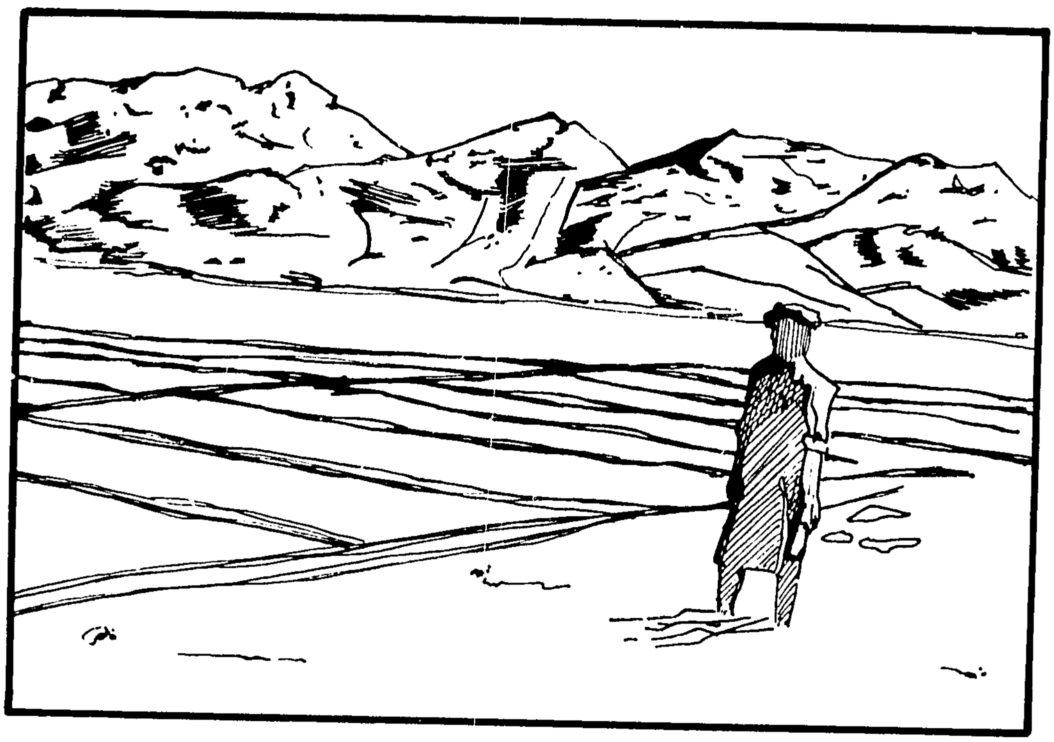
New York State College of Agriculture and Life Sciences
Cornell University
Department of Agronomy

Soil Management Support Services (SMSS)
Soil Conservation Service
U.S. Department of Agriculture

Ministry of Agriculture
Yemen Arab Republic

BENCHMARK SOILS OF THE YEMEN ARAB REPUBLIC
World Benchmark Soils Report No. 1. October 1985.

Jack W. King, Jr.
Terence R. Forbes
Abdul Elah Abu Ghanem



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SOIL MANAGEMENT SUPPORT SERVICES

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Agency for International Development

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FOREWORD

Soil Resource Inventories are the basis for agrotechnology transfer and for national or regional planning. To permit world-wide transfer of agrotechnologies, it is desirable to have inventories developed with the same or similar methodologies. Recent studies by the International Soils Research and Reference Centre, Wageningen, Netherlands, has shown a wide disparity in the quality of soils data from laboratories throughout the world.

The Soil Management Support Services (SMSS) perseveres to assist national institutions in developing countries in making reliable and reproducible soil characterization data and also in making quality soil surveys. There are several indications that in many instances, soil resource inventories are not used due to unreliability or other reasons despite their high cost of production.

In many developing countries, facilities are not available for detailed soil characterization. In some countries, soils of agricultural research stations have never been characterized making the agronomic research site-specific and with the associated problem of not being able to transfer the results of the research to other areas.

When requested, SMSS has been assisting countries to characterize the soils of their major research stations. SMSS also provides technical assistance to soil survey programs.

This monograph on the *Benchmark Soils of the Yemen Arab Republic* is the first of a series in the *Benchmark Soils of the World* to be published by SMSS. Through such monographs, we hope to develop a database of world soils. The soil survey of Yemen was conducted by Cornell University in collaboration with the Ministry of Agriculture of the Yemen Arab Republic, with funding from the Agency for International Development. Separate and more detailed reports of the soil resources of Yemen have been published and are available from the Ministry of Agriculture, YAR.

Hari Eswaran
Program Leader SMSS
November, 1985

PREFACE

Until present, only limited information was available on the soils of the Yemen Arab Republic. The few soil surveys that had been conducted previously were not sufficient or adequately correlated in a national or international system to serve development needs. They varied in degree of detail, and required complementary studies to respond to an increasing demand for soil resource information. This reduced their usefulness and restricted the transfer of technical knowledge from other areas in the world with similar ecological conditions.

The original project involved the mapping of soils of the Yemen Arab Republic. The resulting soil survey is an important part of the data base for planning the development of agriculture and urban infra-structures in North Yemen. The survey will assist in locating areas of high potential where more detailed soil information would facilitate the introduction of new technology for agricultural production.

The objective of the soil survey was to produce a generalized 1:500,000 scale soil map based on field observations, which were also extrapolated by interpretations of satellite and air-photo imagery. The map shows associations of subgroups as recognized by *Soil Taxonomy* (USDA, 1975). The project mapped those areas of Yemen west of longitude 45 degrees, 30 minutes. The survey area does not include islands in the Red Sea.

