 GEOMORPHOLOGY AND PHYSIOGRAPHY

Dhamar research station lies in the "Dhamar Plain", which is part of the "Central Highland Plains" (or "Montane Plains"), flat to undulating areas, with hills and depressions, surrounded in the west and the east by volcanic mountains. In the north the Montane Plains are bordered by the Yizla pass and in the south by the Sumara pass. These plains are remnants of an extensive plateau formed of a thick sequence of basaltic lava flows, ashes and tuffs of tertiary age whose thickness is estimated at up to 2000 m (Acres, 1980). On top of this, a layer of quaternary alluvium, varying in thickness, was deposited. The alluvial material consists of reworked aeolian loess, probably originating from the Rub al Khali or Sahara desert (King, 1983), and of finer textured material originating from the plains. The alluvial deposits in the research farm area are thin and highly calcareous.

At various places in the plain, a dark subhorizon can be found with a high level of organic carbon content which suggests a previous wetter climate compared to the present semi-aride climate (See: Acres, 1982, King 1983, Gibson and Wilkinson, 1996). During this wetter period, marsh areas existed and groundwater levels were higher than they are now and this could explain the strongly developed calcic horizons in soils (due to capillary rise of in groundwater dissolved carbonates) which are now well drained with deep groundwater levels (Acres, 1982). In their article about the archaeology of the Dhamar Plain, Gibson and Wilkinson (1996) postulate a Post-glacial sequence for the area:

- 1) A late Pleistocene/ early Holocene period of reduced vegetation cover during which downslope movement of stones and fine sediments took place (10.000 BP, Before Present).
- 2) A stable, wet period with marshes/open water (\pm 4600-7200 BP) and a persistent vegetation cover (woodland), during which very humic silt loams were formed on most topographic positions (slopes, valley floors).
- 3) A phase of erosion due to removal of the (tree) cover which resulted in an accelerated natural erosion of the slopes and deposition of soil in the valleys and plains.

Within the Dhamar research station, physiography differs from flat (slopes 0 to 0.1%) to moderately sloping (slopes 2-3%). These different land elements (slope, depression) influence soil depth, and hence land suitability, to a large extent. A considerable part of the western farm consists of shallow soils (< 50cm to < 30cm). A small area, north of the entrance gate, is rock outcrop.

1.3 PARENT MATERIAL

Parent material consists of:

(1) Alluvial deposits including reworked loess;

A thin or thicker layer of alluvial deposits can be found everywhere in the farm. The topsoil, a mixture of reworked loess and alluvial / colluvial material, is rich in silt and is moderately calcareous. (Sub)rounded stones found at different depths in the profiles also indicate alluvial processes. The dark subhorizon has partly been formed in situ and at some places has been thickened by alluvial material washed down from surrounding slopes.

(2) In situ weathered material.

In situ weathered, volcanic material can sometimes be found close to the surface. It is always very rich in carbonates and has a silty clay to silty clay loam texture. Different types of bedrock are present in the farm. One is a pinkish sedimentary soft rock (limestone), another a (metamorphic?) harder rocktype with a platy structure, rich in gypsum and calcium carbonates. A third one is the basic igneous basalt rock which is also rich in calcium carbonate. In parts in the eastern farm, deeply weathered basalt, seen as red or dark red material, was found at some depth in the profile.

Conclusively, all parent material, either weathered rocks or alluvial deposits, are rich in calcium carbonates and this is reflected in all soil profiles in the research station.

1.4 LAND USE AND SOIL MANAGEMENT

1.4.1 Crops

The largest part of the western farm, with shallow soils, is used as grazing area for sheep. This area is covered with grass and bushes of varying heights. The bushes (*Atriplex*) serve as a good fodder crop for the sheep. They are very drought resistant and the leaves have a high protein content. In some areas trees were planted along the farm tracks.

The eastern farm and the remaining part of the western farm, is used for trials with annual crops like sorghum, barley, wheat, tomatoes, potatoes, beans, alfalfa and fruit trees. The performance of the five year old fruittrees appears to be very marginal.

At this moment no crop rotation is followed but there is an intention to start it in 1997.

Table 1 gives an overview of the land use in Dhamar research station; indicated is which crops are grown in which season as well as fertilizer application and irrigation system.

Table 1: Land use in Dhamar Research Station

CROPS	SOWING/ PLANTING PERIOD	No. of IRRIGATIONS	FERTILIZER RATE (kg/ha)			IRRIGATION SYSTEM
			N	P	K	
CEREALS						
Wheat	1-15/7 and 1/12	4-5	100	80	0	Irrigated, basin
Barley	1-15/7 and 1/12	1-2 (summer) and 3-4 (winter)	80	60	0	suppl. Irrigated, basin
Sorghum	1-30/5	2-3	80	60	0	suppl. Irrigated, basin
Maize	1-30/3	6-9	120	100	0	Irrigated, basin
LEGUMES						
broad bean	1-15/1	6-7	30	60	0	Irrigated, basin
Bean	1-15/1	2-3	30	60	0	suppl. Irrigated, basin
Lentil (local variety)	Jan-Feb	0	30	60	0	rainfed
Fenugreek	1-15/1	2-3	30	60	0	suppl. irrigated, basin
VEGETABLES						
Potato	Jan-August	7-8	160	160	0	Irrigated, furrow
Tomato	Feb-July	8-10	120	100	0	Irrigated, furrow
Onion	Dec-Jan	7-8	120	100	0	Irrigated, furrow
Garlic	Nov	7-8	120	100	0	Irrigated, furrow
Carrot	Dec	7-8	100	100	0	Irrigated, furrow
Squash	June	7-8	100	100	0	Irrigated
FRUITS (gr. Per tree)						
Strawberry ²	-	1 time each week				
Apricot	-	Every 15 days, except in winter	500	250	0	Irrigated, furrow, drip
Apple	-	Every 15 days, except in winter	500	250	0	Irrigated, basin, tree
Peach	-	Every 15 days, except in winter	500	250	0	Irrigated, basin, tree
Olive	-	Every 15 days, except in winter	250	125	0	irrigated, basin, tree
FODDERS						
Alfalfa	-	Each 10 days	0	30	0	suppl. Irrigated, sprinkler
Barley	1/12 and 1/7		80	60	0	suppl. Irrigated, sprinkler
Sorghum	1-30/5		80	60	0	suppl. irrigated

² Strawberry is irrigated one time every week during mid February till mid October. During the other months (winter) they irrigate once every 20 days to keep the roots alive.

1.4.2 Preparation of the soil

Soil preparation before planting is very important for the crop to be grown. This can be explained by the three or four operations that make the soil ready for the following season.

- (1) Ploughing is always carried out immediately after harvest. At this time, the soil is easy to plough and the formation of big clods is prevented. The mouldboard plough is used for this operation and the depth of ploughing ranges from 20 to 25 cm.
- (2) If there are clods a disc harrow is used to break down the clods.
- (3) If the clods are small and easily scattered, a cultivator is used for harrowing. There is no need for a disc harrow in this case. A small length of woos is always dragged behind the cultivator in order to partial level the soil.
- (4) Plots are laid out according to the design of the trials which will take place. In fields that are allocated for fodder crops the seed is broadcasted by hand, after which a cultivator connected with wood behind it is used to cover the seeds.

1.4.3 Irrigation

Four irrigation systems are applied at the research station:

- 1) Surface (basin) and a furrow type of base irrigation is mostly used for cereals, legumes, vegetables and fruits (except for strawberry).
- 2) Sprinkler irrigation is used with fodder crops such as alfalfa, barley and sorghum.
- 3) Drip irrigation is applied in the green house, on strawberry and has recently been introduced to the fruit trees.
- 4) Moist irrigation is applied in the forestry nursery.

1.4.4 Fertilizers

Fertilizers are very important, especially if the fertility of the soil is low. The application rates for the different crops are given in table 1.1. Five types of fertilizer are used. They are:

- 1) Di-amonium sulphate 46% P_2O_5 , 18% N.
- 2) Mono-amonium sulphate 51% P_2O_5 , 10% N.
- 3) Tripple superphosphate 46% P_2O_5 .
- 4) Amonium sulphate nitrate 26% N.
- 5) Compound 20% P_2O_5 , 16% N.

From this data it appears that no potassium fertilizer is used. For cereals and vegetables nitrogen is applied twice. The first gift is applied at sowing and the second 30 days after sowing. Phosphorus for those crops is applied one time, at sowing. Legumes receive one gift of nitrogen and phosphorus, both at sowing. For strawberry no specific rate of fertilizer is applied.

1.4.5 Research results

During former years research has been carried out at Dhamar and Risabah research stations. Mainly crop variety tests and fertilizer trials were carried out as well as some tillage trials. For an overview of these tests see the documents in the AREA library. In short, some results will be given here.

- *) Three local varieties (white, red and yellow grain) of sorghum showed no significant response to nitrogen. (DAIC³, 1981)
- *) Fertilizer experiments on alfalfa showed a good response to P₂O₅. An optimum response was shown at gifts between 100-150 kg/ha/year. The fodder produced should be higher in phosphorus which will benefit the nutrition of local animals where Ca:P imbalances are reported. As well as yield increases, better utilization of water is claimed (DAIC, 1983).
- *) Apple tree growth has generally been poor due to the presence of a largely unpenetrated calcic horizon in the soil. Attempts to decrease soil pH by applying "flowers of sulphur" and to increase the organic status of the soil, have not shown any significant influences. Replanted trees into deeper planting holes with a broken calcic horizon showed signs of recovery.
- *) Tillage trials using replicated randomly chosen blocks to compare deep inversion with other forms of tillage verified the farmers' belief that deep inversion gives improved yields. However examination of soil profiles show considerable recompaction (Berry, 1986). (Apparently research was only done in deep soils).
- *) Wheat fertilizer trials show a clear increase in yield (both grain* and straw) by P₂O₅ and N-gifts of 100 kg/ha. Crop showed no response to potassium fertilizer gifts (DAIC, 1980, no.1).
- *) Barley also gives a positive response to nitrogen and phosphate, giving highest yields when applied in combination. Optimum gifts between 90 and 100 kg/ha (DAIC, 1980, no.2).
- *) Chicken manure is a good and cheap fertilizer. It releases the nitrogen very slowly because it needs a long time for decomposition. Therefore the application should be done much ahead of planting to avoid negative effects like delay of ripeness and excessive foliage growth (DAIC, 1983, 2).
- *) The buried dark horizons showed a higher short term moisture holding capacity than other soil horizons (DAIC, 1983, 2).

³ DAIC stands for Dhamar Agricultural Improvement Centre, a British project during the eighties.

1.5 CLIMATE

Table 2 shows the mean climatic data over 1987-1992, for Dhamar station, latitude 14°59', altitude 2400m. Total rainfall is on average about 360 mm per year. In a year there are normally two rainy seasons: one in March / April / May and one in July / August. A short wet period in November/ December also normally occurs. In other months rainfall normally is very low. During the rainy seasons precipitation (P) can exceed potential evapotranspiration (PET) (see also the diagrams in appendix 3). In March/April such a wet period ($P > 0.5 \text{ PET}$) is between 15- 45 days long, in July / August precipitation exceeds half the potential evapotranspiration for 15-60 days.

The table shows that on a yearly basis, evapotranspiration is five times higher than rainfall. The relative humidity varies approximately between 40 and 50% during the year. Due to this low relative humidity and high temperatures, potential evapotranspiration in dry months is high. Also the strong winds increase potential evapotranspiration. Crop growth is highly restricted by these climatic conditions. Only drought resistant crops can survive without additional irrigation.

Another restriction for crop growth during the winter months (Nov / Dec / Jan) is the minimum temperature. During this period the temperature sometimes drops below 0 °C during the nights. Consequently, no cold/frost sensitive crops are grown during these months. Mean average winter (November, December, January, February) temperature is 13.5 °C and mean average summer (June, July, August) temperature 19.2 °C.

Data for soil temperatures are available for a depth of 20 cm below the surface (see appendix 4). Estimated soil temperatures at 50 cm below the surface range between 16.5 °C and 21 °C during the year. According to the Soil Taxonomy (1994) the soil temperature regime is isothermic and the soil moisture regime is aridic.

Table 2: Climatic Data for Dhamar Research Station

Dhamar, 1987-1992	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	Yearly Average
Minimum Temperature (°C)	4.1	6.9	8.8	10.0	10.9	11.6	11.7	11.1	9.0	6.1	3.6	2.9		8.1
Maximum Temperature (°C)	22.3	23.2	24.6	25.3	27.2	27.7	30.0	26.2	25.2	23.6	22.6	22.4		24.8
Average Temperature (°C)	13.2	15.1	16.7	17.6	19.0	19.7	19.4	18.7	17.1	14.8	13.1	12.6		16.4
Relative humidity (%)	48	44	47	46	41	40	45	48	44	41	42	46		44
Rainfall (mm)	3.6	36.3	72.6	37.8	10.0	5.2	79.0	88.2	8.5	1.4	5.6	3.3	351	
Potential Evapotransp. (mm)	100	120	132	141	151	146	143	135	131	116	99	93	1503	

2.1 PREVIOUS WORK

Soil survey studies in the Montane plains have been carried out by different researchers. An exploratory survey, scale 1:500,000 done by King and others (1983), covers the former Yemen Arab Republic, including the Montane plains. This study contains a landform map and profile descriptions with analytical data.

A semi detailed study has been carried out by Acres (1980 and 1982). Soils have been described and classified up to soil series level and profile descriptions with the analytical data are given. A soil map at a scale of 1:250,000 is available. Acres' reports give a good overview of the different soil types present and their potential for agriculture.

A detailed soil survey, scale 1:10,000 covering an area of 1000 hectares, including Dhamar research station, was carried out by Gewaifel and Saif in 1983. This report provides maps for stoniness and soil depth phases and a land classification map. A small part of the research station is classified as S1 (i.e. suitable for arable cropping without major limitations), all other areas have major limitations like soil depth, calcic horizon and / or stoniness. Although a general overview is given in this report, no detailed soil map for Dhamar Research Station can be derived from this report and only a general classification was made.

2.2 SURVEY METHODS

For the soil survey two sources of information were used:

- (1) Information from existing surveys. A major idea about existing soil types was gained from the work of Acres (1980, 1982).
- (2) Information from detailed, grid survey fieldwork. This method was adopted since recent, large-scale photographs are not available and because only restricted surface expressions related to soil properties are visible around the farm.

The survey was started by a field scanning of the whole survey area. In this way an impression was obtained about slope differences, depressions, drainage patterns etc. A first indication of differences in soil characteristics (depth, calcic horizon) was noted.

The soil survey was carried out on a detailed scale of 1:5000 and the observation sites were determined through a grid survey for which the Sana'a - Taiz road served as a baseline. Accordingly, the observations describing soil properties like texture, colour, depth, CaCO₃, were spaced every 50 by 100 meters.

The soil was tested by auger holes and profile pits at an overall intensity of two observations per hectare. In the western farm a total of 135 auger observations were made along transects running east west. In the eastern farm another 45 auger observations were made along transects of the same orientation. These observations were used to get an understanding of the major soil types within the farm as well as their distribution. For the different soil types delineated this way, profile pits were described and samples taken. In total 19 pits were described. The location of

the profile pits is shown in appendix 5.

The profile descriptions and the analytical data can be found in Appendix 1. The auger descriptions have not been added to this report but are stored in a separate file available at AREA.

2.3 PHYSICAL SOIL CHARACTERISTICS

Below, a general description of the soils of the western and eastern farm is given by describing and analyzing the different soil characteristics.

2.3.1 Texture

Textures in the eastern farm do not differ from the western farm. The soils of the western farm show little variation in texture. The topsoil, dominated by an aeolian deposited loess, is present all over the farm. It has a silt loam to silty clay loam texture. This silt loam topsoil is good in terms of water storage capacity and available moisture. However, due to the high silt and carbonate content the soil is susceptible to sealing and crusting as has been observed in the field. This might cause problems for seed emergence, infiltration rate and aeration of the soil. In practice, however, crusts can easily be broken and hence real harm to the crops can be limited.

Due to the high silt content the soil is also susceptible to smearing. Consequently, entering the field with heavy equipment while the soil is too wet will result in compaction (platy structure in the subsoil). Slight compaction was observed in some mapping units.

In most soils of Dhamar (CHAR) station, clay content increases with depth (see also the charts in appendix 4), subsoils have a clay, clay loam, or silty clay texture⁴. In most (moderately) deep soils cutans on the pedfaces were observed at some depth. It is not clear if these shiny faces are really clay cutans, pressure faces or the result of calcium carbonate.

The subsoil texture (without rock fragments and/or nodules) has good moisture holding characteristics, though the high clay content may cause some structural problems.

The presence of hard carbonate nodules and concretions in some soils reduce the content of fine materials and hence affects the amount of available water for plants.

2.3.2 Soil colour

The colour of the topsoil in the western farm is brown (10YR 5/3), dry, and brown or yellowish brown when moist (10YR 4/3 and 10YR 4/4). The subsoil has different colours at different places.

Normally the soil colour is a good indication for a diagnostic horizon: A buried mollic subsoil can be recognized by its dark colour: black (10YR 2/1) to very dark grayish brown (10YR 3/2). The presence of a lot of carbonates contributes to the matrix colour in calcic horizons, giving the soil a very pale brown (10YR 7/2-3) colour when dry and yellowish brown (10YR 6/4) when wet. Soil mottles were observed in some profiles. Orange/reddish (possibly iron) and black roundish mottles (magnesium) have been observed.

⁴ A higher clay content in the subsoil was observed in most places. Note that the high CaCO₃ may have influenced the texture judgement in the field. The soil becomes more sticky due to the presence of CaCO₃.

In the eastern farm the dominant colours in the topsoil are brown (10YR 5/3), dark yellowish brown (10YR 4/4) and dark grayish brown (10YR 4/2), moist, and yellowish brown (10YR 5/4) and brown (10YR 4/3), dry. In the control section the colours are mostly yellowish brown (10YR 5/4) or very pale brown (10YR 8/2), dry. The moist colours are dark yellowish brown (10YR 4/4) and light gray (10YR 7/2). Dark layer colours ranges from very dark gray (10YR 3/1) to dark brown (10YR 3/3) when moist and mainly dark brown (10YR 3/3) and very dark grayish brown (10YR 3/2) when dry. Substratum soils have wide range of colours due to different parent materials. These colours are yellowish red (5YR 5/6), brown (7.5YR 5/4) and light yellowish brown (10YR 6/4), dry, and yellowish red (5YR 4/6), brown (7.5YR 4/4) and dark yellowish brown (10YR 4/4), moist.