For eighteen months, one soil surveyor with support equipment and personnel was stationed as a staff member of the Agronomy Department at Cornell in Yemen with operations based in Taizz. Field work included soil profile examination and mapping. Soil analyses were required to place the soils into *Soil Taxonomy* classification. Representative soil profiles were sampled, tested, and described throughout Yemen as part of this effort. The surveyor was assisted by Yemeni personnel, both professional and nonprofessional. Soil samples were analyzed by the FAO-assisted Agricultural Research Service at Aussefeire; some special, texture, and mineralogical analyses were performed at Ithaca. Three soil profiles were analyzed by the National Soil Survey Laboratory (USDA-SCS) at Lincoln, Nebraska.

This report begins with a synopsis of soil-forming factors and the genesis and classification of the soils of North Yemen (Chapter 1). This is followed by a brief description of the field survey and laboratory methods (Chapter 2) and the soil map legend (Chapter 3). Part of the legend information includes estimated total areas (km^2) of each map unit, subgroup, and soil order. A complete soil map (1:500,000) is found in a pocket on the back cover. Chapter 4 provides information for soil interpretations and management considerations. Finally detailed descriptions of the most important benchmark soils are given in the Appendix. It is hoped that all this information will provide the reader with a clear picture of Yemeni soils, their environment and their use.

CHAPTER 1

SOIL-FORMING FACTORS AND THE GENESIS AND CLASSIFICATION OF SOILS IN YEMEN

Climate

The climate of the Yemen Arab Republic is characteristic of arid and semi-arid tropical areas. Rainfall is seasonal and variable, and its quantity is primarily controlled by the effects of the mountains. Weather and climate data are very scarce.

Rainfall varies from approximately 1000 mm/yr in the Ibb area to near 0 mm/yr along the Tihama and in the Rub Al Khali. A probable modal rainfall map is shown in Map 1.1. The largest amounts of rainfall are associated with the western and central highlands as humid winds from the Indian Ocean and Red Sea are forced to rise and cool. Once past the highest mountains, the winds have lost most of their moisture and rainfall decreases rapidly to the east.

Temperature in Yemen is strongly influenced by elevation. The yearly average ranges from approximately 11°C at Rabat to 26°C at Al Hudaydah on the coast.

High potential evapotranspiration rates, resulting from high temperatures (Figure 1.1), are somewhat moderated on the Tihama by the high relative humidity. Extremely dry conditions with dessicating winds, as found in Sahelian Africa, are not common.

Freezing weather seldom occurs in the lowlands. However, nighttime freezing weather is common in some of the highland areas. For example, at the Kitab dairy on the Dhamar Plain one hundred consecutive nights of freezing temperatures were recorded. The lowest recorded temperature at Kitab is -9°C.

Soil Climate Regime Estimations for Yemen

The estimation of soil moisture and soil temperature regimes in Yemen is crucial for the correct classification of soils according to *Soil Taxonomy* (USDA-SCS, 1975). Newhall (1972) developed a computer program to make these estimates, using monthly temperature and rainfall data. However, these data are scarce. Monthly rainfall data are available for a few years at forty sites in Yemen (Map 1.2), while monthly temperature data have been recorded at nine sites only. To make full use of the data available, the sites with temperature data were used to correlate temperature with elevation, and this relationship was applied to estimate soil temperatures at sites with known elevations.

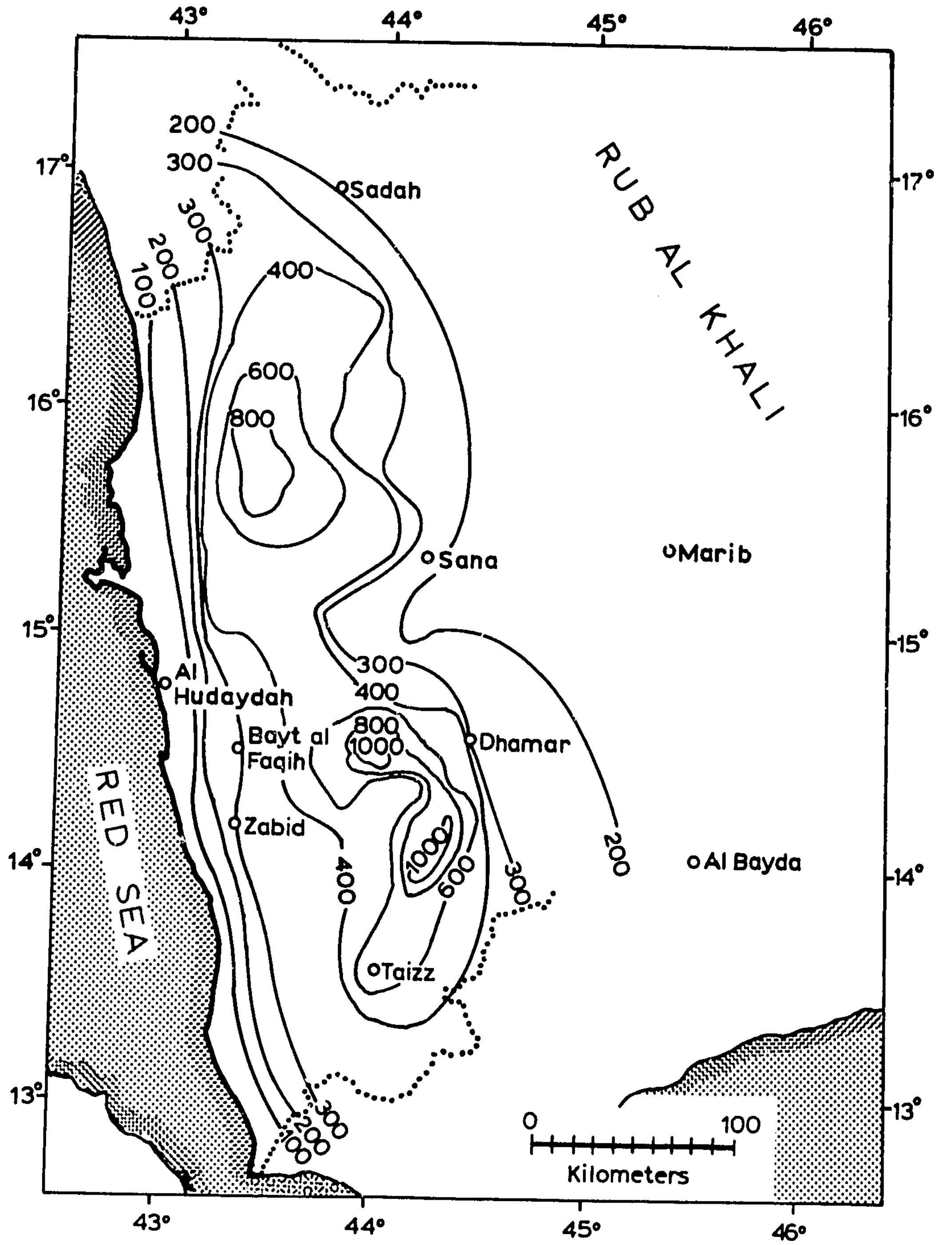
Estimation of Soil Temperature Regimes by Elevation of Site

Nine stations in Yemen have mean annual air temperature and elevation data available (Table 1.1). The mean annual soil temperature was estimated from the mean annual air temperature by adding 2.5°C. These data were statistically processed and regression equations were determined for elevation and mean annual soil temperature.

The highest R (± 96%) value was achieved with an equation involving elevation and elevation squared terms. This equation is $T=32.1-0.069E-0.022E^2$, where T is the mean annual soil temperature in degrees Celsius and E is elevation in hectometers (=100 m). However, this equation was found to result in altitude boundaries for temperature regimes at elevations that were clearly out of line with field experience in Yemen. The most important reason for this was probably the lack of data in the 100–2000 m elevation range—only Taizz data at 1500m are available.

In order to select the best regression equation other climatic data were considered. The temperature decrease with elevation is primarily a result of adiabatic cooling as winds from the Red Sea and Gulf of Aden rise over the mountains. The adiabatic cooling rate (also known as the lapse rate) is linear, depending on the amount of moisture in the air mass. For dry air masses, the adiabatic lapse rate is 1°C per 100 meters elevation. For wet air masses, the lapse rate can be as low as 0.4°C/100 m (Petterssen, 1940). The adiabatic heating rate (when an air mass descends into a valley) is the same for both wet and dry air masses, and it is the dry adiabatic lapse rate, 1.0°C/100 m.

Applied to this situation, the adiabatic lapse rates suggest that a linear rate would serve satisfactorily as a



Map 1.1: Probable r[illegible]al rainfall map for Yemen.