2.3.3 Soil depth

The effective soil depth for the different soils ranges between 20 and \pm 140 cm. Soil depth is limited by the presence of bedrock or a petrocalcic horizon, through which most roots cannot penetrate. The northern part of the western farm has moderately deep to deep soils. Further to the west and south soils become shallower.

The northern part of the eastern farm contains deep and very deep soils together with very limited shallow parts (< 50cm). The rest of the farm is dominated by moderately deep and shallow soils. Soils are underlain by bedrock materials i.e. slightly weathered volcanic materials and / or petrocalcic horizons.

2.3.4 Rootability

Rootability is directly linked with effective soil depth. Factors that limit root penetration are:

- compacted or cemented layers (found in some profiles)
- (petro)calcic horizons (found in some profiles)
- a matrix volume occupied for 40% or more by rock fragments or nodules (found in some profiles)
- shallow depth to bedrock (found in some profiles).

Most profiles show some constraints to root growth, especially for deep rooted crops. Shallow depth to the bedrock and a cemented (petro)calcic layer are the most severe limitations.

2.3.5 Soil structure

Both textural class and the abundance of CaCO₃ have a strong influence on soil structure. The silt loam/ silty clay loam textured horizons mostly show a subangular blocky structure of moderate grade. As stated before, the structure of the silt loam surface soil easily collapses and becomes very weak or massive with a surface crust.

With the increase of clay content in the subhorizons, structure becomes stronger, and is sometimes platy or angular blocky, but mostly subangular blocky. Soils, dominantly those with a black layer, show signs of swell and crimp (pressure faces, cracks), which might have a negative effect on root growth. However no real vertic properties were observed and in general the structure of the black layer is moderate.

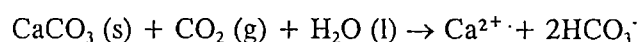
Calcic horizons often show a very weak or even massive structure.

2.4 CHEMICAL SOIL CHARACTERISTICS

2.4.1 Calcium carbonate

All soils appear to be calcareous throughout their soil profile. Percentages of calcium carbonate in the soil range from 1 to 70. The calcic horizons have percentages of 30 to 70. In the subsoil, calcium carbonate is mainly present in the form of nodules, concretions or a cemented layer in a (petro) calcic horizon. In the surface horizon, a strong reaction to HCl (10%) indicates the presence of high CaCO₃, although often not present in visible forms. Visible forms of calcium carbonate in the surface and subsurface horizon are soft segregations, and sometimes pseudomycelia or concretions.

The process of calcium carbonate accumulation in the soil will be briefly explained here. The parent material is rich in calcium carbonates and accumulation of the carbonates takes place because of low precipitation and high evaporation figures. Parent material on the farm is rich in calcite (CaCO₃). The weathering of calcite is shown in the following equation:



The solubility of calcite is highest at high CO₂ pressures and low temperatures. CO₂ is produced by plant roots and by respiration of microorganisms in the soil.

An excess of evapotranspiration over rainfall, as is the case in Dhamar, 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, 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 CO₂ pressure from the roots and can be moved to a greater depth where it precipitates again (so called secondary CaCO₃). The secondary CaCO₃ formed first consists of filamentous material in the smaller biopores (pseudomycelia). Later, continued accumulation produces soft or hard nodules.

The presence of free carbonates normally indicates that the clay complex is dominated by exchangeable Ca. Excess Ca can lead to deficiencies of minor elements (Cu, Fe) as well as antagonising the action of others. Where a significant amount of free carbonates is present in a soil, other essential nutrients (P) may be less available, particularly if they are in relatively limited supply.

A high CaCO₃ content, especially the active fraction, affects the chemical characteristics of the soil, its fertility and its physical properties. In general the problems of calcareous soils are:

- 1) Crusting of the surface, especially in soils with a high silt fraction. 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.
- 2) Cemented condition of the subsoil layers decrease rootability. Calcic horizons tend to have higher bulk densities than non-calcareous related horizons. This is caused by the partial infilling of the pore space with calcium carbonate segregations. In hypercalcic horizons

almost all pores are filled. These horizons therefore act as a barrier through which roots hardly penetrate (FAO, ISRIC, 1994). Experiments in Egypt with growing alfalfa on calcareous soils showed an increase in organic matter, a decrease in bulk density and an increased porosity.

- 3) Availability of phosphorus is low. Research on calcareous soils in Egypt (FAO, 1973, p. 233) gave the following results for phosphorus. Calcium carbonate limits the phosphate availability, particularly if the calcium carbonate is in fine particles. Relative high temperatures along with successive wetting and drying cycles of the soil seemed to encourage phosphate retention.
- 4) Problems of magnesium (and sometimes potassium) nutrition occurred as a result of the nutritional imbalance between these elements and calcium.
- 5) Availability of micronutrients is low. On calcareous soils, zinc deficiency is normal. Crops that are sensitive to zinc deficiencies include maize, citrus, legumes and cotton. Deficiencies in iron are most commonly encountered in calcareous soils. Research in calcareous soils in Egypt (FAO, 1973, p. 233) showed that the application of iron in the form of FeSO_4 did not have a positive effect on the available iron (because of rapid oxidation/ precipitation of FeSO_4). A positive response in plant growth, dry matter and protein nitrogen content was obtained when iron was applied in the form of Fe EDDHA.
- 6) Problems of water availability. A high percentage of CaCO_3 in form of nodules, concretions or cemented peds, decreases the moisture retention and available water for the plants.

The laboratory figures show a very sharp increase of CaCO_3 content in the calcic horizons. CaCO_3 in these horizons is sometimes 20 times higher than in the above lying layers. In general the depth to a calcic horizon is a determining factor for land use. Deep cultivation (ploughing) on shallow soils over a calcic horizon, should be avoided.

2.4.2 pH

Together with the organic carbon content, the pH is an important indicator for the fertility status of the soil. The pH of the soils varies between 7.5 and 8.1. In most of the cases the pH of the topsoil is a bit higher than in the subsoil. However, pH differences between horizons are very small and insignificant.

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.

2.4.3 Organic Carbon

Organic matter is an important source and reserve of plant nutrients and soil moisture. It gives an indication of soil fertility. Organic matter figures can be calculated from organic carbon figures:

$$\text{Soil Organic Carbon (\%)} \times 1.72 = \% \text{ Organic Matter}$$

Organic matter figures are all less than 1%, varying between 0.64% and 0.84%. The organic matter content in the calcic horizons (between 0.17 and 0.43%) is lower than in the topsoil and buried horizons. The buried, black horizons were expected to classify as buried mollic horizons. However, the organic carbon content in these horizons is lower than the 0.6% criteria.

2.4.4 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 Dhamar soils range from 0.3 to 1.7. Some highly sensitive plants (e.g. carrots and strawberry) may show reduced yields when EC figures are between 1 and 2. For these crops yield reduction at an EC of 1.7 is between 10 and 25% (Landon, 1996). In general, no salinity hazard exists on the research farm.

2.4.5 N, P, K

Phosphorus is an important macronutrient influencing crop performance. Often, figures for Yemen soils are rather low. Figures for Dhamar research farm range between 1 and 5 ppm. For the topsoil the available phosphorus is mainly between 3 and 5 ppm. These figures indicate a deficiency for almost all crops. Especially for crops like potatoes, tomatoes and onions P-levels are far too low and no satisfactory yield can be expected without fertilizer.

2.4.6 CEC soil

The CEC (Cation Exchange Capacity) of the soil is an indication of the potential fertility of a soil and possible response to fertiliser application. Figures for the eastern farm are out of range and are not considered here. Only CEC figures for the western farm are discussed here. CEC figures for the topsoil range between 23 and 31 and can be classified as medium to high. For the subsoil figures range from 22 to 45 and are positively correlated with the clay content in the soil.

2.5 SOIL CLASSIFICATION

The soils under investigation have been classified according to Soil Taxonomy (1994) and World Reference Base for soil resources (FAO, ISSS, ISRIC, 1994). Soil Taxonomy is a hierarchical system with different categories. 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 of Soil Taxonomy, are used at detailed level. Soil series consist of a specific regional name such as "Wasitah, fine loamy".

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".

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 all used and named in a previous survey by Acres (1980 and 1982) for the Montane Plains. Acres gave a very good description of the various soil series in the Montane plains, including the Dhamar plain. It was expected that the soils found at CHAR, Dhamar station would all fit in one of these existing soil series, even though descriptions of the soil series in Acres' report do not always match completely with the taxonomic

units found in the Dhamar farm.

Acres assumed that most parts of the montane plains have an ustic moisture regime. However, recent information (Bruggeman, 1997) indicates that the moisture regime around Dhamar is aridic. This implies that soils described by Acres, did not classify as Aridisols while they do in this report. Table 3 shows similar soils, indicated by soil series names with their Soil Taxonomy classification in Acres (1982) and this report.

Table 3: Soil series with Soil Taxonomy classification in 1982 and this report.

Soil series	Soil Taxonomy (Acres, 1982)	Soil Taxonomy (this report)
Tinnan	Udic Ustochrept / Cumulic Haplustoll	Typic Haplocalcid
Wasitah	Typic (aridic) Ustochrept	Typic Haplocalcid
Yafa	Lithic Ustochrept	Lithic Torriorthents
Balasan	Typic Ustochrept	Petronodic Haplocalcid
Darb	Lithic Ustochrept	Calcic Petrocalcic

Soils of the Dhamar research station belong to different orders within Soil Taxonomy: Aridisols and Entisols. These soils were correlated with Calcisols and Leptosols, major groups of the FAO classification system. It was expected that soils of Tinnan series would classify as Mollisols. However, criteria were not met, especially the percentage of organic carbon in the dark buried horizon was not high enough.

Aridisols (Soil Taxonomy 1994) are characterized by the presence of an ochric surface horizon and an aridic climate. Apart from that, soils in the farm have a (petro)calcic horizon (often) or a cambic horizon. The soils are related to the Calcisols (with calcic horizon) and Cambisols (soil differentiation in the subsoil) of the FAO classification system and with the Darb, Tinnan, Wasitah and Balasan Series.

Entisols are soils with little development, lacking a clear cambic horizon or other clear signs of soil development. These soils are found on the shallow parts, overlying bedrock. They are related to the Leptosols of the FAO system and to the Yafa series.

At family level (Soil Taxonomy) the following classifications were given. Textural class families are fine loamy or fine clayey. Soils are isohyperthermic (mean annual soil temperatures at 50 cm depth between 18 and 22 °C or higher with difference of less than 5 °C between mean summer and mean winter soil temperatures) and have a mixed clay mineralogy. Since all soils are calcareous, calcareousness was not indicated in the family name.

2.6 SOIL SERIES

The five soil series used in this report are described below and the differentiating characteristics are summarized in table 4.

2.6.1 Wasitah series

This soil is well drained, typically moderately deep, with a well defined calcic horizon, often associated with underlying gravel deposits. The soil is formed on slopes, typically in very undulating terrain of low ridges and shallow depressions. Wasitah series is distinguished from the Balasan Series in the degree of development of the calcic horizon in that it is usually a distinct layer in the soil profile and is weakly cemented having a platy structure in its upper part that strongly inhibits root development. It occurs at depths ranging from 30 to 80 and varies in thickness from 10-20 to more than 50 cm. In most cases also a buried dark horizon, colour 10YR 3/2 moist, with a thickness ranging from 10-30 cm, is found. Texture of the surface horizons is loam or silt loam over a subsoil of silty clay, or clay loam.

Soils differ from Tinnan series in that Tinnan series are deep and mostly have a thicker buried black horizon. The calcic horizon in Tinnan series is found deeper in the profile than in Wasitah series. Wasitah series is the most common soil within the research farm. They are associated with Tinnan series, Darb series, Yafa series and Balasan series.

FAO/UNESCO classification: Cambic Calcisol

Soil Taxonomy classification: Typic Haplocalcid, fine loamy, mixed, isohyperthermic

2.6.2 Tinnan series

Tinnan Series are deep and very deep soils, with a well developed calcic horizon occurring between 50-100 cm from the surface, with a calcium carbonate content from 0-50 cm of < 15%. Soils are well drained and textures below the plough layer are dominantly silty clay and clay with some clay loam and silty clay loam layers. The calcic horizon (between 50-100 cm) is usually thick, greyish in colour and with a weak or massive structure. It contains many hard nodules and is weakly cemented. On top of the calcic horizon a distinct black buried horizon (colour 10YR 3/2, moist) is found. Thickness of this horizon varies between 30 and 50 cm. Organic matter content varies irregularly with depth and is usually about 1%. Normally, the boundaries between the dark horizon, the overlying soil, and the underlying calcic horizon, are clear. Sometimes shells are found in these soils, possibly indicating lacustrine conditions.

Soils are mainly associated with Wasitah series.

FAO/ UNESCO classification: Cambic Calcisol (closely related to a Calcic Kastanozem).

Soil Taxonomy classification: Typic Haplocalcid, fine clayey, mixed, isohyperthermic.

2.6.3 Balasan series

This is a deep, well drained soil with a surface texture of silt loam and a texture below the plough layer of dominantly clay loam and silty clay loam. It has a calcic horizon made up of many, usually hard, lime nodules. So much lime is formed that the calcium carbonate content is greater than 15% and CEC values of the soil are affected, being lower than normal for the equivalent texture. Frequently the lime nodules are present within 50 cm of the surface. Organic matter content is low, though dark horizons may occur.

This series occurs on plains in gently undulating terrain. It is found on upper slopes and low ridges in association with Wasitah series.

FAO/UNESCO classification: Cambic Calcisol

Soil Taxonomy classification: Petronodic Haplocalcid, fine loamy, mixed, isohyperthermic.

2.6.4 Darb series

This is a shallow to very shallow soil overlying a massive petrocalcic horizon within 50 cm of the surface. The petrocalcic horizon can contain more than 90% calcium carbonate. A thin dark horizon in the profile may occur. Soils are alike Yafa series in that they are shallow to very shallow. They differ from Yafa series in that they lie on a petrocalcic horizon instead of on bedrock. In the Dhamar farm both shallow and very shallow Darb series are found. On the shallow ones an effective soil depth of 50 cm enables arable cropping. Darb series are associated with Yafa series and Wasitah series

FAO/UNESCO classification: Eutric Leptosol

Soil Taxonomy classification: Calcic Petrocalcic, fine loamy, mixed, isohyperthermic.

2.6.5 Yafa series

This is a well drained soil developed over basalt rock. It is distinguished by depth and texture. It is a shallow or very shallow soil with rock at 50 cm or less. Texture of the plough layer is loam which lies over clay loam. Where the basalt rock is hard and little weathered the soil lies directly on the rock with stones near the base of the profile. Where the rock is softer or more strongly weathered a discontinuous calcic horizon may have developed above the rock. Some soils are very stony. Yafa series are associated with Darb series and Wasitah series.

FAO/UNESCO classification: Eutric Leptosol

Soil Taxonomy classification: Lithic Torriorthent, fine loamy, mixed, isohyperthermic.

Table 4: Differentiating soil characteristics for Soil Series in CHAR Dhamar station.

SOIL SERIES	TEXTURE (subsoil)	BURIED DARK HORIZON	EFFECTIVE SOIL DEPTH	CALCIUM CARBONATE	REPRESENT. PROFILE
Tinnan	SiC, C	30-50 cm thick 10YR 3/2, moist	deep to very deep	Calcic horizon, weakly cemented at 50-100 cm depth	DHE079, DHE067
Wasitah	SiC, CL	10-30 cm thick 10YR 3/2, moist	moderately deep	Calcic horizon, weakly cemented at 30-80 cm depth.	DHE071
Yafa	CL	-	shallow to very shallow	Calcic horizon may occur	DHE081
Balasan	CL, SiC, C	Dark horizon may occur 10YR 3/3, moist	deep to moderately deep	Calcic horizon with many nodules	DHE086, DHE084
Darb	L, SiL, CL	thin dark horizon may occur	shallow to very shallow	Petrocalcic horizon	DHE087

2.7 SOIL MAPPING

An important aim of this soil survey is to delineate between soil types with different land qualities and crop suitabilities. Therefore, major soil characteristics related to land qualities and crop growth have been selected to delineate soil types. Since the farm was already leveled and cultivated some years ago, surface features are no longer existing to help in delineating map unit boundaries. Soil profile characteristics are the main criteria used for this purpose. In this survey the following five characteristics (or criteria) have been used to differentiate between mapping (taxonomic) units.

- | | | |
|----------------|-----------------|-----------|
| (1) Soil depth | very shallow | < 30cm |
| | shallow | < 50cm |
| | moderately deep | 50-75 cm |
| | deep | 75-125 cm |
| | very deep | > 125cm |
- (2) Presence of a buried dark horizon and its thickness
 (3) Presence of a calcic and/or petrocalcic horizon
 (4) Presence and amount of rock fragments in the soil matrix.
 (5) Presence and amount of concretions or nodules in the soil matrix.

The relation of these five characteristics with other soil properties and land qualities are given in table 5.

Table 5: Mapping criteria and their related land qualities

MAPPING CRITERIA	RELATED LAND QUALITIES AND SOIL PROPERTIES
Soil depth	Rooting depth, available moisture, suitability for irrigation.
Dark layer	Organic carbon content, structure, available moisture, nutrient availability
(Petro)Calcic horizon	Structure, rootability, nutrient availability.
Rock fragments/ nodules	Rootability, available moisture, workability.

Mapping units are composed of one or more soil series. In the legend it is indicated which series is dominant (> 50%) within the mapping unit, which are associated soils (> 20%) and which soils are inclusions (< 20% of mapping unit). In a mapping unit the dominant soil type is most likely to be encountered.

2.8 DESCRIPTION OF MAP UNITS

The map units symbol, area of map unit, physiography, percentages of soil components and soil classification are described for the nine map units within Dhamar (CHARS) research station. Table 6 gives an overview of the nine map units. Below, every map unit is described in detail.