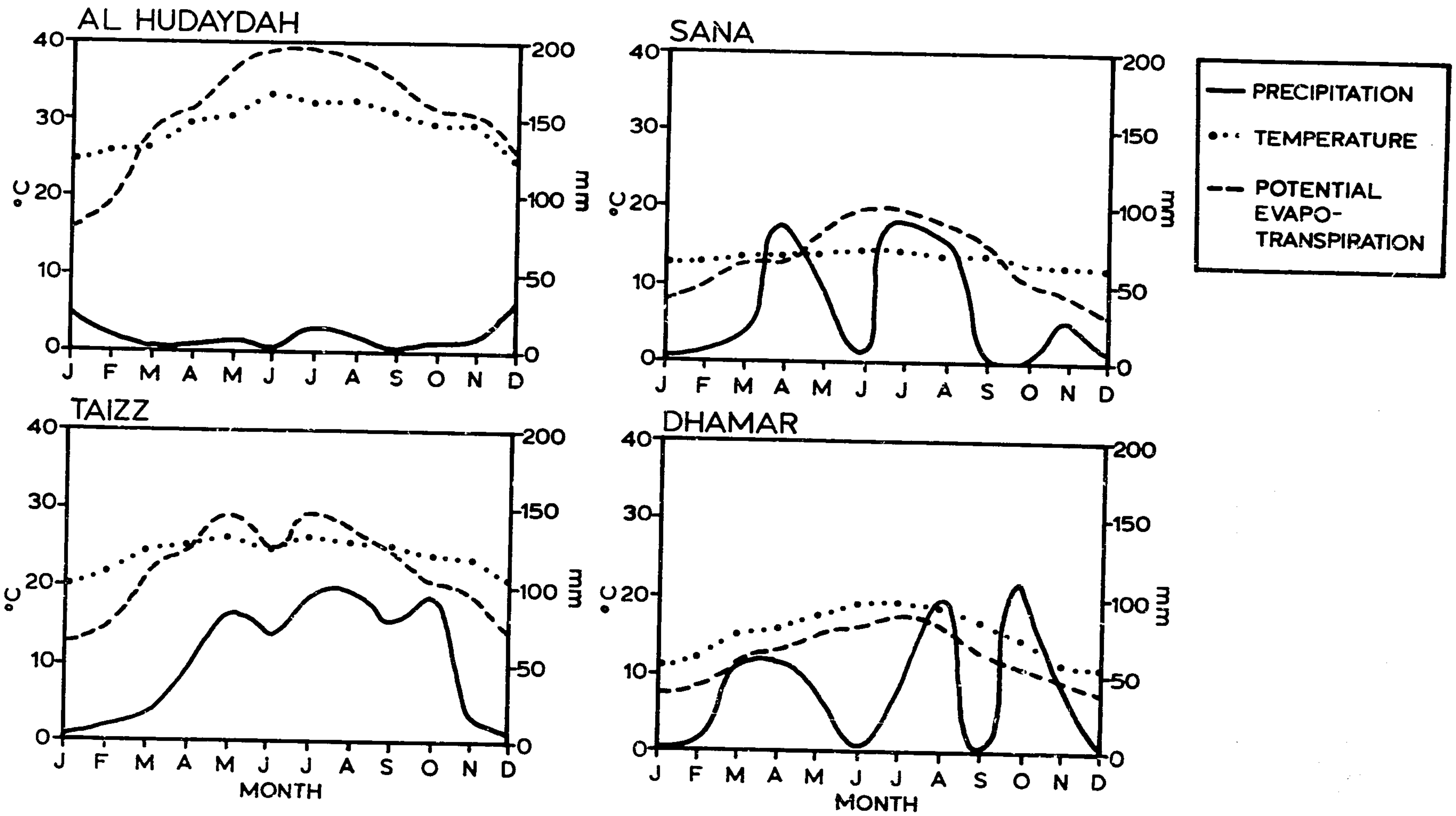
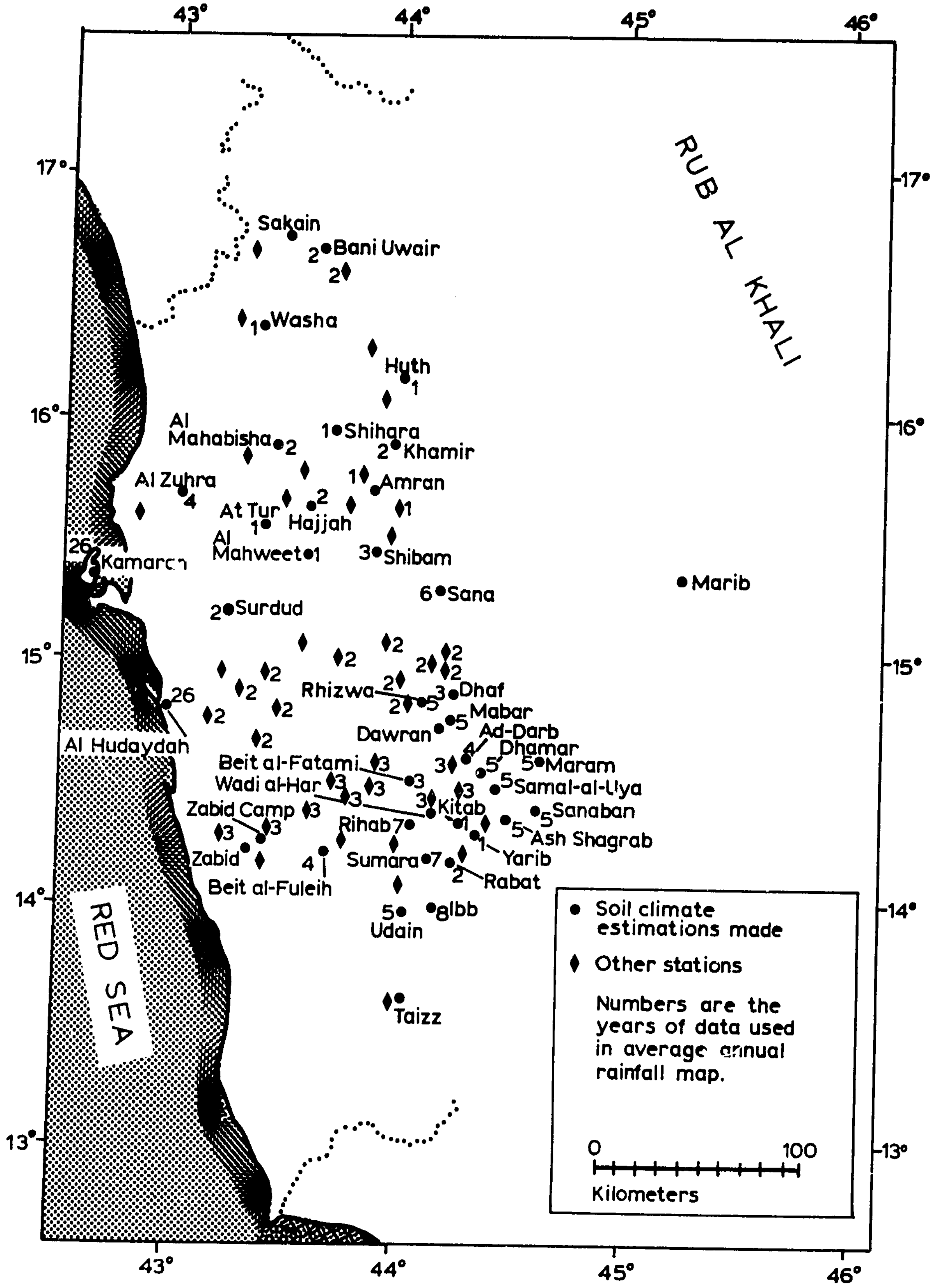


Figure 1.1: Precipitation, temperature and potential evapotranspiration for four stations in Yemen.