Table 6: Main characteristics of map units of Dhamar research station

MAPPING UNIT SYMBOL	AREA (HA)	PHYSIOGRAPHY	SOIL SERIES	SOIL TAXONOMY (1994)	FAO/UNESCO CLASSIFICATION (1994)	DEPTH	TEXTURE (SUBSOIL)	DEPTH TO CALCIC HORIZON (cm)
TN1	10.1	Slightly depressional terrain	Tinnan Wasitah 80% 20%	Typic Haplocalcid 100%	Cambic Calcisol	Deep and very deep	SiC, C	65
TN 2	3.2	Flat, slightly depressional terrain	Tinnan Wasitah 65% 35%	Typic Haplocalcid	Cambic Calcisol	Deep	SiC, C	45-80
WS	7.0	Almost flat terrain	Wasitah Tinnan 70% 30%	Typic haplocalcid 100%	Cambic Calcisol	Deep and moderately deep	SiC, C, CL	50-75
YF1	35	Slightly sloping and almost flat terrain	Yafa 30-50cm Wasitah 50% 50%	Lithic Torriorthent 60% Typic Ha0plocalcid 40%	Calcaric cambisol 60% Cambic Calcisol 40%	Shallow and some moderately deep	CL	Not Applicable
YF2	78	Slightly sloping and flat terrain	Yafa < 35 cm Wasitah 85% 15%	Lithic Torriorthent 85% Typic Haplocalcid 15%	Eutric Leptosol 85% Calcaric Cambisol 15%	very shallow	CL, SiCL	Not Applicable
YF3	7	Almost flat terrain	Yafa Darb 70% 30%	Lithic Torriorthent 70% Calcic Petrocalcic 30%	Eutric Leptosol 70% Petric Calcisol 30%	Shallow	CL, gravelly (20-40 cm)	20-30
BL1	18.2	Flat and almost flat terrain	Balasan Wasitah 90% 10%	Petronodic Haplocalcid	Haplic Calcisol	Moderately deep and deep	CL, SiCL	40-70
BL2	3	Gently sloping terrain	Balasan Wasitah 70% 30%	Petronodic Haplocalcid 70% Typic Haplocalcid 30%	Cambic Calcisol	Moderately deep and deep	CL, SiCL Gravelly (> 40 cm)	40
Db	10	Almost flat terrain	Darb, Wasitah 70% 30%	Calcic Petrocalcic 70% Typic Haplocalcid 30%	Petric Calcisol 70% Cambic Calcisol 30%	Moderately deep and shallow	SiL, L, CL	25-50

- TN1** This mapping unit is composed of Tinnan and Wasitah series. Well drained soils, lying in slightly depressional sites and therefore receiving runoff water. In former periods also considerable amounts of sediments were deposited in these sites.
Soils are deep and very deep, with a topsoil of (silt) loam texture, underlain by an extremely calcareous, buried dark horizon, at 40-100 cm depth, 30-50 cm thick, of clay loam / silty clay texture. This layer has a high carbon content and contains many calcium carbonate mycelia. Beneath it between a depth of 60 and 135 cm, a calcic horizon (10YR 7/3, moist) is found, normally 30 cm thick. The calcic horizon is underlain by a dark (10YR 3/3, moist) weakly cemented layer of silty clay texture below which a massive, silt loam, dark red layer of weathered parent material is found. Soil shows cracks starting from the surface (not deep and wide enough to be vertic).
Soil aggregates from the topsoil and dark horizon can be very hard when dry. On the eastern farm a large area of very deep soils of this mapping unit can be found. Here also some shells were found in the dark layer.
Tinnan series within this mapping unit are soils which are deep and very deep. Wasitah series within this mapping unit are soils which are deep and have a thinner buried dark horizon than Tinnan series. This unit differs from TN2 unit in that it has a thicker loess topsoil and a thicker dark horizon.
Profile: DHE067, DHE068, DHE079
- TN2** Well drained, moderately deep to deep soils, lying at the bottom of the depression, with a brown, silt loam topsoil and beneath it at 20-45 cm a buried dark horizon (possibly mollic), with a higher clay content (silty clay loam/ silty clay) and a prismatic structure. The dark horizon is underlain by a calcic horizon at 45-110 cm of silty loam or silty clay loam texture. At 80-130 cm depth a massive, silt loam, dark red layer of weathered parent material is found which is extremely calcareous at 80-110 cm and contains a lot of nodules. This mapping consists of two soil series, i.e. Tinnan (80%) and Wasitah (20%). The composition of the mapping unit is equal to the TN1 mapping unit. This unit differs from the TN1-unit in that it has a thinner dark, buried horizon which has a prismatic structure (30-50 cm), probably due to sodium, and the loess topsoil is less thick. The massive, red, probably in situ weathered material starts closer to the surface than in the TN1 unit.
Profiles: DHE066
- WS** Well drained soils, moderately deep to deep, with a silt loam topsoil and beneath it a buried dark horizon at a depth of 20 to 50 cm. The dark horizon contains more clay than the topsoil. Beneath the dark horizon a yellowish brown coloured, calcic horizon of silty clay texture is found at \pm 50 - 100 cm.
Soils in this mapping unit have the same characteristics as the TN1 soils, but are less deep. The dark layer is thinner and less carbonate concentrations were found in the dark layer compared to the TN1-unit. WS consists of Tinnan and Wasitah series.
Profile: DHE088
- YF1** Well drained, dominantly shallow and moderately deep soils with a lithic contact between 50 and 70 cm. Soils have a silt loam to silty clay loam surface texture and are mostly underlain by a thin, dark subhorizon of silty clay or clay loam. Sometimes a lighter coloured horizon of silty clay texture is found beneath the dark horizon.
Part of the soils (50%, Yafa series) do not show a clear horizon development, though enrichment with calcium carbonates is present. The other part (50% Wasitah series) consists of moderately deep soils (Wasitah series) that have a thin buried, black horizon that is sometimes underlain by a layer rich in calcium carbonates (> 50cm depth). Soils sometimes are gravelly at 30-50 cm. Soils differ from YF2 mapping unit in that the soils are

deeper and more developed.

Profile: DHE082

- YF2** Well drained, very shallow soils, having a (para)lithic contact between 20 and 40 cm from the surface. Soils have a brown, silt loam to clay loam surface texture and sometimes a thin, darker (dark brown to black) subhorizon of silty clay loam. Soils do not show a clear horizon development. Beneath 40 cm some cracks are present in the parent rock. Where the bedrock is softer and more strongly weathered, a discontinuous calcic horizon may develop above the rock (this was found in two pits out of eleven). The mapping unit consists for 85% of Yafa series, with a shallow phase (< 35 cm). In the remaining 15% of the mapping unit inclusions of somewhat deeper soils (Wasitah series) are found.
Profiles: nine existing pits, western farm, DHE072, DHE073, DHE075, DHE076, DHE077 eastern farm.
- YF3** Well drained, shallow and very shallow soils with a brown topsoil of loam or silt loam. Soils lack a dark buried horizon and the topsoil is underlain by light brown silt loam to silty clay loam material. Soils are gravelly between 20-50 cm. Sometimes at a depth of 30-35 cm from the surface the upper boundary of a very hard petrocalcic horizon can be found. Some parts (western part of mapping unit) are covered by abundant surface gravels. The mapping unit consists of shallow soils without clear development (70%, Yafa series) and shallow soils with a hard petrocalcic horizon close to the surface (30% Darb series).
Profile: DHE087
- BL1** Well drained, moderately deep soils with a surface of silt loam, sometimes underlain by a thin, dark layer of silty clay. A well defined calcic or petrocalcic horizon of silty clay, ranging in thickness between 30 and 100 cm thick, lies on top of the in situ weathered, red material of silty clay texture. From 45-70 on and deeper, the soil contains a high amount of nodules and gravels. The mapping unit consists for 90% of Balasan series. Some inclusions of Wasitah series can be encountered.
Profiles: DHE064, DHE062, DHE069
- BL2** Well drained, moderately deep and deep soils, with a brown surface layer of silt loam texture. The subsoil is light yellowish brown and of clay / silty clay texture. Soils have an extended, weakly cemented, calcic horizon between a depth of 40 and 115 cm and 60 to 80 cm long. Sometimes the calcic horizon starts already 20 cm below the surface. The calcic horizon is yellowish brown coloured, sometimes mixed or underlain with dark brown (mollic) material which is extremely calcareous. The calcic horizon contains a high percentage of nodules. These nodules, impeding root growth, occur at depth ranging from 40-120 cm, normally 50-80 cm. Beneath the calcic horizon, reddish, weathered material can be found, mixed with white nodules. Especially in the eastern farm a distinct red layer was found.
This mapping unit consists for 70% of Balasan series and for 30% of Wasitah series.
Profiles: DHE086, DHE085, DHE084, DHE061
- Db** Well drained, moderately deep soils with a brown surface soil of silty clay loam and silt loam texture. Soils have a calcic horizon between 25 and 50 cm, overlying a petrocalcic horizon between 50-100 cm. The grayish brown calcic horizon has a silty clay texture. The petrocalcic horizon is brown and texture is difficult to determine but seems to be silty clay. The deeper part of the petrocalcic horizon has mainly a reddish colour, mixed with pockets of dark coloured material. This mapping unit consists of Darb series (80%), soils with a petrocalcic horizon starting at 50 cm from the surface, and is associated with Balasan series,

soils with a high content of carbonatic nodules.
Profiles: DHE083, DHE070

2.9 REPRESENTATIVENESS OF DHAMAR RESEARCH STATION

Researchers and extensionists need to know to what extent their research results can be extrapolated to other areas. An indication for the representativeness of Dhamar research station is given below.

Considering the climate, CHARS Dhamar research station is representative for an area of approximately 112,000 ha's. This agro-climatic zone has been defined in field document 11 (Bruggeman, 1997). The zone stretches roughly from Ma'bar in the north to east of Yarim in the south. This area is bordered in the north by the villages Daf and Yakar, northwest by Wasitah and Ma'bar, northeast by Al Malha, middle west by Sana'ah, middle east by Maram, Sanaban and Ad-Ru'ah, south east by As-sawma'ah and south by Ribat (see also climatologic map prepared by GCP/YEM/021/NET, 1997). This area is characterized by uniform climatological conditions. In a normal year it has two and sometimes three growing periods. One from March/April to April/ May of 14-45 days and one from July till August of 15-60 days. In less than 50% of the years a third growing period occurs in November (and December) of 15-30 days.

In respect of landforms, Dhamar Research station is representative for the dissected plain, bordering in the north at Risabah and in the south at Qa' Shara'a. West and eastwards the area extends to the same borders as used for the representative climatic area.

The soils of Dhamar research station were compared to the soils described in the Montane Plains survey. It was found that soils in Dhamar station were found in five major land units distinguished by Acres.

Within the agroclimatic zone described above, areas can be delineated with soils comparable to those at CHARS, Dhamar station. The agro-ecological zone (with similar climate and soils), represented by CHARS, Dhamar research station, is an area bordered in the north by Risabah and in the south by Ribat. This area has been delineated and is shown on a map in Appendix 6.

3.1 INTRODUCTION

Land evaluation is the final stage of this survey. Land evaluation is carried out according to the FAO system (see a.o. 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 land for a certain crop/ land use type.

3.2 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 potato and tomato, or rainfed arable farming based on sorghum and lentils. There are four categories or levels of classification: Land suitability orders, classes, subclasses and units. These suitability classes are assessed separately for each kind of land use under consideration, with respect to each land 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 (cultivating 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', refer 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 cost of production. 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.

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.

- z= Soil depth (effective for plant growth) to carbonate accumulations
- b= Soil depth (effective for plant growth) to parent rock / impervious material
- y= Soil fertility
- c= Soil structure (crusting, compaction)
- g= Soil texture, gravels, concretions, stones
- h= soil texture, very fine textures (clay)

Table 7: Categories of land suitability classification

Category		
Order	Class	Subclass
S, suitable	S1	<u>S2z</u>
	<u>S2</u>	<u>S2y</u>
	S3	<u>S2zy</u>
NS, not suitable	<u>N1</u>	<u>N1z</u>
	N2	<u>N1y</u>

3.3 SOIL LIMITATIONS AND LAND SUITABILITY CLASSIFICATION

Crop growth in Dhamar research station is to a large extent constrained by climatological conditions like amount of rainfall, evapotranspiration and temperature. Without (supplementary) irrigation the range of crops that can be grown is limited: sorghum, lentils and barley. Most crops are grown with supplementary irrigation (like alfalfa, maize and potatoes).

Limitations directly related to the soil are: depth of rooting, calcic horizon, slope, nutrient availability, available water, texture, crusting and rock fragments on the surface or in the soil itself.

Table 9 gives an overview of some of the crop requirements for crops grown at the research station. Mainly requirements related to the soil are mentioned in this table. In tables 10 and 11 information about the soils of Dhamar research station and crop requirements is combined. These tables give a soil suitability classification. First, some additional remarks are made.

Very shallow soils (<30 cm) are not suitable for crop growth and can only be used for rangeland (as it is at present). Some tree species possibly can establish in the shallow soil because their roots can penetrate through cracks in the bedrock. This applies to YF2 mapping unit.

Shallow soils (30- 50 cm) are suitable for shallow rooting crops like barley, wheat and sorghum. Care should be taken when irrigating on these shallow soils. If the soils are underlain by impervious parent material / bedrock, an artificial shallow groundwater table can quickly develop. This groundwater table can soak the roots and /or can cause salinity problems due to capillary rise of the groundwater/ irrigation water. Sprinkler or drip irrigation is recommended in these cases. This applies to mapping unit YF3.

Moderately deep soils are deep enough for most crops, including sorghum, maize, alfalfa and potatoes. Fruit trees need at least 100 cm of soil and can only be grown on deep and very deep soils.

The buried dark horizon presents some specific problems. It was observed that this layer (of clay texture) becomes very hard upon drying. Roots are not able to penetrate this layer anymore and grow horizontally instead. This is a major problem for the apple trees. Additionally, research at Risabah station has shown that the presence of a calcic horizon prohibits the development of a deep rooting system and severely limits the growth of the tree. Common additional negative effects are (micro) nutrient deficiencies (Rhebergen, 1990). This especially applies to TN1, TN2 and WS mapping units.

For potatoes in the Dhamar area, the relation between calcium carbonate content and yield

reduction is given by Rhebergen and Al-Meshriky (1990), see table 8. Potato needs at least 50 cm of soil to give a satisfactory yield. Additionally, soils with a lot of gravels / concretions will affect the growth of roots and tubers like potato, carrot and onion. This applies to BL1, BL2 and Db mapping units.

Table 8: Yield reduction in potato due to calcium carbonate content.

CaCO ₃ content (%)		Yield reduction (%)
0-10	slightly to moderately calcareous	0
10-20	strongly calcareous	20
20-40	very strongly calcareous	50
> 40	extremely calcareous	90

Table 9: Climatic and soil requirements for some selected crops

Crop	Total Growing Period (days)	Temperature Requirements for growth(OC) 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)
Pea	Fresh: 65-100; dry 85-120	15-18(10-23)	slight frost tolerance when young	5.5 - 7.0 (O) 4.5 - 8.3 (O)	Wide range of textures (O + R), well drained and aerated soils;	Sensitive	Medium (O) Shallow (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) Shallow (R)	Moderate (O) Low (R)
Garlic				6.0 - 6.6 (O) 5 - 8.5 (R)	Light to medium textures (O) Wide range of textures (R)	Moderately sensitive	Medium (O) Shallow (R)	High (O) Low (R)

Table 9 (continued)

Crop	Total Growing period (days)	Temperature requirements for growth(OC) optimum(range)	Specific climatic constraints and/or requirements	PH ranges	Texture / drainage	Sensitivity to salinity	Soil depth	Soil fertility
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)
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)
Broad bean	90-120	18-28(10-30)	sensitive to frost; excessive rain and hot weather	6.0 – 8.0 (O)	medium textures (O)	Sensitive		
Fenugreek	90-120	13-28(5-30)	resistant to frost	6.0 – 8.0 (O)	medium textures (O)	Sensitive	Deep (O)	

O= Optimum

R= Range

Table 11: Suitability classification for some crops for each mapping unit

Mapping Unit (symbol)	Wheat, barley	maize	alfalfa	Carrot	Potato	tomato	onion, garlic	apple	peach
TN	S1	S2y	S2h	S2h	S2c	S2f	S2h	S3c,y,h	S3c,y,h
TN2	S1	S2y	S2h	S2h	S2c	S2f	S2	S3,c,y,h	S3c,y,h,z
WS	S1	S2y	S2b	S2h	S2c	S2y	S2h	NS	NS
YF1	S2b	S2b	S2b	S2g	S3g	S2y	S2g	NS	NS
YF2	NS	NS	NS	NS	NS	NS	NS	NS	NS
YF3	S3g,b	NS	NS	NS	NS	NS	NS	NS	NS
BL1	S2g,z	S3z,y	S3z,y	NS	NS	S3z,y	NS	NS	NS
BL2	S2g,z	S3z,y	S3z,y	NS	NS	S3z,y	NS	NS	NS
Db	S2b	S3b,y	S3b	S3b,c	S3b,c	S3y	S3b,c	NS	NS

z= Soil depth (effective for plant growth) to carbonate accumulations
b= Soil depth (effective for plant growth) to parent rock / impervious material
y= Soil fertility
c= Soil structure (crusting, compaction)
g= Soil texture, gravels, concretions, stones
h= soil texture, very fine textures (clay)
k= calcium carbonate

Table 10: Major soil limitations for each mapping unit and land suitability classification