Map 1.2: Weather recording stations in Yemen.

Table 1.1: Observed annual air temperature, estimated mean annual soil temperature and elevation for nine stations in Yemen.

Stations	Observed mean annual air temp. (°C)	Estimated mean annual soil temp. (°C)	Elevation (m)	Source	Years of data
Al Hudaydah	29.6	32.1	13	1	26
Kamaran	29.6	32.1	20	1	26
Al Zuhra	30.0	32.5	70	5	6
Taizz	23.6	26.1	1500	3	10+
Amran	14.6	17.1	2190	4	1
Sana	15.1	17.6	2300	?	6
Kitab	10.9	13.4	2550	4	1
Ma'bar	15.3	17.8	2583	2	2
Rabat	11.4	13.9	2743	2	2

Sources: 1-Naval Weather Services. 1974. Worldwide Airfield Summaries.
2-Land Resources Development Centre. 1979. Montane Plains and Wadi Rima Project Report.
3-Wernstedt, F. 1972. World Climatic Data.
4-Gibb, Sir Alexander and Partners. 1979. Development of Wadis Bana and Rasyan, Stage I.
5-Tipton and Kalmbach, Inc. 1979. Development of Wadi Mawr. Appendix B.

general lapse rate for Yemen. This linear approximation is best for areas along the mountain front, where adiabatic cooling is most important. It is less accurate for highland areas, particularly in areas of steep relief. In these areas, adiabatic heating and cooling take place at varying rates as the air rises and falls over the topography.

A linear equation was used to approximate the lapse rate for Yemen. The equation is T=32.9-0.657E where T= estimated annual soil temperature in degrees Celsius and E is elevation in hectometers. The lapse rate is 0.657°C/100m. This is about midway between the wet and dry adiabatic lapse rates. The correlation coefficent for the linear regression is 94%.

The equation given above was used to assign soil temperatures to elevations. Thus soil temperature regimes can be assigned to elevation ranges. These elevation ranges are given in Table 1.2. Using Table 1.2, soil temperature regimes can be estimated for sites where only elevations are known. A soil temperature regime map based on this table is given in Map 1.3.

Table 1.2: Elevation ranges for iso-temperature regimes (*Soil Taxonomy*, 1975) appropriate for the classification of soils in Yemen.

Temperature regime	Range of mean annual soil temperature (°C)	Estimated range of elevations (m)
Isomesic	8-15	3790-2725
Isothermic	15-22	2725-1660
Isohyperthermic	22-28	1660-745
Isomegathermic*	>28	745 and below