Mapping Units	Depth	Texture (subsoil)	Calcium carbonate (content and depth)	Presence of petrocalcic horizon (depth)	Available Water Capacity (mm m ⁻¹)	Structure	Suitability classification
TN1	>100	C, SiC	0-65 cm (1-10%) 65-100 cm (45%)	-	144	30-70 cm, very hard when dry 90-110 cm massive	S1 for lentils, sorghum, wheat, barley S2h for garlick, onion, carrot, alfalfa S2c for potato (hazard for tuber moth due to cracking) S2f for tomato S3y, c,k for apple and peach
WS	50-100	SiC, SiCL	0-20 cm (2%) 20-50 cm (20%) 50-75 cm (48%) > 75cm (17%)	-	80 to 155	20-50 cm, very hard when dry	S1 for lentils, sorghum, wheat, barley S2h for garlick, onion, carrot S2b for alfalfa S2c for potato (hazard for tuber moth due to cracking) S2y for tomato NS for apple and peach
YF1	40-70	SiC, SiCL Gravelly at 30-50 cm	0-45 cm (1-10%) >45 cm (17-50%)	-	65-87		S2b for wheat, sorghum, barley, alfalfa S2g for carrot, onion S3g for potato S2y for tomato NS for fruit trees
YF2	20-35	SiL, SiCL	0-30 cm (1-5%) > 30 cm (5-10%)	-	26 to 52		NS for vegetables, cereals, legumes S2 for grassland
YF3	< 50	SiL, SiCL, grav- elly between 20- 50 cm	0-15 cm (1-10%) 15-30 cm (10-20%) >30 cm (15-60%)	Sometimes, at >35 cm	40-57		NS for potato, carrot, alfalfa, onion, barley, maize, apple, peach S3g,b for wheat, sorghum
BL2	> 75	SiCL, SiC, C gravelly from 45 cm.	0-70 cm (1-15%) 70-100 cm (30-60%)	-	45 to 90	10-30 cm platiness 30-80 cm, massive, or weakly cemented	NS for carrot, potato, onion, garlic, fruit trees S3z, y for tomato, alfalfa, maize S2g, z for wheat, barley
Db	40-90	SiCL, SiC	0-25 cm (5-15%) 25-55 cm (15-50%) 55-100 cm (>35%)	Most cases, at 50-100 cm.	40 to 54	50-100 cm strongly cemented	S2b for wheat, sorghum, pea S3y, for tomato S3b,y for maize S3b,c for potato, onion S3b for alfalfa NS for apple, peach
TN2	75-150	CL, SiC, C	0-45 cm (1-10%) 45-80 cm ? >80 cm (> 15%)	-	100 to 140	20-45 cm, very hard when dry 80-110 cm, massive structure	S1 for lentils, sorghum, wheat, barley S2h for garlick, onion, carrot, alfalfa S2c for potato (hazard for tuber moth due to cracking) S2f for tomato S3h,k for apple and peach
BL1	75-100	SiCL, SiC, gravelly from 45/70 cm onwards.	0-20 cm (8-20%) 20-40 cm (13-30%) > 40 cm (30-50%)	-	55 to 100	45-70, massive structure (compaction)	S2g,z for wheat, barley, sorghum S3z,y for maize, tomato, alfalfa NS for potato, carrot, onion, apple, peach

-Suitability Classes: S1= Highly suitable S2= moderately suitable S3= marginally suitable NS= Not Suitable

-Texture: SiL= silty loam, SiCL= silty clay loam, SiC= silty clay, CL=clay loam, C=Clay

z= Soil depth (effective for plant growth) to carbonate accumulations

b= Soil depth (effective for plant growth) to parent rock / impervious material

y= Soil fertility

c= Soil structure (crusting, compaction)

g= Soil texture, gravels, concretions, stones

h= soil texture, very fine textures (clay)

k= calcium carbonate

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Based on the soil survey the following conclusions can be drawn.

- * The nutrient situation is critical. Trials with N and P fertilizers showed an increase in yield. It is expected that micronutrient spraying on fruit trees will have a positive effect on crop performance and yield.
Due to a high pH and high calcium carbonate contents, deficiencies in phosphate, zinc and iron occur. Calcium, potassium, sodium, sulphate and chloride are natural well supplied.
- * Soil texture and structure has an impact on crop performance. Especially growth of fruit trees and tuber crops is restricted due to compaction and hardening after drying of soil.
- * A restricted number of crops can be grown without additional irrigation. In a dry year harvest of rainfed crops is very little and not commercially rewarding.
- * Present field layout and crop choice in Dhamar Research station correspond well with the land qualities and soil limitations present.
- * The Central Highlands Agriculture Research Station very well represents the different soils found in an area bordered in the north by Risabah and in the south by Qa Shara'a

4.2 RECOMMENDATIONS

4.2.1 Recommendations on cultivation practices

- * Ploughing has to be carried out at precise moisture conditions. The soil should not be too wet in order to avoid smearing or compaction, or too dry since ploughing becomes difficult and large, very hard clods are formed.
- * Only shallow ploughing (15cm) should be carried out on soils with a shallow Calcic horizon (Db, BL1 mapping units).
- * Mixing of first 70-90 cm (topsoil and buried dark horizon) of TN1, TN2 and WS mapping units, will improve the rootability. The dark layer, that becomes very hard upon drying, but otherwise has good qualities, will be loosened and mixed with the surface layer. The soil that shows clear stratification will be mixed, thus removing abrupt textural changes and likewise improving the rootability of the soil. Also it might be favourable to mix the very fine (silty clay) textured dark horizon with the lighter textured surface soil.
- * Regular irrigation of the fruit trees prevents upward movement of active lime. It also keeps the dark buried horizon moist, preventing it from becoming very hard. It is expected that this will improve the performance of apple trees.
- * Retain high moisture content in the topsoil after sowing in order to avoid formation of thick crusts and thus to facilitate seed emergence.
- * Improve the structure of the topsoil in order to decrease crust formation and sealing by: application of mulch/ crop leftovers (stems, leaves, roots). This will decrease the impact of raindrops on the bare soil. Braking of crusts before expected rains will improve infiltration.

4.2.2 Recommendations on agronomic practices

- * Select shallow rooting crops for shallow soils (YF2 and YF3) and soils with a cemented calcic or petrocalcic horizon (BL1, BL2, Db).

- * Application of manure decreases the pH and increases the availability of nutrients like phosphorus. Chicken manure is known to lower the pH and contains a lot of nutrients. An increase in organic matter content (by applying green manure, dung, crop residues etc) will improve soil structure and soil fertility and reduce risks for sealing/ crusting. (However in general it is difficult to increase organic carbon because of a lack of manure.
- * Sprinkler irrigation (as used already) is a good way of irrigating on shallow, CaCO₃ rich soils.

4.2.3 Recommendations for further research

- * Inventarisation of the harmful effects of crust formation and sealing (on silt loam soils) on infiltration and aeration of the soil and seedling emergence.
- * Fruit trees might have micronutrients deficiencies especially Zn and Fe. This year the farm management will start to apply nutrient spraying of the trees. A follow up of the results of spraying is important.
- * The research station could start some specific trials for crop performance on calcareous soils / cultivation practices on calcareous soils. Also some trials on crop performance on shallow soils and their treatment are recommended.

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**APPENDIX 1
PROFILE DESCRIPTIONS**

DHE061

Soil series: Balasan
 Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, isothermic
 Date: 6-12-1995
 Authors: Ahmed Sallam, Lotfi Al-Asbahi, Abbas Doka
 Slope gradient: 0.1-2%
 Rock outcrops: none
 Sealing/ crusting: nil
 Effective soil depth: 130 cm
 Parent material: alluvium and loess

FAO (1994): Cambic Calcisol
 Location: Dhamar, AREA, eastern research farm, see map
 Coordinates:
 Surface stones: nil
 Drainage: moderately well
 Moisture conditions: dry 0-130, slightly moist 130-150
 Cracks:
 Land use: arable land (wheat, barley, sorghum)

- | | | |
|---------|----|---|
| 0-25 | Ap | Loam, brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry. Very weak, coarse and very coarse, columnar structure. Slightly hard (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, very fine pores. Very few, fine, irregular, soft carbonatic segregations. Extremely calcareous. Common, fine and medium roots. Clear, smooth boundary. |
| 25-75 | Bk | Silty clay, dark yellowish brown (10YR 4/4) moist, yellowish brown (10YR 5/4) dry. Strong, fine and medium, angular blocky structure. Very hard (dry), very friable (moist), very sticky and very plastic (wet) consistence. Common, prominent, clay cutans on vertical pedfaces. Few, very fine pores. Common, fine to coarse, irregular, soft carbonatic segregations. Strongly calcareous. Few, fine roots. Gradual, wavy boundary. |
| 75-105 | | Clay loam, very dark brown (10YR 2/2) moist, very dark grayish brown (10YR 3/2) dry. Moderate, fine and medium, subangular blocky structure. Very hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, very fine pores. Few, medium and coarse, subrounded and angular, slightly weathered rock fragments. Common, fine and medium, irregular, soft and hard carbonatic segregations, filaments and nodules. Strongly calcareous. Very few, very fine roots. Diffuse, irregular boundary. |
| 105-130 | | Clay loam, dark yellowish brown (10YR 3/4) moist, yellowish brown (10YR 5/4) dry. Massive structure. Hard (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, very fine pores. Common, fine to coarse, irregular, soft and hard carbonatic and gypsum segregations, filaments and nodules. Strongly calcareous. Very few, very fine roots. |

Analytical data for profile DHE061

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-25	33	52	15	SiL	7.6	6.14	223	31.2	3
25-75	24	52	24	SiL	7.7	1.4	187	21.4	7
75-100	30	41	29	CL	7.5	0.22	136	6.2	11

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						Na	K	Ca	Mg
0-25	0.98	8	21	0.83	0.34				
25-75		2	51	1.1	0.38				
75-100		2	59	1.1	0.26				

DHE062

Soil series: Balasan

Soil Taxonomy 1994: Petronodic Haplocalcid, fine loamy, mixed, isothermic

Date: 9-12-1995

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: crusting

Effective soil depth: 130 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: nil

Drainage: moderately well

Moisture conditions: dry 0-130, slightly moist 130-150

Cracks:

Land use: arable land (wheat, barley, sorghum)

0-25	Ap	Clay loam, dark brown (10YR 3/3) moist, brown (10YR 5/3) dry. Moderate, fine and medium, subangular blocky structure. Slightly hard (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, distinct, undifferentiated cutans on pedfaces. Common, fine pores. Few, fine, subrounded, weathered rock fragments. Strongly calcareous. Many, fine and medium roots. Clear, irregular boundary.
25-42	Bk	Clay, pale brown (10YR 6/3) moist, very pale brown (10YR 8/2) dry. Moderate, medium and coarse, subangular blocky structure. Slightly hard (dry), very friable (moist), sticky and plastic (wet) consistence. Common, prominent, undifferentiated cutans on vertical pedfaces. Few, fine pores. Very few, fine, subrounded, weathered rock fragments. Common, fine and medium, irregular, soft segregations and concretions (carbonates). Extremely calcareous. Few, fine and medium roots. Diffuse, irregular boundary.
42-70	Bmk1	Clay, light, brownish gray (10YR 6/2) moist, light gray (10YR 7/2) dry. Weak and moderate, fine to coarse, subangular blocky structure. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Few, distinct, undifferentiated cutans on pedfaces. Continuous cementation by carbonates. Few, fine pores. Few, fine, subrounded, weathered rock fragments. Dominant, medium, irregular, soft and hard nodules and concretions (carbonates). Extremely calcareous. Very few, fine roots. Clear, smooth boundary.
70-90	Cmk	Silty clay, light gray (10YR 7/2) moist, very pale brown (10YR 8/2) dry. Weak, fine and medium, subangular blocky structure. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Very few, faint, undifferentiated cutans. Cementation by carbonates. Common, medium pores. Few, medium, subrounded, weathered rock fragments. Dominant, medium, irregular, soft and hard nodules and concretions (carbonates). Extremely calcareous. Very few, medium roots. Gradual, smooth boundary.
90-103	Cck1	Clay loam, brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry. Weak, medium and coarse, subangular blocky structure. Hard (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, distinct undifferentiated cutans on pores and voids. Common, medium pores. Few, medium, subrounded, weathered rock fragments. Dominant, medium, irregular, hard concretions (carbonates). Extremely calcareous. Very few, medium roots. Gradual, smooth boundary.
103-130	Cck2	Clay loam, brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry. Very weak, medium and coarse, subangular blocky structure. Hard (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, distinct undifferentiated cutans on pores and voids. Common, medium pores. Common, coarse, subrounded, weathered rock fragments. Dominant, coarse, irregular, hard concretions (carbonates). Extremely calcareous. Very few, medium roots. Gradual, wavy boundary.
130-150	Cmk	Silty clay, reddish brown (5YR 5/4) moist, yellowish red (5YR 4/6) dry. Massive. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, distinct, undifferentiated cutans in pores and voids. Cementation by carbonates. Few, fine pores. Dominant, very coarse, subrounded and flat, weathered rock fragments. Dominant, coarse, irregular, hard concretions (carbonates and gypsum). Extremely calcareous. Very few, medium roots.

Analytical data DHE062

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-25	29	55	16	SiL	7.8	0.40	126	24.0	3
25-40	28	56	16	SiL	7.7	2.3	279	25.8	3
40-70	20	61	19	SiCL	7.5	1.8	382	15.1	4
70-90	30	43	27	CL	7.6	0.65	711	2.7	7
90-103	33	46	21	L	7.5	0.21	368	3.5	12
103-129	30	47	23	L	7.7	0.35	772	25.8	4

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Anions (cmol/l saturated extract)		
						Cl	CO ₃	HCO ₃
0-25	0.84	5	21.6	1.4	0.15	2.2	0	2.2
25-40		2	20.6	1.6	0.16	4.4	0	2.0
40-70		1	14.4	1.4	0.38	10.4	0	1.2
70-90		4	35.4	1.4	0.15	2.2	0	1.6
90-103		4	50.3	1.6	0.16	1.8	0	1.4
103-129		1	61	1.4	0.38	1.6	0	1.6

DHE063

Soil series: Darb

Soil Taxonomy (1994): Calcic Petrocalcic, fine loamy, mixed, isothermic

Date: 16-12-1995

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient:

Rock outcrops: none

Sealing/ crusting: crusting

Effective soil depth: 80 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: very few

Drainage: moderately well

Moisture conditions: dry 0-70, slightly moist 70+

Cracks:

Land use: arable land (cereals)

0-23	Ap	Silt loam, brown (10YR 4/3) moist, yellowish brown (10YR 5/4) dry. Weak, medium, subangular blocky structure. Slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet) consistence. Common, very fine pores. No rock fragments. Very few, fine, spherical, soft, carbonatic nodules. Strongly calcareous. Many, medium roots. Abrupt boundary.
23-53	Bk	Clay loam, light gray (10YR 7/2) moist, very pale brown (10YR 8/2) dry. Moderate, medium and coarse, subangular blocky structure. Slightly hard (dry), friable (moist), sticky and plastic (wet) consistence. Common, very fine pores. Common, fine, subrounded, weathered rock fragments. Common, medium, irregular, soft, carbonatic nodules. Strongly calcareous. Common, very fine roots. Gradual, wavy boundary.
53-80	Bkm	Silty clay, dark, yellowish brown (10YR 4/4) moist, very pale brown (10YR 7/3) dry. Weak, fine and medium, angular blocky structure. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Strong cementation. Common, fine pores. Many, medium, flat, weathered rock fragments. Common, coarse, irregular, hard, carbonatic nodules. Strongly calcareous. Many, very fine roots. Gradual, wavy boundary.
80+	R	Bedrock

DHE064

Soil series: Tinnan

Soil Taxonomy (1994): Typic Haplocalcid, fine clayey, mixed, isothermic

Date: 10-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 150 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Nil

Drainage: well

Moisture conditions: dry 0-55, slightly moist 55-150

Cracks:

Land use: arable land (cereals, vegetables)

0-25	Ap	Clay loam, dark brown (10YR 3/3) moist, brown (10YR 5/3) dry. Weak, medium and coarse, angular and subangular blocky structure. Soft (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, fine pores. Moderately calcareous. Common, very fine and fine roots. Clear, smooth boundary.
25-55	2Ab	Silty clay, black (10YR 2/1) moist, very dark gray (10YR 3/1) dry. Moderate and strong, medium and coarse, angular and subangular blocky structure. Slightly hard (dry), friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Moderately calcareous. few, fine roots. Clear, smooth boundary.
55-78	2Bw	Silty clay, pale brown (10YR 6/3) moist, very pale brown (10YR 8/3) dry. Moderate, fine and medium, angular blocky structure. Hard (dry), firm (moist), very sticky and very plastic (wet) consistence. Common, fine pores. Extremely calcareous. Few roots. Clear, smooth boundary.
78-93	Ck1	Silty clay, light brownish gray (10YR 6/2) and brown (7.5YR 4/4) moist, very pale brown (10YR 8/3) and brown (7.5YR 5/4) dry. Weak, fine and medium, subangular blocky structure. Soft (dry), very friable (moist), very sticky and very plastic (wet) consistence. Common, fine pores. Common, fine and medium, spherical and irregular, hard nodules (carbonates). Strongly calcareous. Very few, fine and medium roots. Clear, smooth boundary.
93-115	Ck2	Silty clay, yellowish red (5YR 4/6) moist, yellowish red (5YR 5/6) dry. Weak, fine and medium, subangular blocky structure. Soft (dry), very friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Very few, fine and medium, subrounded, weathered rock fragments. Common, fine and medium, spherical and irregular, hard nodules (carbonates). Strongly calcareous. Very few, fine roots. Gradual, wavy boundary.
115-150	C	Silty clay, yellowish red (5YR 4/6) moist, yellowish red (5YR 5/6) dry. Massive structure. Soft (dry), very friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Very few, fine and medium, subrounded, weathered rock fragments. Few, fine and medium, spherical and irregular, hard nodules (carbonates). Strongly calcareous. Very few, fine roots.

Analytical data for profile DHE064

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-25	29	54	17	SiL	7.7	0.44	245		4
25-55	15	48	37	SiCL	7.6	0.45	663	24.0	9
55-78	15	43	42	SiC	7.5	0.77	304	32.0	14
78-93	36	35	29	CL	7.9	0.36	826	9.7	4
93-115	26	45	29	CL	7.8	0.23	986	5.3	8
115-150					7.8	0.72	425	2.8	

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-25	1.4	8	33.3	1.82	0.2	2.0	0	3.0	-
25-55		2	64.3	1.52	0.3	2.0	0	1.6	2
55-78		4	42.0	1.55	0.2	2.6	0	1.4	3
78-93		4	36.4	1.25	0.1	1.0	0	1.6	1.5
93-115		5	67.0	1.45	0.1	0.6	0	1.6	0.9
115-150		6	40	1.60	0.1	0.6	0	1.4	0.7

DHE065

Soil series: Balasan

Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, isothermic

Date: 1-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 110 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Nil

Drainage: well

Moisture conditions: dry 0-130

Cracks:

Land use: arable land (cereals, vegetables)

0-26	Ap	Silty clay, dark grayish brown (10YR 4/2) moist, brown (10YR 4/3) dry. Weak and moderate, fine and coarse, subangular blocky structure. Slightly hard (dry), very friable (moist), sticky and plastic (wet) consistence. Few, very fine pores. Strongly calcareous. Common, very fine roots. Abrupt, smooth boundary.
26-50	Bw	Silty clay, very pale brown (10YR 7/4) moist, very pale brown (10YR 8/2) dry. Very weak, coarse, subangular blocky structure. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Continuous, massive compaction. Common, fine pores. Few, medium, iregular, soft segregations and nodules (carbonates). Extremely calcareous. Very few, fine roots. Diffuse, wavy boundary.
50-87	Bk	Silty clay, brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry. Moderate, fine and medium, subangular blocky structure. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Few, medium and coarse, subrounded and angular, slightly weathered rock fragments. Common, medium and coarse, irregular, soft and hard nodules (carbonates). Strongly calcareous. Very few, fine roots. Gradual, wavy boundary.
87-110	Cck	Loam, yellowish red (5YR 4/6) moist, reddish yellow (5YR 6/6) dry. Weak, fine and medium, subangular blocky structure. Hard (dry), friable (moist), sticky and slightly plastic (wet) consistence. Common, fine pores. Very few, medium, subrounded, weathered rock fragments. Many, medium and coarse, irregular, hard nodules (carbonates). Moderately calcareous. Common, fine roots. Clear, wavy boundary.
110-130	R	Massive structure. Extremely hard (dry), firm (moist) (wet) consistence. Many, coarse and very coarse, flat and angular, weathered rock fragments.

DHE066

Soil series: Tinnan

Soil Taxonomy (1994): Typic Haplocalcid, fine clayey, mixed, isothermic

Date: 21-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 130 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Nil

Drainage: well

Moisture conditions: dry 0-130

Cracks:

Land use: arable land (cereals, vegetables)

0-20	Ap	Silt loam, brown (10YR 4/3) moist, brown (10YR5/3) dry. Weak, fine, angular blocky structure. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, very fine pores. Moderately calcareous. Common, fine roots. Clear boundary.
20-30	2Ab	Silty clay loam, very dark grayish brown (10YR 3/2) moist, dark brown (10YR3/3) dry. Weak, fine, granular structure. Hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, very fine pores. Strongly calcareous. Many, fine roots. Clear boundary.
30-45	2Ab2	Silty clay loam, very dark grayish brown (10YR 3/2) moist, very dark grayish brown (10YR 3/2) dry. Weak, fine, prismatic structure. Hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Many, undifferentiated cutans on vertical pedfaces. Few, very fine pores. Strongly calcareous. Common, fine roots. Clear boundary.
45-80	2Bw	Silty loam, dark brown (10YR 5/3) moist, pale brown (10YR6/3) dry. Weak, fine, crumb structure. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, distinct, pressure faces. Few pores. Extremely calcareous. Very few, fine roots. Diffuse boundary.
80-110	Ck1	Silty loam, dark red (2.5YR 4/8) moist, red (2.5YR 5/8) dry. Massive. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, distinct, pressure faces. Few pores. Few, medium, flat, weathered rock fragments. Few, fine, irregular, hard nodules (carbonates). Extremely calcareous. Very few, fine roots. Gradual, wavy boundary.
110-130	Ck2	Silty loam, dark red (2.5YR 4/8) moist, red (2.5YR 5/8) dry. Massive. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Few pores. Very few, medium, subrounded, weathered rock fragments. Common, medium, irregular and angular, hard nodules (carbonates). Slightly calcareous. Few, fine roots.

DHE067

Soil series: Tinnan

Soil Taxonomy (1994): Typic Haplocalcid, fine clayey, mixed, isothermic

Date: 21-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 110 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Nil

Drainage: well

Moisture conditions: dry

Cracks:

Land use: orchard

0-30	Ap	Silty clay, brown (10YR 4/3) moist, brown (10YR5/3) dry. Weak, fine, crumb structure. Slightly hard (dry), friable (moist), sticky and plastic (wet) consistence. Few, very fine pores. Very few, fine rock fragments. Moderately calcareous. Many, medium roots. Clear smooth boundary.
30-70	2Ab	Silty clay, black (10YR 2/1) moist, very dark gray (10YR3/1) dry. Weak, fine, angular blocky structure. Hard (dry), friable (moist), non sticky and non plastic (wet) consistence. Many, prominent, clay cutans in pores/voids. Few, very fine pores. Strongly calcareous. Common, fine, roots. Clear smooth boundary.
70-110	2Bw	Clay loam, dark brown (10YR 3/3) moist, brown (10YR 4/3) dry. Moderate, fine, angular blocky structure. Very hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, distinct, pressure faces on pedfaces. Slight cementation by carbonates. Few pores. Strongly calcareous. Very few, fine, roots. Gradual, wavy boundary.
110-135	2Bk	Silty clay, light yellowish brown (10YR 6/4) moist, very pale brown (10YR 7/4) dry. Strong, fine, subangular and angular blocky structure. Hard (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Very few, distinct, pressure faces on pedfaces. Slight cementation by carbonates. Few pores. Strongly calcareous. Gradual, wavy boundary.
135-150	C	Silty clay, dark yellowish brown (10YR 4/4) moist, light yellowish brown (10YR 6/4) dry. Weak, fine, subangular and angular blocky structure. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, very fine pores. Very few, medium, flat rock fragments. Few, fine to coarse, irregular, hard carbonate concretions. Extremely calcareous.

Analytical data for profile DHE067

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-30	25	59	16	SiL	7.7	0.3	92	33.8	4
30-55	18	49	33	SiCL	7.7	0.23	884	15.1	7
55-75	22	49	29	CL	7.7	0.20	53	15.1	7
75-110	27	43	30	CL	7.8	0.28	700	8.0	4
110-135	28	36	36	CL	7.9	0.25	124	6.2	9

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-30	1.4	4	40	0.88	0.35	1.0	0	2.0	
30-55			30	0.85	0.39	0.8	0	1.6	
55-75			35	0.72	0.3	1.0	0	1.4	
75-110			27	0.9	0.48	1.0	0	1.8	
110-135			26	0.8	0.3	1.4	0	1.6	

DHE068

Soil series: Tinnan

Soil Taxonomy (1994): Typic Haplocalcid, fine clayey, mixed, isothermic

Date: 21-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 100 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Nil

Drainage: Moderately well

Moisture conditions: slightly moist 30-150 cm

Cracks:

Land use: arable land (cereals, potatoes)

0-30	Ap	Clay loam. Dark brown (10YR 3/3) moist, dark, yellowish brown (10YR 4/4) dry. Moderate and strong, fine, medium and coarse, subangular blocky and granular structure. Soft (dry), very friable (moist), slightly sticky and slightly plastic consistency. Common, fine and medium pores. Many, fine and medium roots. Strongly calcareous. Clear smooth boundary.
30-50	2Ab	Clay, black (10YR 2.5/1) moist, very dark greyish brown (10YR 3/2) dry. Weak and moderate, fine and medium, subangular blocky structure. Slightly hard (dry), very friable (moist), very sticky and very plastic (wet) consistence. Few cutans, distinct, pressure faces, on horizontal and vertical pedfaces. Common, fine and medium pores. Many, very fine and fine roots. Strongly calcareous. Very few concentrations: filaments, fine, soft carbonates. Gradual, smooth boundary.
50-75	2Bw	Clay, dark brown (10YR 3/3) moist, brown (10YR 4/3) dry. Common mottles, very dark grayish brown (10YR3/2), fine, distinct, clear boundary. Weak and moderate, fine and medium, prismatic structure. Hard (dry), friable (moist), very sticky and very plastic (wet) consistence. Common cutans, distinct, pressure faces, on horizontal and vertical pedfaces. Few, fine pores. Many, very fine and fine roots. Strongly calcareous. Few concentrations: filaments, fine, soft carbonates. Clear, smooth boundary.
75-100	Ck	Silty clay, brown (10YR 4/3) moist, dark yellowish brown (10YR 4/4) dry. Common mottles, very dark grayish brown (10YR 3/2) fine and medium, distinct, clear boundary. Weak, fine and medium, subangular blocky structure. Hard (dry), friable (moist), very sticky and very plastic (wet) consistence. Very few cutans, faint, pressure faces, on pedfaces. Common, fine pores. Many concentrations: soft segregations and filaments, medium and coarse, irregular, soft, carbonates. Extremely calcareous. Gradual, smooth boundary.
100-125	Ck2	Silty clay, brown (7.5YR 4/4) moist, brown (10YR 4/3) dry. Many mottles, very dark grayish brown (10YR 3/2) fine and medium, distinct and prominent, clear boundary. Weak, fine and medium, subangular blocky structure. Very hard (dry), friable (moist), very sticky and very plastic (wet) consistence. Very few cutans, faint, pressure faces, on pedfaces. Common, fine pores. Common concentrations: soft segregations, filaments and nodules, medium, irregular, soft and hard carbonates. Extremely calcareous. Diffuse, wavy boundary.
125-150	C	Silty clay, yellowish red (5YR 5/8) moist, yellowish red (5YR 5/8) dry. Common mottles, very dark grayish brown (10YR 3/2) fine and medium, distinct and prominent, clear boundary. Massive. Very hard and extremely hard (dry), friable and firm (moist), sticky and plastic (wet) consistence. Weakly cemented by carbonates. Few, fine pores. Few rock fragments, medium and coarse, subrounded, weathered stones. Few/common concentrations: nodules, medium, irregular, hard carbonates. Moderately calcareous.

DHE069

Soil series: Balasan

Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, isothermic

Date: 22-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: > 100 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Nil

Drainage: Well

Moisture conditions: dry 0-150 cm

Cracks:

Land use: arable land (cereals)

- 0-30 Ap Silty loam, brown (10YR 4/3) moist, brown (10YR 5/3) dry. Massive. Soft (dry), friable (moist), sticky and plastic (wet) consistence. Few, fine pores. Common concentrations: concretions, medium, spherical, carbonates. Common, fine roots. Moderately calcareous. Clear boundary.
- 30-80 Bk1 Silty clay, light gray (10YR 7/1) moist, white (10YR 8/1) dry. Weak and moderate, fine and medium, subangular blocky structure. Soft (dry), friable (moist), sticky and plastic (wet) consistence. Few, fine pores. Common, medium, subrounded rock fragments. Many concentrations: soft segregations, coarse, irregular, hard, carbonates. Very few, very fine roots. Strongly calcareous. Gradual boundary.
- 80-150 Ck Silty clay, reddish brown (5YR 3/4) moist, yellowish red (5YR 4/6) dry. Weak and moderate, fine, subangular blocky structure. Slightly hard (dry), friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Many, coarse, subrounded rock fragments. Many concentrations: soft segregations, coarse, irregular, hard, carbonates. Very few, very fine roots. Strongly calcareous.

DHE070

Soil series: Balasan

Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, isothermic

Date: 22-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0.1-2%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 70 cm

Parent material: alluvium and loess

FAO (1988): Haplic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Nil

Drainage: moderately well

Moisture conditions: dry 0-70 cm

Cracks:

Land use: arable land (cereals)

- | | | |
|-------|----|--|
| 0-35 | Ap | Silty clay loam, brown (10YR 4/4) moist, brown (10YR 5/4) dry. Weak, medium and coarse angular blocky structure. Soft (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, fine pores. Very few, medium, irregular, hard carbonate concentrations (concretions). Many, very fine, fine and medium roots. Strongly calcareous. Clear wavy boundary. |
| 35-60 | Bk | Clay loam, very pale brown (10YR 7/3) moist, white (10YR 8/1) dry. Brown mottles. Moderate and strong, fine, medium and coarse angular blocky structure. Soft (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, distinct cutans (pressure faces). Few, very fine pores. Common, fine to coarse, irregular, soft and hard carbonate concentrations (concretions, soft segregations, nodules). Very few, fine roots. Extremely calcareous. Gradual, wavy boundary. |
| 60-70 | Ck | Silty clay loam, reddish brown (5YR 4/4) moist, reddish brown (5YR 5/4) dry. Brown mottles. Moderate, fine and medium angular blocky structure. Slightly hard (dry), friable (moist), sticky and plastic (wet) consistence. Many, distinct cutans (pressure faces and clay). Few, very fine pores. Common, medium and coarse, subrounded, slightly weathered rock fragments. Few, medium, irregular, hard carbonate concentrations. Very few, fine roots. Strongly calcareous. |
| 70+ | R | Bedrock |

DHE071

Soil series: Wasitah

Soil Taxonomy (1994): Typic Haplocalcid, fine loamy, mixed, thermic

Date: 22-01-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0.1-2%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 80 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: Very few

Drainage: moderately well

Moisture conditions: slightly moist 50-125 cm

Cracks:

Land use: arable land (cereals)

- | | | |
|---------|-----|---|
| 0-30 | Ap | Loam, brown (10YR 4/3) moist, brown (10YR 5/3) dry. Strong, fine to coarse, subangular blocky structure. Soft (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, very fine pores. Common, very fine, fine and medium roots. Strongly calcareous. Clear, wavy boundary. |
| 30-50 | 2Ab | Silty clay loam, dark grayish brown (10YR 4/2) moist, grayish brown (10YR 5/2) dry. Very weak, medium and coarse subangular blocky structure. Slightly hard (dry), friable (moist), sticky and plastic (wet) consistence. Very few, distinct cutans (pressure faces and clay). Many, very fine and fine pores. Common, fine, irregular, soft carbonate concentrations (filaments). Few, very fine, fine, medium roots. Strongly calcareous. Clear, wavy boundary. |
| 50-80 | 2Bk | Clay loam, very dark grayish brown (10YR 3/2) moist, gray (10YR 6/1) dry. Porous massive. Slightly hard (dry), friable (moist), sticky and plastic (wet) consistence. Many, very fine and fine pores. Few, medium, subrounded rock fragments. Dominant, fine, irregular, soft carbonate concentrations (filaments). Few, very fine roots. Extremely calcareous. Gradual, wavy boundary. |
| 80-105 | C | Sandy loam, dark brown (10YR 3/3) moist, yellowish brown (10YR 5/4) dry. Many, fine and medium, diffuse, dusky red (7.5YR 3/4) moist, red (7.5YR 4/6) dry mottles. Porous massive. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Many, fine pores. Common, medium and coarse, subrounded and flat rock fragments. Common, fine, irregular, soft carbonate concentrations (filaments). Very few, very fine roots. Strongly calcareous. Clear, wavy boundary. |
| 105-125 | C | Brown (7.5YR 4/4) moist and yellowish brown (10YR 5/4) dry. |

Analytical data for profile DHE071

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-25	28	61	11	SiL	7.5	0.31	713	24	3
25-35	30	39	31	CL	7.6	0.36	899		7
35-70	32	43	25	L	7.7	0.82	176		7
70-105	49	38	13	L	7.8	0.62	523		12

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-25	0.7	4	34	0.75	0.3	2.8	0	2.4	0.24
25-35			15	0.9	0.28				
35-70			45	1.1	0.23				
70-105				1.6	0.34				

DHE072

Soil series: Darb

Soil Taxonomy (1994): Calcic Petrocalcic, fine loamy, mixed, isothermic

Date: 3-3-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0- 0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 45 cm

Parent material: alluvium and loess

FAO (1988): Petric Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: nil

Drainage: moderately well

Moisture conditions: dry 0-45 cm

Cracks:

Land use: arable land (cereals, vegetables)

- 0-25 : Ap Silt loam, brown (10YR 4/3) moist, grayish brown (10YR 5/2) dry. Weak, fine subangular blocky structure. Slightly hard (dry), very friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Very few, fine, subrounded, weathered rock fragments. Few, fine roots. Non calcareous. Clear, wavy boundary.
- 25-43 2Ck Silty clay loam, dark reddish brown (5YR 2.5/2) moist, dark reddish brown (5YR 3/2) dry. Very weak, fine granular structure. Loose (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Many, medium pores. Common, fine, subrounded, slightly weathered rock fragments. Common, fine, spherical and irregular, hard carbonate concentrations (concretions). Very few, very fine roots. Strongly calcareous. Abrupt, irregular boundary.
- 43+ 2R Bedrock.

Analytical data for profile DHE072

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-25	45	46	9	L	7.5	0.43	194	5.4	4
25-43	63	25	12	SL	7.5	0.43	163		4

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-25	1.7	4	47	0.63	0.3	7	0	2.4	2.6
25-43			78	0.76	0.3	5	0	2.0	1.8

DHE073

Soil series: Yafa

Soil Taxonomy (1994): Lithic Torriorthent, fine loamy, mixed, isothermic

Date: 3-3-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0- 0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 25 cm

Parent material: alluvium and loess

FAO (1988): Eutric Leptosol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: nil

Drainage: moderately well

Moisture conditions: dry

Cracks:

Land use: arable land (cereals, vegetables)

- | | | |
|-------|------|---|
| 0-20 | Ap | Silty clay loam, dark brown (10YR 3/3) moist, brown (10YR 4/3) dry. Massive. Very hard (dry), firm (moist), slightly sticky and slightly plastic (wet) consistence. Continuous, massive compaction. Few pores. Very few, medium, irregular, hard carbonate concentrations (nodules). Common, fine roots. Moderately calcareous. Clear, wavy boundary. |
| 20-25 | 2Bk | Silty clay, black (10YR 2/1) moist, dark gray (10YR 4/1) dry. Very weak, fine and medium, subangular blocky structure. Soft (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, fine pores. Many, medium, subrounded and flat, weathered rock fragments. Few, medium and coarse, irregular, hard carbonate concentrations (concretions). Very few, very fine roots. Strongly calcareous. Clear, wavy boundary. |
| 25+ | 2Ckm | Petrocalcic horizon. |

Analytical data for profile DHE073

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-20	35	54	11	SiL	7.3	0.32	166	4.0	4
20-25	63	22	15	SL	-	-	286	5.1	8

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-20	0.98	20	28	0.61	0.3	1	0	2.4	0.42
20-25	0.84	13	61	0.67	0.4	2	0	2.0	-

DHE074

Soil series: Balasan

Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, isothermic

Date: 3-3-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0- 0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 100 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: nil

Drainage: well

Moisture conditions: dry

Cracks:

Land use: arable land (cereals, vegetables)

0-35	Ap	Silty clay loam, dark brown (10YR 3/3) moist, brown (10YR 4/3) dry. Weak, fine, subangular blocky structure. Soft (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Few, very fine pores. Very few, medium, irregular, hard carbonate concentrations (nodules). Common, fine roots. Slightly calcareous. Clear, smooth boundary.
35-50	2Ab	Silty clay loam, very dark brown (10YR 2/2) moist, very dark grayish brown (10YR 3/2) dry. Very weak, fine and medium, crumb structure. Soft (dry), very friable (moist), sticky and plastic (wet) consistence. Common, medium pores. Very few, medium, spherical, hard, carbonate concentrations (nodules). Few, very fine roots. Moderately calcareous. Clear, smooth boundary.
50-100	2Bwk	Clay, pale brown (10YR 6/3) moist, light gray (10YR 7/2) dry. Moderate, medium, subangular blocky structure. Slightly hard (dry), firm (moist), non sticky and non plastic (wet) consistence. Common, medium pores. Many, medium, subrounded and flat, weathered rock fragments. Many, coarse, irregular, hard, carbonate concentrations (concretions). Very few, very fine roots. Strongly calcareous. Abrupt, wavy boundary.
100+	2Ckm	Petrocalcic horizon

Analytical data for profile DHE074

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-35	27	49	24	L	7.4	0.32	124	4.2	7
35-50	19	40	41	SiC	7.5	0.51	234	5.1	8
50-100	48	24	28	SCL	7.8	0.39	490	4.7	8

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-35	0.56	3.8	41	0.62	0.3	3.0	0	4.0	1.2
35-50			63	0.10	0.3	1.6	0	2.4	2.0
50-100			47	1.35	0.2	3.6		2.4	2.6

DHE075

Soil series: Yafa

Soil Taxonomy (1994): Lithic Torriorthent, fine loamy, mixed, isothermic

Date: 4-3-1996

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Slope gradient: 0- 0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 25 cm

Parent material: alluvium and loess

FAO (1988): Eutric Leptosol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: few boulders

Drainage: well

Moisture conditions: dry

Cracks:

Land use: arable land (cereals and vegetables)

0-25 A Clay loam, brown (10YR 4/3) moist, brown (10YR 5/3) dry. Weak, fine, subangular blocky structure. Soft (dry), very friable (moist), slightly sticky and plastic (wet) consistence. Common, fine pores. Few, medium, flat rock fragments. Common, fine roots. Clear, wavy boundary.