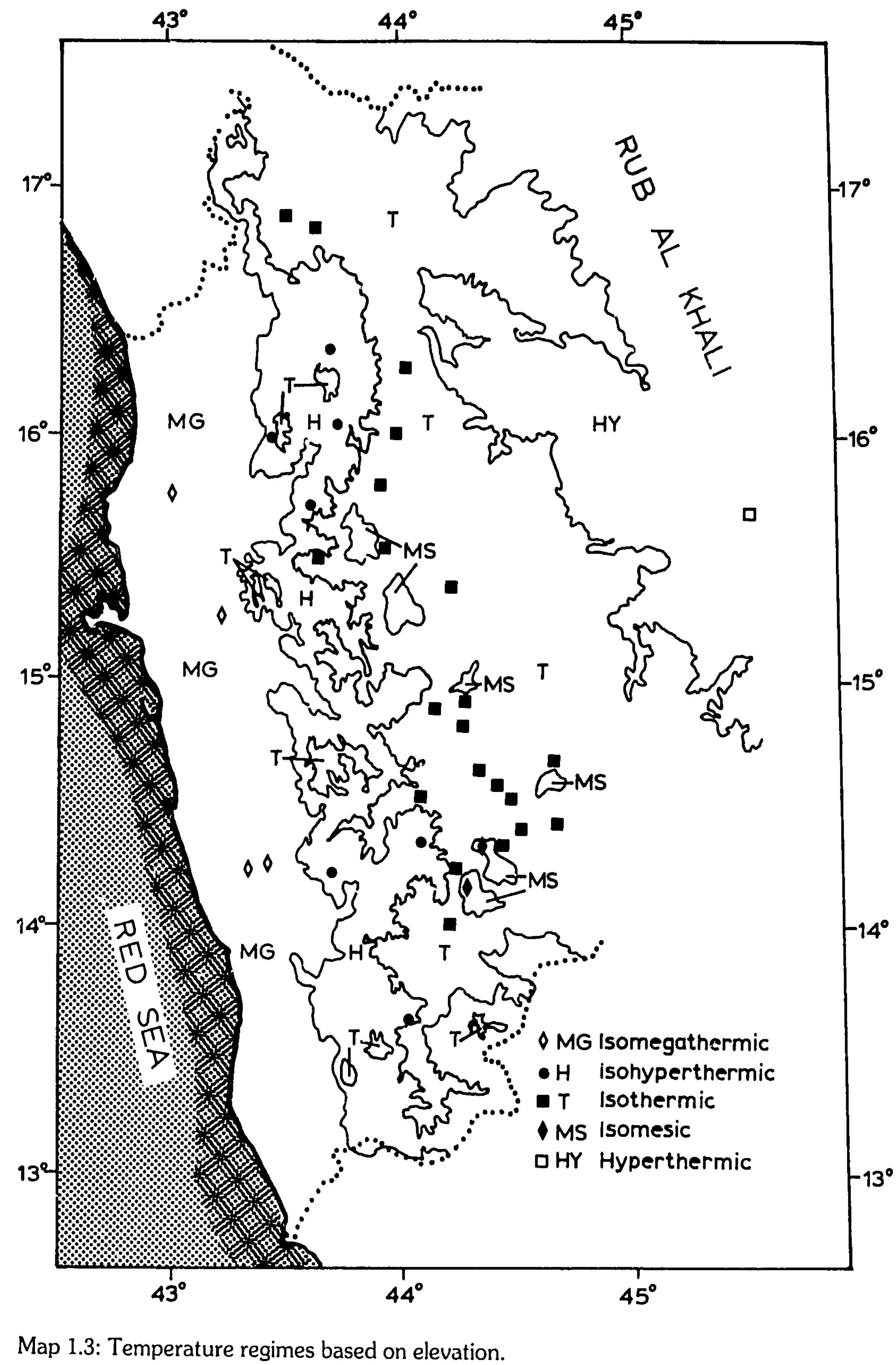
*proposed new soil temperature regime

Using Table 1.2, the elevation of Kitab suggests that Kitab should be isothermic. However, the results for the year for which data are available show Kitab as isomesic. Kitab is known for its unusually cold temperatures. This may be a result of the immediate topography around Kitab. This points out the care with which these estimates should be used. The generalizations made here need to be interpreted in the light of each individual situation.

For most stations for which average monthly temperature data were available, the temperature regimes calculated are iso-temperature regimes. This means that there is little seasonal difference (less than 5°C between winter and summer) in the soil temperature. Al Zuhra, for which monthly temperatures for individual years were available, was iso- two years and non-iso another two years. Ma'rib, for which data are a combination of observed data and data derived from the patterns of nearby stations (Agrar und Hydrotechnik, 1980) is also non-iso, as are nearby stations in Saudi Arabia and South Yemen. These data suggest that latitude and location either east or west of the mountains are the primary influences on whether or not an area is iso or non-iso. However, insufficient data make it difficult to clearly delineate the boundary in Yemen. For the purposes here, it is assumed that all temperature regimes to the west of the eastern thermic/hyperthermic boundary are iso-, while the area to the east of this boundary are not.

Estimation of Soil Moisture Regimes

Two computer programs were available to estimate soil moisture regimes for Yemen. The first uses mean monthly temperature and rainfall data averaged over a number of years to estimate a single soil temperature and moisture



Map 1.3: Temperature regimes based on elevation.

Table 1.3: Elevation and estimated soil moisture regimes for sites with monthly rainfall data in Yemen.

Site	Elevation (m)	Number of years of data	Calculated mean annual soil temperature	Estimated temperature regime	Estimated moisture regime
Ad-Darb	2750	4	15.0	Isomesic	Ustic
Al Mahabisha	1600	2	22.5	Isohyperth.	Ustic
Al Mahweet	2100	1	19.3	Isothermic	Ustic
Ash-Shagrab	2770	5	14.9	Isomesic	Aridic
At Tur	200	2	31.8	Isohyperth.	Ustic
Bani Uwair	2100	2	19.3	Isothermic	Aridic
Beit Al Fatami	2000	5	19.9	Isothermic	Aridic
Beit Al Fuleih	800	4	27.8	Isohyperth.	Aridic
Dawran	2900	2	14.0	Isomesic	Udic
Dhaf	2625	3	15.8	Isothermic	Aridic
Dhamar	2770	5	14.9	Isomesic	Ustic
Hajjah	1650	2	22.2	Isohyperth.	Ustic
Huth	1850	2	20.9	Isothermic	Aridic
Ibb	1800	8	21.2	Isothermic	Udic
Khamir	2350	2	17.6	Isothermic	Ustic
Maram	2375	5	17.4	Isothermic	Aridic
Rhizwa	2400	5	17.3	Isothermic	Aridic
Rihab	1500	7	23.2	Isohyperth.	Aridic
Sakain	2230	2	18.4	Isothermic	Ustic
Samah-Al-Uya	2500	5	16.4	Isothermic	Aridic
Sanaban	2300	5	16.6	Isothermic	Aridic
Shibam	2650	2	15.6	Isothermic	Ustic
Shihara	1250	1	24.9	Isohyperth.	Aridic
Sumara	1800	7	21.1	Isothermic	Ustic
Surdud	250	2	31.5	Isohyperth.	Aridic
Udayn	1500	6	23.2	Isohyperth.	Aridic
Wadi Al Har	2300	1	17.9	Isothermic	Aridic
Washa	500	1	29.8	Isohyperth.	Aridic
Yerim	2400	8	17.3	Isothermic	Ustic
Zabid	240	6	31.5	Isohyperth.	Aridic
Zabid Camp	240	10	31.5	Isohyperth.	Aridic