25+ R Bedrock

Analytical data for profile DHE075

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-25	28	53	19	SiL	7.5	0.3	155	4.4	4

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-25	0.7	10	35	0.6	0.4	1	0	2.8	0.4

DHE076

Soil series: Yafa

Soil Taxonomy (1994): Lithic Torriorthent, fine loamy, mixed, isothermic

Date: 4-3-1996

Slope gradient: 0- 0.1%

Authors: Ahmed Sallam, Lotfi Al-Asbahi, El-Abbas Doka

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 20 cm

Parent material: alluvium and loess

FAO (1988): Eutric Leptosol

Location: Dhamar, AREA, eastern research farm, see map

Surface stones: very few gravels and stones

Coordinates:

Drainage: moderately well

Moisture conditions: dry

Cracks:

Land use: arable land (cereals, vegetables)

0-20 Ap Clay loam, brown (10YR 4/3) moist, brown (10YR 5/3) dry. Weak, fine, subangular blocky structure. Soft (dry), very friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Very few, fine, flat, weathered rock fragments. Very few, medium, irregular, hard carbonate concentrations (nodules). Common, fine roots. Non calcareous. Clear, smooth boundary.

20+ R Bedrock

Analytical data for profile DHE076

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-20	32	58	10	SiL	7.4	0.4	130	5.1	3

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-20	1.12	2	29	0.7	0.4	1	0	2.8	1.2

DHE077

Soil series: Yafa

Soil Taxonomy (1994): Lithic Torriorthent, fine loamy, mixed, isothermic

Date: 4-3-1996

Authors: Lotfi Al-Asbahi, Ahmed Sallam

Slope gradient: 0- 0.1 %

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 30 cm

Parent material: alluvium and loess

FAO (1988): Eutric Leptosol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: few boulders

Drainage: moderately well

Moisture conditions: dry

Cracks:

Land use: arable land (cereals, vegetables)

0-15	Ap	Clay loam, brown (10YR 4/3) moist, brown (10YR 5/3) dry. Weak and moderate, fine, subangular blocky structure. Soft (dry), very friable (moist), sticky and plastic (wet) consistence. Common, fine pores. Very few, fine, subrounded, weathered rock fragments. Very few, medium, irregular, hard carbonate concentrations (nodules). Few, fine roots. Non calcareous. Clear, smooth boundary.
15-30	2Bw	Clay loam, dark, reddish gray (2.5YR 4/1) moist, weak red (2.5YR 5/2) dry. Weak, medium, subangular blocky structure. Hard (dry), friable and firm (moist), sticky and plastic (wet) consistence. Common, fine and medium pores. Many, medium, subrounded, weathered rock fragments. Few, coarse, irregular, hard carbonate concentrations (concretions). Very few, fine roots. Slightly calcareous. Clear, wavy boundary.
30+	R	Bedrock

Analytical data for profile DHE077

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-15	33	55	12	SiL	8.1	0.3	157	4.7	2
15-30	43	38	19	L	7.9	0.3	349	9.7	7

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-15	0.98	2	31	0.9	0.4	1.6	0	2.0	0.4
15-30	0.56	2	58	0.9	0.3	2.0		3.4	1.0

DHE078

Soil series: Darb

Soil Taxonomy (1994): Calcic Petrocalcic, fine loamy, mixed, isothermic

Date: 4-3-1996

Authors: Lotfi Al-Asbahi, Ahmed Sallam

Slope gradient: 0- 0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 85 cm

Parent material: alluvium and loess

FAO (1988): Petric Calcisol

Location: Dhamar, AREA, eastern research farm, see map

Coordinates:

Surface stones: nil

Drainage: moderately well

Moisture conditions: dry

Cracks:

Land use: arable land (cereals, vegetables)

- | | | |
|-------|-----|--|
| 0-25 | Ap | Clay loam, dark, grayish brown (10YR 4/2) moist, pale brown (10YR 6/3) dry. Weak, fine, angular blocky structure. Soft (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, fine pores. Very few, fine, subrounded, weathered rock fragments. Very few, medium, irregular, hard carbonate concentrations (nodules). Common, fine roots. Clear, smooth boundary. |
| 25-85 | Bwk | Clay loam, dark, dark, reddish brown (5YR 3/4) moist, dark, reddish brown (5YR 3/3) dry. Weak and moderate, fine, angular blocky structure. Slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet) consistence. Common, medium pores. Very few, fine, subrounded, weathered rock fragments. Many, medium, irregular, soft and hard carbonate concentrations (filaments). Common, fine roots. Diffuse, wavy boundary. |
| 85+ | R | Bedrock |

Analytical data for profile DHE078

Depth	Mechanical Analysis				pH paste	EC (dS/m)	CaCO ₃ (g/kg)	Organic C (g/kg)	Moisture (%)
	Sand	Silt	Clay	Texture Class					
0-25	37	54	12	SiL	8.0	0.33	835	5.9	4
25-85	41	29	28	CL	8.0	0.37			7

Depth (cm)	Total N (g/kg)	Available P (mg/kg)	CEC soil (cmol/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
						CL	CO ₃	HCO ₃	Na
0-25	0.7	3	25	0.7	0.4	1.0	0	2.6	1.6
25-85			51	0.7	0.3	0.4		1.2	2.0

DHE079

Series: Tinnan

Soil Taxonomy (1994): Typic Haplocalcid, fine clayey, mixed, isothermic.

Date: 26-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 110 cm

Parent material: alluvium and loess

FAO: Cambic Calcisol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: Nil

Drainage: Well

Moisture conditions: dry 0-110 cm

Cracks: 0-50 cm, <5mm wide.

Land use: arable land (bare, alfalfa, cereals)

0-35	Ap	Silt loam. Brown (10YR 4/3) moist, pale brown (10YR 6/3) dry. Strong, coarse, subangular blocky structure. Very hard (dry), firm (moist), very sticky and very plastic (wet) consistence. Common, fine and medium pores. Many, medium and coarse roots. Moderately calcareous. Few biological features: burrows. Clear smooth boundary.
35-65	2Ab	Clay loam, very dark grayish brown (10YR 3/2) moist, very dark gray (10YR 3/1) dry. Weak and moderate, very fine and fine, subangular blocky structure. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Common, distinct, undifferentiated cutans on pedfaces. No compaction. Few, very fine and fine pores. Common, fine and medium roots. Strongly calcareous. Common concentrations: fine, irregular, soft filaments (carbonates). Clear and smooth boundary.
65-90	2Ck1	Silty clay, grayish brown (10YR 5/2) moist, light gray (10YR 7/2) dry. Massive. Very hard (dry), very friable (moist), very sticky and very plastic (wet) consistence. Extremely calcareous. Dominant carbonatic concentrations: fine to coarse, irregular, soft and hard filaments and soft segregations. Few, very fine pores. Few, very fine roots. Clear, smooth boundary.
90-110	2Ck2	Silty clay, dark brown (10YR 3/3) moist, grayish brown (10YR 5/2) dry. Very weak (almost massive), very fine and fine angular blocky structure. Very hard (dry), very friable (moist), sticky and plastic (wet) consistence. Extremely calcareous. Common carbonatic concentrations: fine, irregular, soft and hard filaments. Weak cementation. Few, very fine pores. Common, very fine roots.

Analytical data for profile DHE079

Depth (cm)	Mechanical Analysis				pH paste	EC dS/m	CaCO ₃ (%)
	Sand	Silt	Clay	Texture Class			
0 - 35	20	51	29	SiCL	8.0	0.49	1.3
35 - 65	12	39	49	C	8.1	0.46	2
65 - 90	10	29	61	C	7.9	0.59	47
90 - 110	20	41	39	CL	7.8	1.6	12.8

Depth (cm)	Organic C (g/kg)	Available P (mg/kg)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)				CEC soil (Cmol/kg)
					Na	K	Ca	Mg	
0 - 35	4.3	3	0.5	0.4	2.4	0.17	2.4	2.4	
35 - 65	4.8	3	0.9	0.3	0.4	0.16	4.0	1.2	
65 - 90	2.6	3	0.8	0.2	2.7	0.17	2.8	2.4	
90 - 110	2.9	4	1.2	0.2	4.5	0.17	8		

DHE080

Series: Yafa

Soil Taxonomy (1994): Lithic Torriorthent, fine loamy, mixed, isothermic.

Date: 27-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: No

Effective soil depth: 35 cm

Parent material: alluvium and loess

FAO (1994): Eutric Regosol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: Few, stones

Drainage:

Moisture conditions: dry 0-35 cm

Cracks: no

Land use: arable land (maize)

0-35	Ap	Silty clay. Brown (10YR 4/3) moist, brown (10YR 5/3) dry. Moderate, fine and medium, subangular and angular blocky structure. Slightly hard (dry), friable (moist), very sticky and very plastic (wet) consistence. No cutans. No compaction. Many, very fine and fine pores: channels and interstitial pores. Many, fine and medium roots. Few, medium, subrounded slightly weathered rock fragments. Moderately calcareous. No concentrations. Gradual, smooth boundary.
35+	R	Pinkish bedrock, rich in gypsum and carbonates.

DHE081

Series: Yafa

Soil Taxonomy (1994): Lithic Torriorthent, fine loamy, mixed, isothermic.

Date: 27-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting:

Effective soil depth: 30 cm

Parent material: alluvium and loess

FAO (1994): Eutric Regosol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones:

Drainage:

Moisture conditions: dry 0-30 cm

Cracks: no

Land use: arable land (barley)

0-22	Ap	Silty clay. Brown (10YR 4/3) moist, brown (10YR 5/3) dry. Moderate, fine and medium, subangular blocky structur. Slightly hard (dry), very friable moist, sticky and plastic (wet) consistence. No cutans. Mechanical compaction. Many, fine and medium interstitial pores. Many, very fine and fine roots. Few, fine and medium, rounded and flat rock fragments. Strongly calcareous. Very few concentrations: fine, irregular soft segregations (carbonates). Gradual, smooth boundary.
22-30	C	Clay loam. Very dark, gray (10YR 3/1) moist, very dark grayish brown (10YR 3/2) dry. Weak, fine and medium subangular blocky structur. Slightly hard (dry), very friable (moist), sticky and plastic (wet) consistence. Few, faint, clay cutans on pedfaces. Many, fine and medium, interstitial pores. Common, very fine roots. Few, fine and medium, rounded and flat, slightly weathered rock fragments. Strongly calcareous. Concentrations: few, fine, irregular, soft, filaments and soft segregations (carbonates).
30+	R	Bedrock (limestone?)

DHE082

Series: Yafa

Soil Taxonomy (1994): Lithic Torriorthent, gravelly fine loamy, mixed, isothermic.

Date: 27-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting:

Effective soil depth: 45 cm

Parent material: alluvium and loess

FAO (1994): Eutric Regosol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: Common, stones

Drainage:

Moisture conditions: dry 0-45 cm

Cracks: no

0-25	Ap	Silty clay. Brown (10YR 4/3) moist, brown (10YR 5/3) dry. Moderate, fine and medium, subangular blocky structure. Soft (dry), very friable moist, very sticky and very plastic (wet) consistence. Common, fine and medium pores, type: interstitial and channels. Many, fine and medium roots. Few, fine and medium, rock fragments. Strongly calcareous. Clear, smooth boundary.
25-45	2AB	Clay loam. Very dark, grayish brown (10YR 3/2) moist, dark grayish brown (10YR 4/2) dry. Moderate, fine and medium subangular blocky structure. Very hard (dry), friable (moist), sticky and plastic (wet) consistence. Few, faint, clay cutans on pedfaces. Common, fine and medium, interstitial pores. Few, very fine and fine roots. Many, fine and medium, subrounded, slightly weathered rock fragments. Extremely calcareous. Concentrations: common, fine, irregular, soft filaments (carbonates).
45+	R	Bedrock

Analytical data for profile DHE081

Depth (cm)	Mechanical Analysis				pH paste	EC dS/m	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC soil (Cmol/kg)	CaCO ₃ (%)
	Sand	Silt	Clay	Texture Class							
0 - 22	23	52	25	SiL	8.0	0.48	4.3		5	28	3.8
22 - 30	20	51	29	SiCL	8.0	0.41	4.1		2	23	2.8

Depth (cm)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
			Na	K	Ca	Mg
0 - 22	0.5	0.5	1.5	0.13	2.8	2
22 - 30	0.7	0.3	1.8	0.14	3.2	4

DHE083

Soil series: Darb

Soil Taxonomy (1994): Calcic Petrocalcic, fine loamy, mixed, isothermic.

Date: 28-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting:

Effective soil depth: 50-80 cm

Parent material: alluvium and loess

FAO (1994): Petric calcisol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: Few, gravels

Drainage:

Moisture conditions: dry 0-100 cm

Cracks: no

Land use: arable land (Bare, cereals)

0-10	Ap	Silty clay loam. Brown (10YR 4/3) moist, pale brown (10YR 6/3) dry. Very weak, fine and medium, crumb structur. Soft (dry), very friable moist, sticky and plastic (wet) consistence. Common, very fine pores. Few, fine and medium, rounded rock fragments. Strongly calcareous. few, medium roots. Clear, smooth boundary.
10-25	Ap2	Silty clay, brown (10YR 5/3) moist, pale brown (10YR 6/3). Moderate, fine and medium, prismatic structure. Soft (dry), friable (moist), sticky and plastic (wet) consistence. Common, very fine pores. Few, fine and medium rock fragments. Few, soft segregation, fine concentration of carbonates. Strongly calcareous. Few, fine roots. Clear, smooth boundary.
25-55	Cmk	Silty clay. Layer contains material with different colours: dark grayish brown (10YR 4/2) and very pale brown (10YR 7/3) moist, grayish brown (10YR 5/2) and white (10YR 8/1) dry. Massive. Extremely hard (dry), friable (moist), sticky and plastic. Few, very fine pores. Common, fine, rounded, slightly weathered rock fragments. Many concentrations: medium, irregular, soft and hard concretions and soft segregations (calcium carbonates) and crystals (gypsum). Extremely calcareous. Very few, very fine roots. Gradual, wavy boundary.
55-100	Cmk2	Brown (7.5YR 4/2) and brown (7.5YR 3/2) moist, brown (7.5YR 5/4) and very dark grey (7.5YR 3/1), dry. Massive. Extremely hard (dry) and friable (moist). Very few, faint, clay cutans on pedfaces. Horizon strongly cemented from carbonates and gypsum. Few, coarse pores. Few, fine, rounded, slightly weathered rock fragments. Many concentrations: medium and coarse, irregular, soft and hard concretions and soft segregations (calcium carbonates) and crystals (gypsum). Extremely calcareous. Very few, very fine roots.

Analytical data for profile DHE083

Depth (cm)	Mechanical Analysis				pH paste	EC dS/m	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC soil (Cmol/kg)	CaCO ₃ (%)
	Sand	Silt	Clay	Texture Class							
0 - 10	21	52	27	SiL	7.9	0.53	4.2		5	25	15
10 - 25	22	51	27	SiCL	7.9	0.39	3.1		3	25	14.5
25 - 55	20	36	44	C	7.9	0.48	2.5		1	30	47
55 - 100	20	38	42	C	7.7	1.1	1.2		1	32	37.5

Depth (cm)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
			Na	K	Ca	Mg
0 - 10	0.3	0.4	1	0.13	4.0	0.4
10 - 25	0.3	0.3	1	0.16	2.4	1.6
25 - 55	0.6	0.2	2	0.14	2.4	2.4
55 - 100	1.7	0.3	4.4	0.16	5.6	2.4

DHE084

Series: Balasan

Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, thermic.

Date: 28-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0-0.1%

Rock outcrops: none

Sealing/ crusting: crusting

Effective soil depth: 120 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: Few, gravels

Drainage:

Moisture conditions: dry 0-120 cm

Cracks: 0-30 cm, 1 mm wide

Land use: arable land (bare, cereals)

0-10	Ap	Silty clay loam, brown (10YR 4/3) moist, brown (10YR 5/3), dry. Weak, very fine, crumb and subangular blocky structure. Soft (dry), friable (moist), sticky and plastic consistence. Common, very fine and fine pores. Strongly calcareous. Few concentrations: Medium, irregular, soft carbonate segregations. Few, fine roots. Few, fine, rounded, slightly weathered, rock fragments. Clear, smooth boundary.
10-30	Ap2	Silty clay loam, brown (10YR 4/3) moist, brown (10YR 5/3), dry. Moderate, medium, subangular blocky and platy structure. Soft (dry), friable (moist), sticky and plastic (wet) consistence. Continuous, mechanical compaction (platiness). Common, very fine and fine pores. Strongly calcareous. Few concentrations: Medium, irregular, soft and hard carbonate concretions. Few, fine and medium roots. Few, fine, rounded, slightly weathered, rock fragments. Clear, smooth boundary.
30-80	2Bk	Silty clay, dark brown (10YR 3/3) moist, brown (10YR 4/3), dry. Weak, fine, angular blocky structure. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Continuous, massive compaction. Many, fine and medium pores. Extremely calcareous. Many concentrations: medium and coarse, irregular, soft and hard carbonatic and gypsic concretions and soft segregations. Very few, very fine roots. Gradual, wavy boundary.
80-120	2Cmk	Silty clay. Mixed matrix colours: very pale brown (10YR 7/3) and strong brown (7.5YR 5/6) moist, white (10YR 8/1) and reddish yellow (7.5YR 6/6), dry. Weak, fine, angular blocky structure. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Continuously, weakly cemented by (carbonates/gypsum). Common, fine pores. Extremely calcareous. Dominant concentrations: coarse, irregular, hard, carbonatic and gypsic concretions. very few, very fine roots.

Analytical data for profile DHE084

Depth (cm)	Mechanical Analysis						pH paste	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC soil (Cmol/kg)	EC dS/m	CaCO ₃ (%)
	Sand	Silt	Clay	Texture Class									
0 - 10	25	54	29	SICL	7.8	1.3	1	22	0.96	8.3			
10 - 30	24	29	47	C	7.5	1.9	1	37	1.7	30.5			
30 - 80	22	36	42	C	7.8	1.8	4	25	0.59	48			
80 - 120	22	33	45	C	7.7				0.72	42.5			

Depth (cm)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
			Na	K	Ca	Mg
0 - 10	0.3	0.4	1.3	0.12	8	1.2
10 - 30	1.1	0.2	5.6	0.16	9.2	2.8
30 - 80	0.4	0.2	1.9	0.12	3.6	1.2
80 - 120	1.7	0.2	3.4	0.17	4.4	2.4

DHE085

Series: Balasan

Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, isothermic.

Date: 30-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0.1 - 2%

Rock outcrops: none

Sealing/ crusting: nil

Effective soil depth: 107 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: Few, gravels

Drainage:

Moisture conditions: dry 0-130 cm

Land use: arable land (bare, cereals, sorghum)

0-15	Ap	Silt loam , yellowish brown (10YR 5/4) moist, pale brown (10YR 6/3), dry. Moderate, fine and medium, subangular blocky structure. Soft (dry), very friable (moist), slightly sticky and plastic (wet) consistence. Many, fine and medium pores. Strongly calcareous. Few concentrations, concretions and soft segregations, fine, spherical, soft and hard, nature carbonates and gypsum. Very few, fine, rounded, slightly weathered, rock fragments. Common, medium roots. Clear, wavy boundary.
15-45	Bw	Silty clay loam, yellowish brown (10YR 5/4) moist, pale brown (10YR 6/3), dry. Moderate, medium, subangular blocky structure. Soft (dry), very friable (moist), sticky and plastic consistence. Few, very fine, interstitial pores. Very few, fine, rounded, slightly weathered rock fragments. Common concentrations: concretions and soft segregations, fine, spherical, soft and hard, nature: carbonats and gypsum. Common, medium roots. Clear, smooth boundary.
45-65	Cck	Silty clay, light yellowish brown (10YR 6/4) moist, very pale brown, (10YR 7/3), dry. Weak, medium subangular and angular blocky structure. Hard (dry) friable (moist) very sticky and plastic (wet) consistence. Few, fine and coarse, rounded, slightly weathered rock fragments. Extremely calcareous. Many carbonatic and gypsum concentrations: fine to coarse concretions and soft segregations with an irregular shape, both soft and hard. Compaction: continuous, weakly cemented by carbonates/gypsum. Many, fine, interstitial pores. Few, fine and medium roots. Few, fine, distinct, clear, reddish mottles. Gradual and smooth boundary.
65-107	Ck	Clay loam, dark brown (10YR 3/3) moist, brown (10YR 5/3) dry. Moderate and strong structure, fine and medium angular blocky. Hard (dry), friable (moist), sticky and plastic (wet) consistence. Extremely calcareous. Many, medium sized, soft, irregular filaments of carbonatic nature. Few, faint, clay (?) cutans on pedfaces. Many, medium pores. Few, very fine roots. Gradual, smooth boundary.
107-130	R	Bedrock, less than 10% soil. Very pale brown (10YR 7/4) moist, very pale brown (10YR 8/2) dry. Dominant (90%) rock fragments, which are coarse, flat and slightly weathered. Strongly calcareous. No roots.

DHE086

Soil series: Balasan

Soil Taxonomy (1994): Petronodic Haplocalcid, fine loamy, mixed, isothermic.

Date: 30-10-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0.1 - 2%

Rock outcrops: none

Sealing/ crusting: nil

Effective soil depth: 0-95 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: Few, fine gravels and gravels

Drainage:

Moisture conditions: dry 0-115 cm

Land use: arable land (cereals, i.e. sorghum)

0-20	Ap	Silty clay loam, brown (10YR 5/3) moist, light yellowish brown (10YR 6/4) dry. Weak, very fine and fine, crumb structure. Soft (dry), very friable (moist), sticky and plastic (wet) consistence. Common, very fine and medium, interstitial pores and channels. Few rock fragments. Extremely calcareous. Few carbonatic concentrations. Few, fine roots. Abrupt, smooth boundary.
20-40	Ap2	Silty clay loam, dark yellowish brown (10YR 4/4) moist, pale brown (10YR 6/3) dry. Moderate, fine and medium, subangular blocky structure. Soft (dry), very friable (moist), sticky and plastic consistence. Common, very fine and medium, interstitial pores and channels. Few, fine, rounded rock fragments. Extremely calcareous. Few, medium roots. Abrupt, smooth boundary.
40-95	Cck1	Silty clay, dark yellowish brown (10YR 4/4) moist, pale brown (10YR 6/3) dry. Weak (mostly) and moderate, fine, subangular and angular blocky structure. hard (dry), very friable (moist), sticky and plastic consistence. Few, distinct, clay cutans on pedfaces. Continuous, weakly cemented compaction. Few, interstitial pores. Very few, fine, subrounded rock fragments. Extremely calcareous. Many concentrations: soft segregations, nodules and concretions, fine to coarse, spherical and irregular, soft and hard, nature; carbonate and gypsum. Few, fine, distinct, diffuse, reddish mottles. Very few, very fine and fine roots. Gradual, wavy boundary.
95-115	Cck2	Silty clay loam, yellowish brown (10YR 5/4) moist, pale brown (10YR 6/3) dry. Very weak, very fine, granular and angular blocky structure. Loose and hard (dry), very friable (moist), sticky and plastic consistence. Few, distinct, clay cutans on pedfaces. Continuous, weakly cemented compaction from carbonates/gypsum. Few, interstitial pores. Common, fine and coarse, subrounded rock fragments. Extremely calcareous. Many concentrations: soft segregations and concretions, fine to coarse, spherical and irregular, soft and hard, nature; carbonate and gypsum. Few, fine, distinct, diffuse, reddish mottles. No roots.

Analytical data for profile DHE086

Depth (cm)	Mechanical Analysis				pH paste	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC soil (Cmol/kg)	EC dS/m	CaCO ₃ (%)
	Sand	Silt	Clay	Texture Class							
0 - 20	24	49	27	L	8.0	4.7		2	23	0.39	17
20 - 40	20	35	45	C	8.0	3.8		0.4	28	0.37	13.8
40 - 95	26	47	27	CL	7.9	1.2		1	32	0.83	34.5
95 - 115	20	25	55	C	7.9	1.0		1	31	1.1	38.8

Depth (cm)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
			Na	K	Ca	Mg
0 - 20	0.4	0.3	1.2	0.14	3.2	1.6
20 - 40	0.4	0.3	1.1	0.10	2.8	1.6
40 - 95	0.9	0.3	2.7	0.15	4.8	2.4
95 - 115	1.0	0.3	4	0.14	6.8	1.6

DHE087

Soil series: Darb

Soil Taxonomy (1994): Calcic Petrocalcic, fine loamy, mixed, isothermic.

Date: 2-11-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0.1%

Rock outcrops: none

Sealing/ crusting: slight sealing

Effective soil depth: 30 cm

Parent material: alluvium and loess

FAO (1994): Eutric Leptosol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: common, gravel

Drainage: moderately well

Moisture conditions: dry 0-30 cm

Land use: rangeland

0-20	A1	Loam, brown (10YR 4/3) moist, brown (10YR 5/3) dry. Moderate, fine and medium, subangular blocky structure. Soft (dry), very friable (moist) slightly sticky and plastic consistence. Common, very fine and fine interstitial pores. Fine and medium, rounded and flat rock fragments. Strongly calcareous. Very few concentrations: fine, irregular, soft concretions and soft segregations. Common, very fine roots. Gradual, smooth boundary.
20-30	Ck	Yellowish brown (10YR 5/4) moist and light brownish grey (10YR 6/2) dry. Many, fine and medium pores. Dominant, medium and coarse, subrounded and flat, slightly weathered and weathered rock fragments. Extremely calcareous. Very few, fine roots.
30+	Cmk	Upper boundary of petrocalcic horizon

DHE088

Soil series: Tinnan

Soil Taxonomy (1994): Typic Haplocalcid, fine clayey, mixed, isothermic.

Date: 19-11-1996

Authors: Lotfi Al-Asbahi, Marleen Belder

Slope gradient: 0.1%

Rock outcrops: none

Sealing/ crusting: slight sealing

Effective soil depth: 100 cm

Parent material: alluvium and loess

FAO (1994): Cambic Calcisol

Location: Dhamar, AREA, western research farm, see map

Coordinates:

Surface stones: very few, fine gravel

Drainage: moderately well

Moisture conditions: dry 0-125 cm

Land use: rangeland

0-20	A	Loam, dark brown (10YR 3/3) moist, brown (10YR 5/3) dry. Moderate, fine and medium, subangular blocky structure. Soft (dry), very friable (moist) sticky and plastic consistence. Common, very fine pores. Very few, fine, subrounded rock fragments. Moderately calcareous. Common, fine roots. Abrupt, smooth boundary.
20-50	2Ab	Silty clay to silty clay loam, very dark greyish brown (10YR 3/2) moist and dry. Moderate, fine and medium, subangular and angular blocky structure. Slightly hard (dry), friable (moist), very sticky and very plastic consistence. Few, faint, clay cutans on pedfaces. Many, fine and medium pores. Concentrations: few, fine, irregular, soft, carbonate, filaments. Slightly calcareous. Many, very fine roots. Clear, wavy boundary.
50-75	2Bk1	Silty clay, light yellowish brown (10YR 6/4) moist, very pale brown (10YR 8/2) dry. Weak, fine, subangular and angular blocky structure. Slightly hard (dry), very friable (moist), very sticky, plastic consistence. Common, fine pores. Concentrations: many, medium, irregular and angular, carbonatic soft segregations and nodules, both soft and hard. Extremely calcareous. Very few, very fine roots. Gradual, wavy boundary.
75-125	2Bk2	Silty clay, dark yellowish brown (10YR 4/4) moist, brown (10YR 5/3) dry. Moderate, fine and medium, subangular and angular blocky structure. Slightly hard (dry), very friable (moist), very sticky, plastic consistence. Few, faint clay cutans on pedfaces. Common, fine and medium pores. Concentrations: common, medium, irregular and angular, carbonatic soft segregations and nodules, both soft and hard. Extremely calcareous. Very few, very fine roots.

Analytical data for profile DHE088

Depth (cm)	Mechanical Analysis				pH paste	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC soil (Cmol/kg)	EC dS/m	CaCO ₃ (%)
	Sand	Silt	Clay	Texture Class							
0 - 20	23	52	25	SiL	8.1	3.7		4		0.33	1.8
20 - 50	14	29	57	C	7.6	4.0		3		0.83	20.5
50 - 75	14	30	56	C	7.6	1.7		5		1.0	48.5
75 - 125	17	52	31	SiCL	7.7	4.9		2		0.52	17

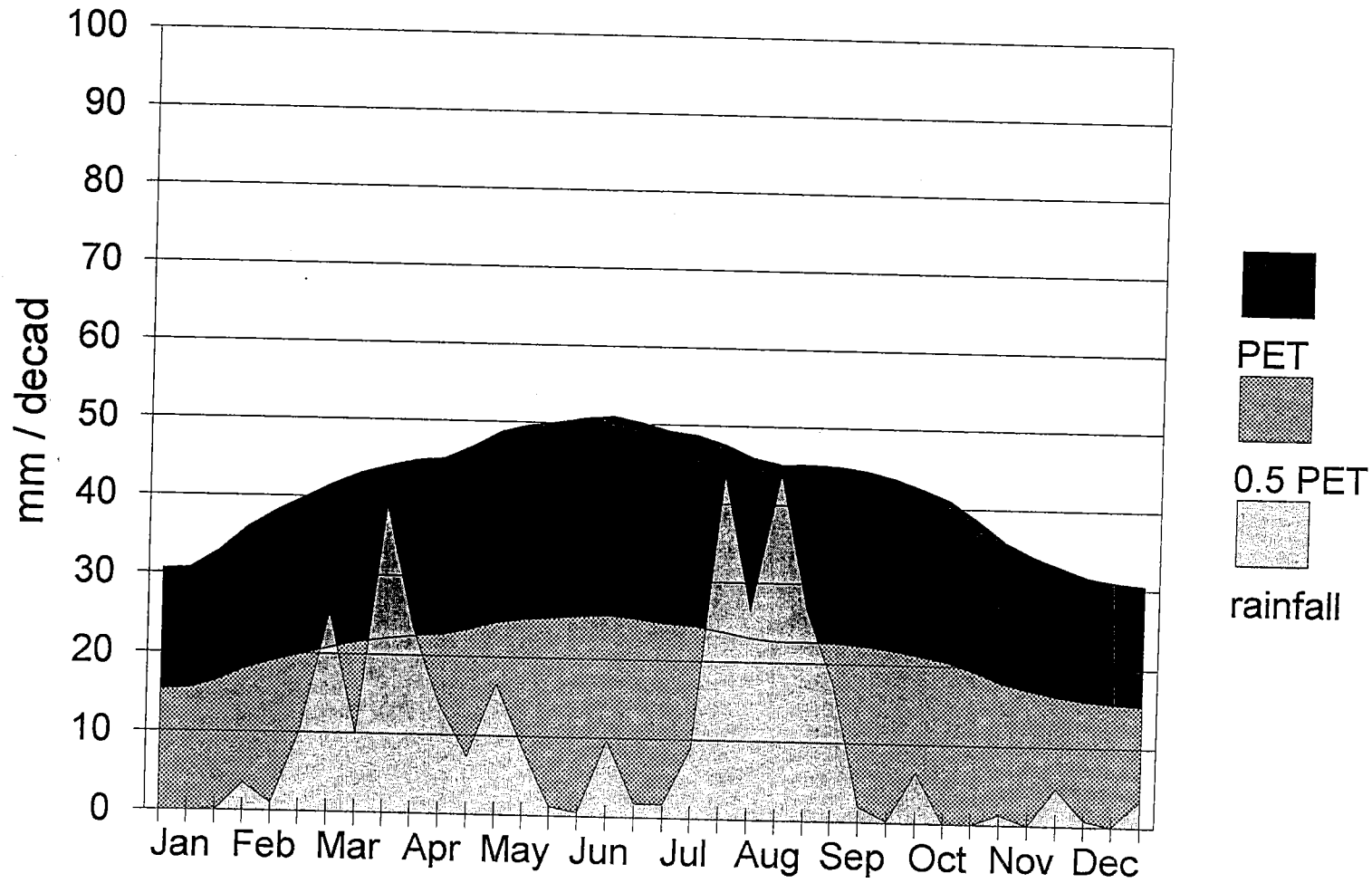
Depth (cm)	Exchangeable Na (cmol/kg)	Exchangeable K (cmol/kg)	Soluble Cations and Anions (cmol/l saturated extract)			
			Na	K	Ca	Mg
0 - 20	0.5	0.3	1.3	0.16	2.4	1.6
20 - 50	0.8	0.3	2.7	0.16	5.6	2
50 - 75	0.6	0.2	3.3	0.15	6.4	2.8
75 - 125	0.4	0.3	1.1	0.17	4.4	1.6