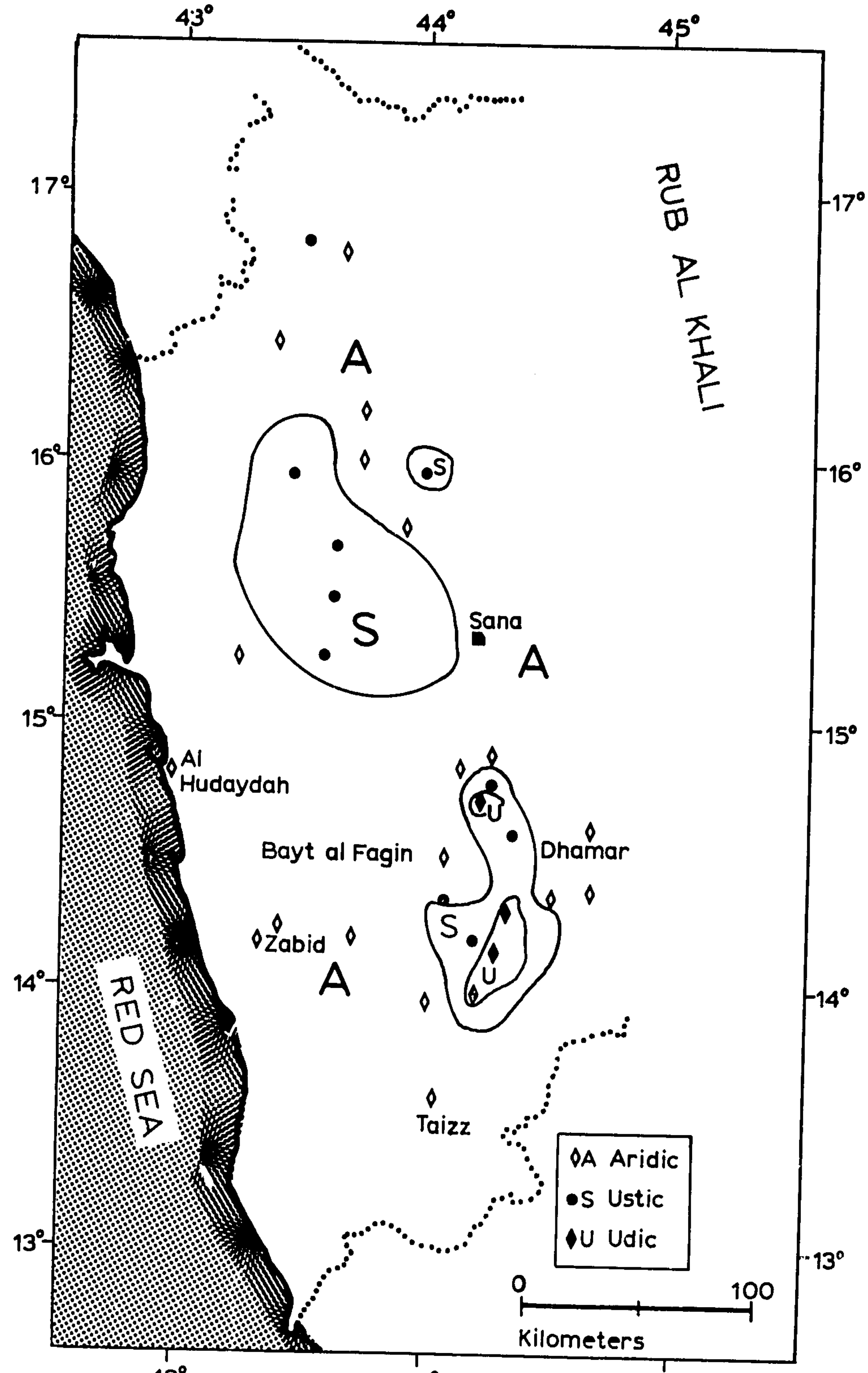
regime for that set of years. The second uses data from each of several years individually to produce a separate temperature and moisture regime estimate for each year. Both programs print out soil moisture calendars for the years for which they estimate temperature and moisture regimes. The second program also gives an overall estimate of the temperature and moisture regimes for the years given based on a "truth table," which tests the moisture calendars for the probability of occurrence of moisture conditions specified in the definitions of *Soil Taxonomy*.

Monthly rainfall and elevation data were available for the stations listed in Table 1.3. The mean monthly air temperatures were calculated by producing linear regression equations for each of the twelve months in the manner described for annual soil temperatures. The calculated temperatures were then used in estimating the soil moisture and temperature regimes.

A summary of the estimated temperature and moisture regimes are given in Tables 1.3 and 1.4. Table 1.4 gives results for stations for which observed temperature data are available, and Table 1.3 gives results for stations for which temperature data were calculated on the basis of elevation. Map 1.4 shows the estimated soil moisture regimes.

Limitations of the Model in Yemen

The Newhall model used in making the soil climate estimations has several important limitations when applied to Yemen. It assumes that there are no significant gains or losses of rainfall due to runoff or inflow. This is commonly not the case in Yemen, particularly along the Tihama



Map 1.4: Estimated soil moisture regimes of Yemen.

Table 1.4: Results for sites with observed rainfall and precipitation data.

Site	Estimated temperature regime	Estimated moisture regime
Al Hudaydah	Isohyperthermic	Aridic
Al Zuhra	Isohyperthermic	Aridic
Amran	Isothermic	Aridic
Kamaran	Isohyperthermic	Aridic
Kitab	Isomesic	Udic
Ma'bar	Isothermic	Ustic
Rabat	Isomesic	Udic
Sana	Isothermic	Aridic
Taizz	Isohyperthermic	Aridic

mountain front and along wadis in the mountains. Much of the precipitation along the Tihama mountain front probably flows onto the Tihama before it can infiltrate into the subsoil. Therefore, the ustic areas along the mountain front may be drier than predicted by the model and the wadi areas near the front are probably more moist.

The same may be true in areas along mountain wadis. However, in the mountains, water runoff is significantly affected by terracing. Water remains in the terraces more readily than it would on an unterraced slope. The computer-estimated moisture regimes probably are more accurate in terraced areas because the precipitation is made more effective by the terraces. In water-harvesting situations, terraced areas may be moister than predicted by the computer model.

Geology

This information is adapted from reports by Geukens (1966) and Grolier and Overstreet (1978).