APPENDIX 2
CLASSIFICATION CHART FOR SOIL TAXONOMY

CLASSIFICATION OF SOILS ACCORDING TO SOIL TAXONOMY AND ITS RELATED SOIL SERIES

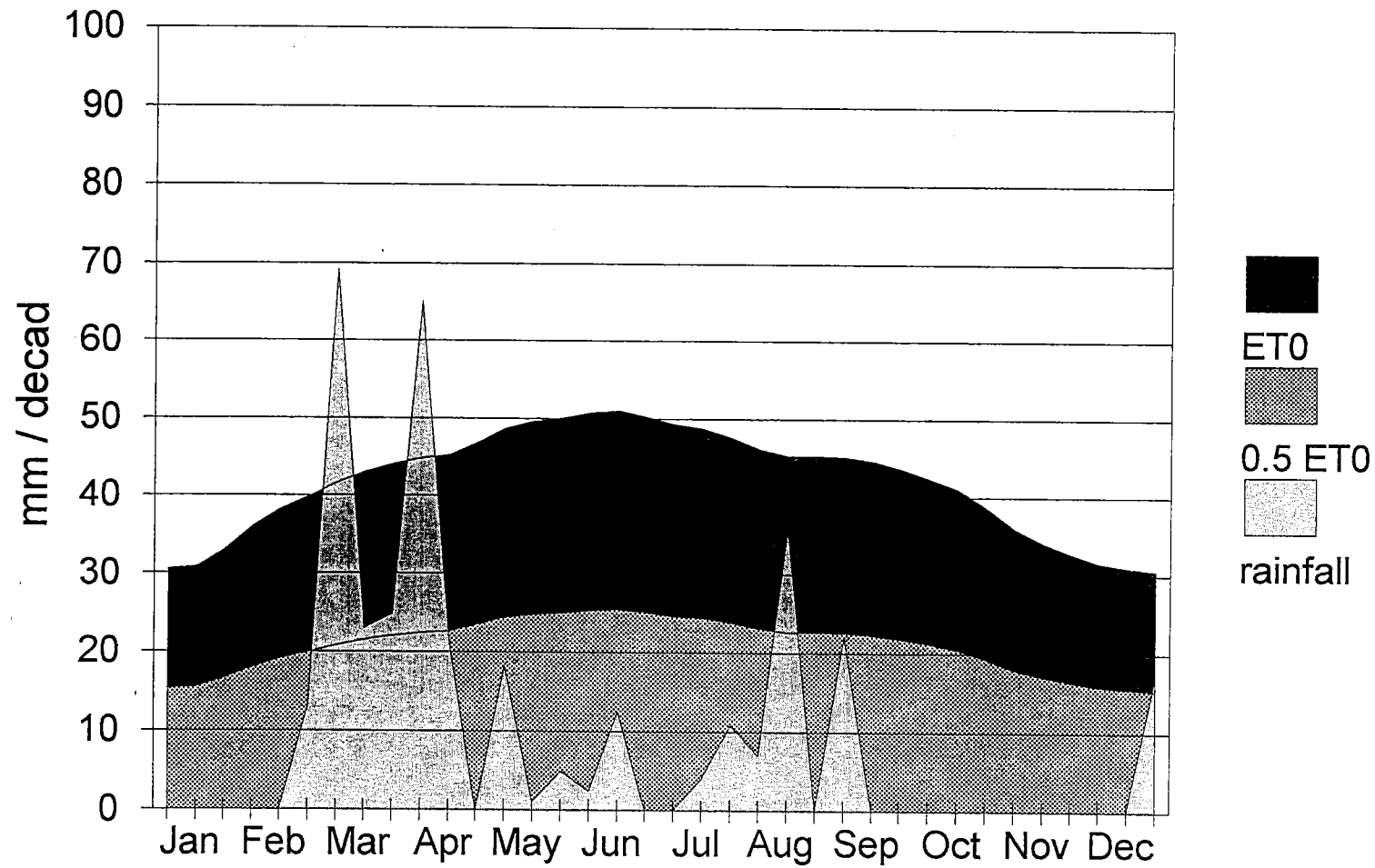
ORDER	SUBORDER	GROUP	GREAT GROUP	FAMILY	SERIES
Entisols	Orthents	Torriorthents	Lithic Torriorthents	Lithic Torriorthents, fine loamy, (iso)thermic	Yafa
Aridisol	calcids	petrocalcids	calcic petrocalcids	Calcic Petrocalcids, fine loamy, (iso)thermic	Darb
Aridisol	calcids	haplocalcids	petronodic haplocalcids	Petronodic Haplocalcids, fine loamy, (iso)thermic	Balasan, Wasitah
Aridisol	cambids	haplocambids	typic haplocambids	Typic Haplocambids, fine clayey, (iso)thermic	Tinnan

Growing period zone 6, Dhamar



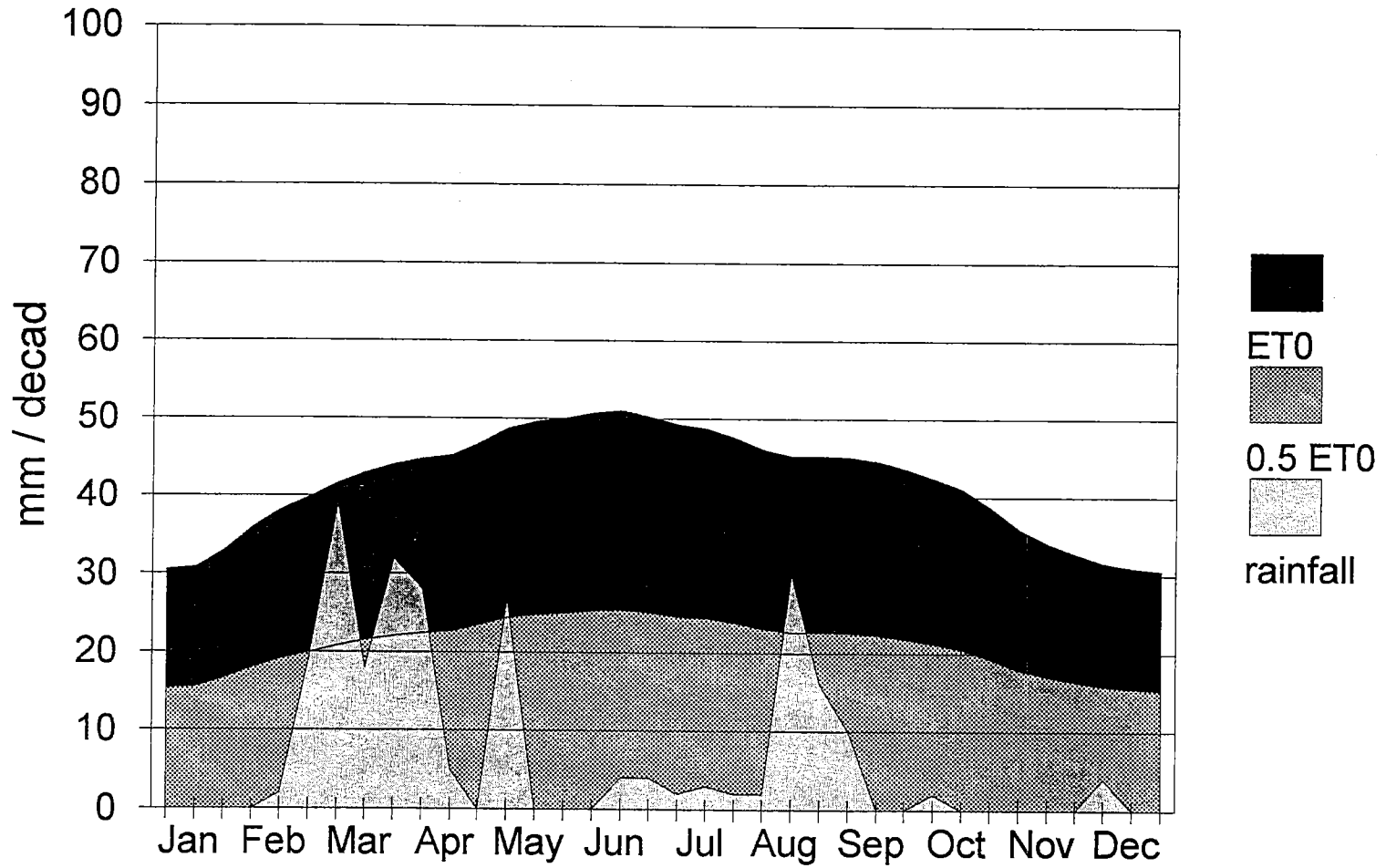
LGP - median year (1987)

Zone 6 - Dhamar



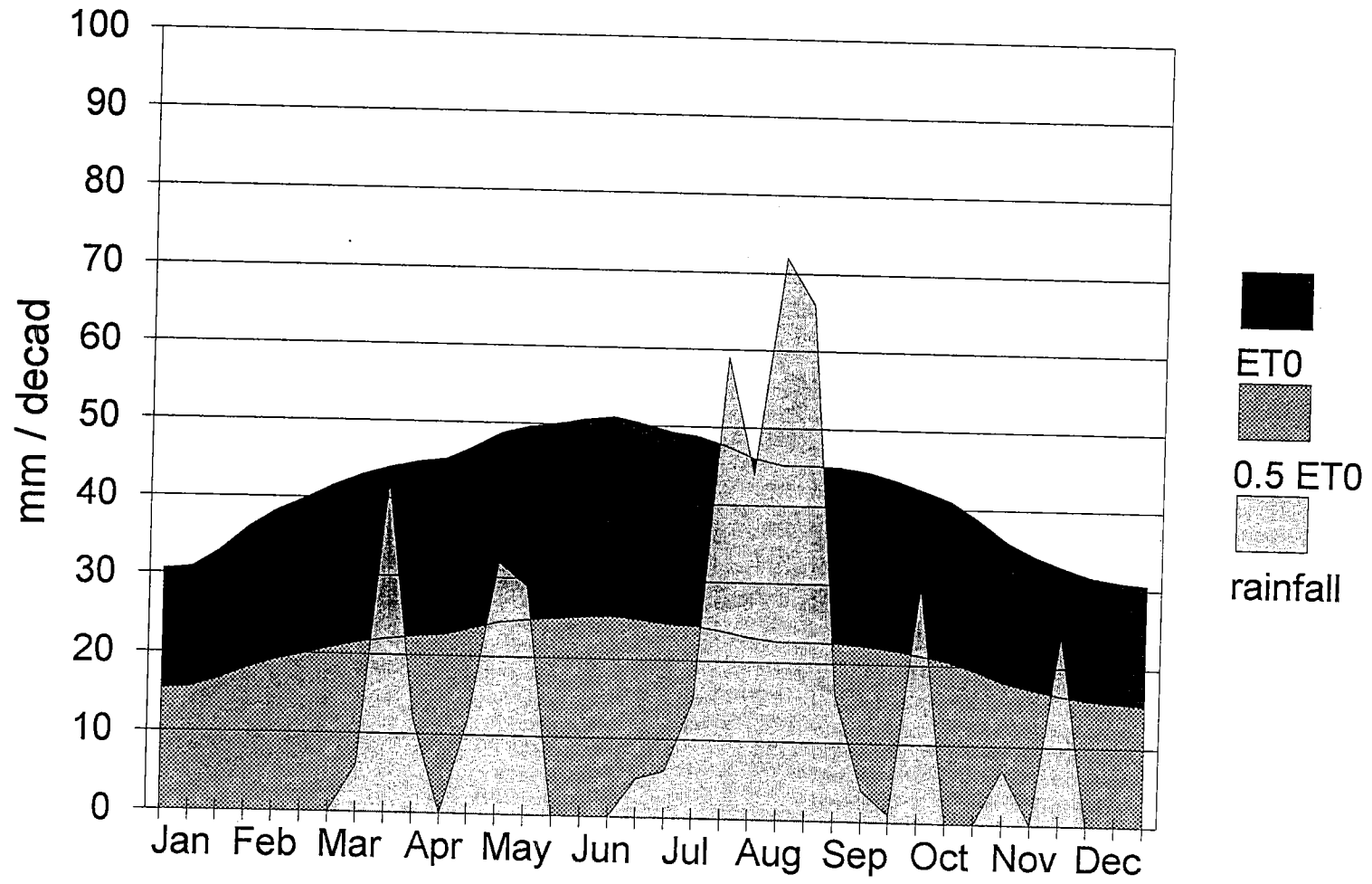
LGP - dry year (1991)

Zone 6 - Dhamar



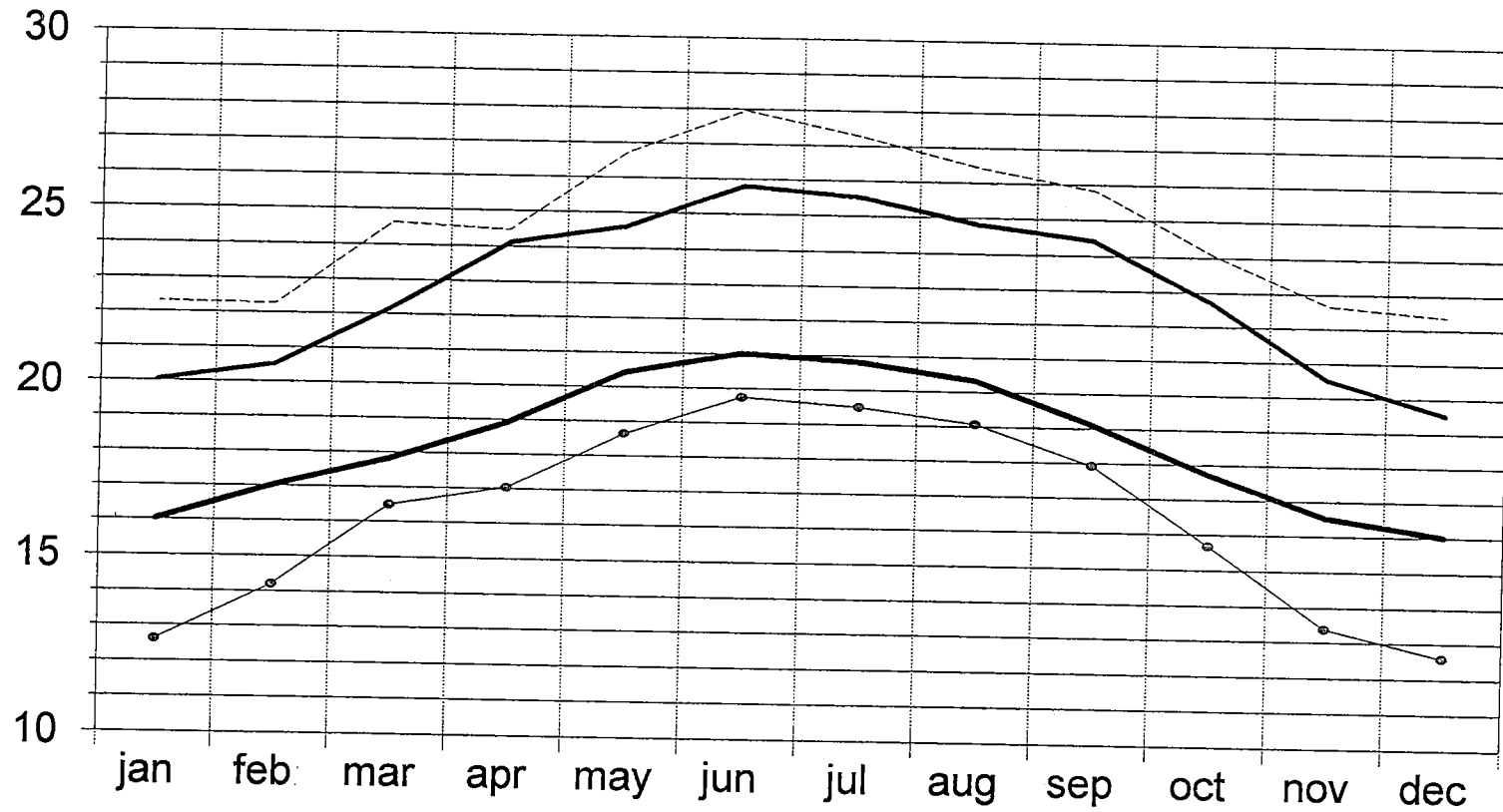
LGP - wet year (1992)

Zone 6 - Dhamar



Dhamar

relation soil and air temperatures



—○— T mean

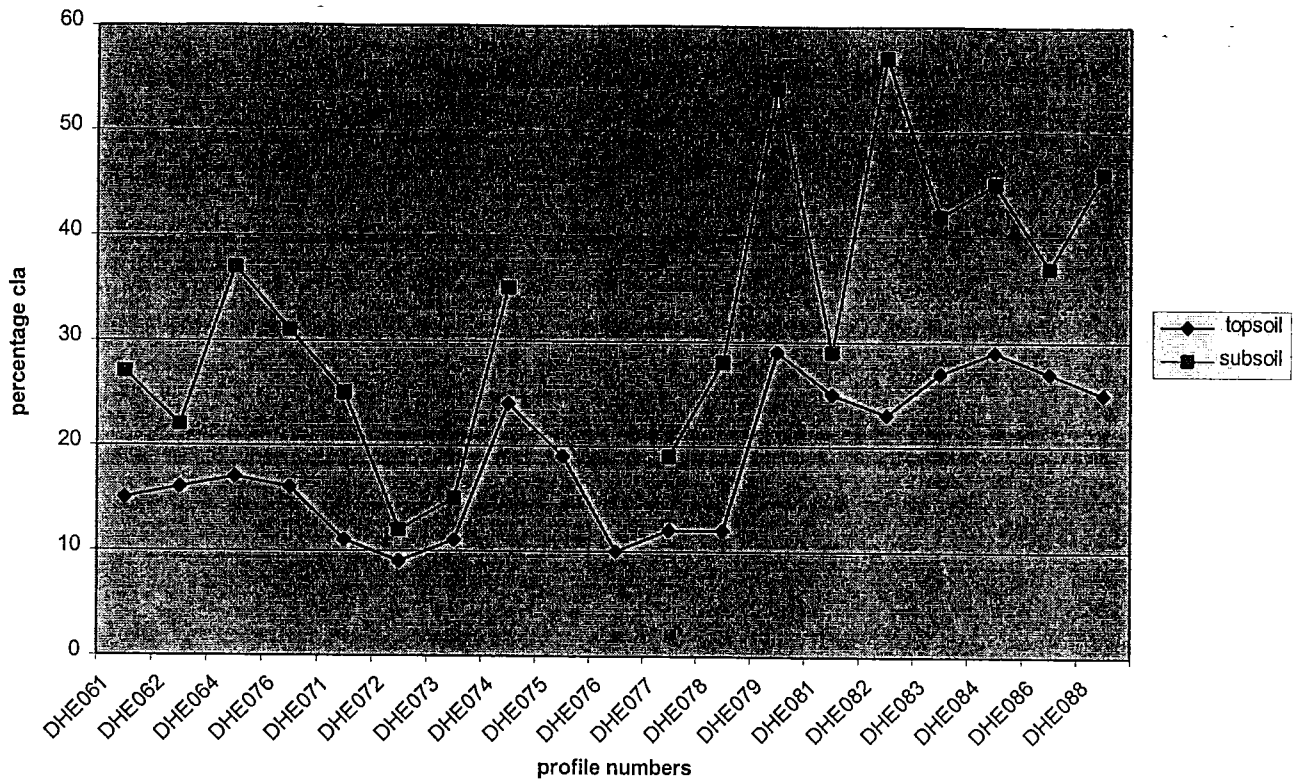
----- T maximum

—— T soil - 20 cm

—— T soil - 50cm (estimated)

APPENDIX 4 TEXTURE CHARTS

clay percentage in topsoil and subsoil for 19 profiles



silt percentage in topsoil and subsoil for 19 profiles