The Yemen Arab Republic includes four major geologic provinces: 1) the Precambrian shield areas, 2) sedimentary rocks of Paleozoic and Mesozoic ages, 3) Tertiary and Quaternary volcanics, and 4) Quaternary alluvial deposits.

A generalized geologic map is given in Map 1.5.

Precambrian Shield

The Precambrian shield, composed of igneous and metamorphic rocks, is the basement of the Arabian peninsula. The igneous rocks include pink orthoclase granites, diorite, gabbro, and mafic volcanics. Metamorphic rocks include mica, chlorite and garnet schists, gneiss, quartzite, marble, slate, and amphibolite. The structure of the shield is very complex, because the rocks have been folded and faulted several times.

Sedimentary Rocks

There are three sets of sedimentary rocks in Yemen: the Wajid sandstone, the Kohlan and Amran groups, and the Taliwah and Medj-Zir groups, going from oldest to youngest.

All of the sedimentary rock groups are approximately horizontal. The Wajid sandstone rests directly on the Precambrian shield. The Kohlan group is also in contact with basement rocks. The Kohlan and Amran groups and the Taliwah and Medj-Zir groups are conformable. The Amran and Taliwah groups are unconformable.

WAJID SANDSTONE

The Ordivician Wajid sandstone is a cross-bedded, coarse-grained, well-rounded, quartz sandstone. It includes frequent conglomeratic gravel lenses. The grain size decreases to the north. It contains no fossils.

The Wajid sandstone outcrops in the dry northern area. They are less rugged than the Taliwah areas, with broader plains between mountains. Some agriculture is found on these plains, where rainfall or groundwater supplies permit.

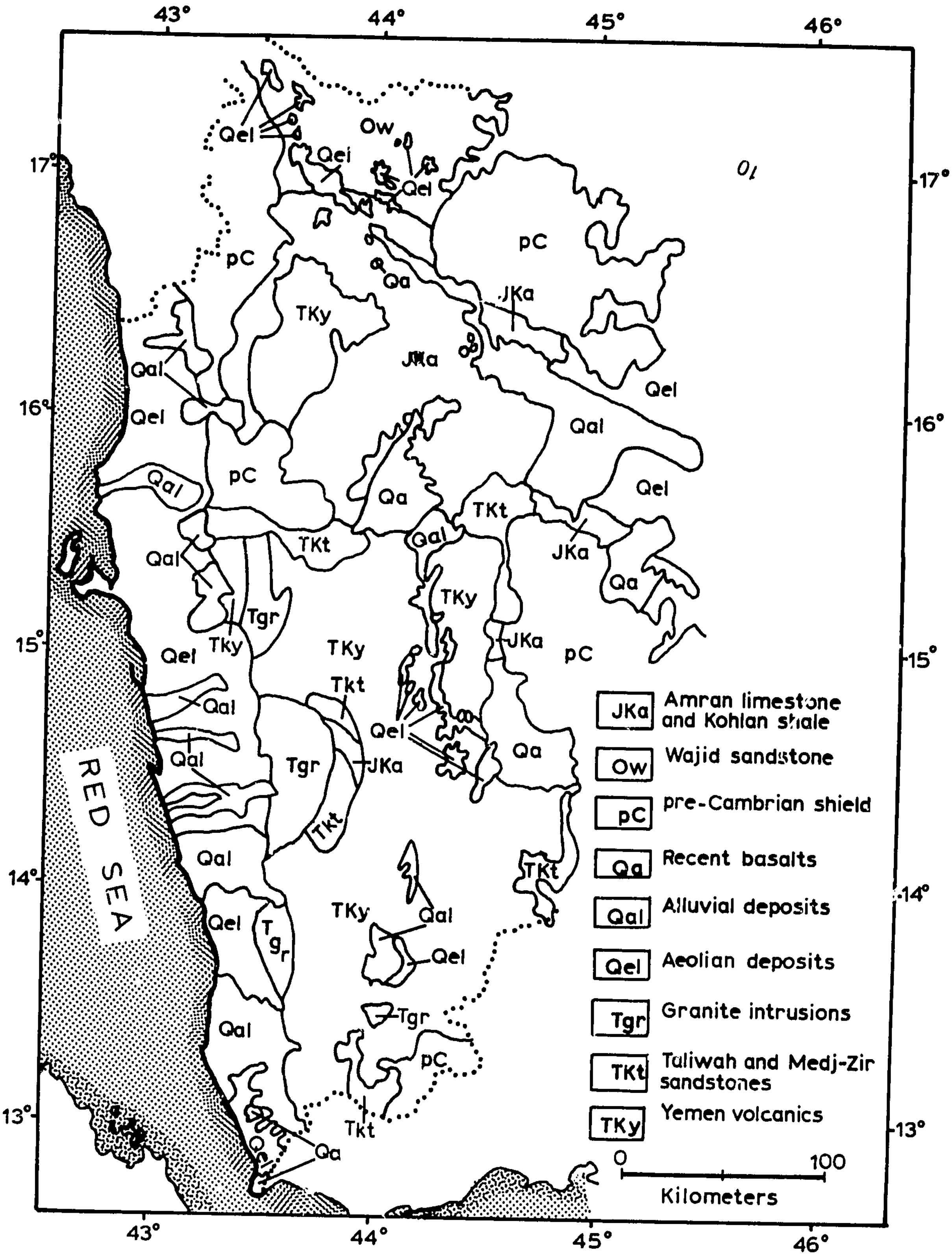
YEMEN VOLCANICS

The Yemen Volcanics formation occurs extensively over southwestern Yemen. The area is a rugged igneous plateau, which has been strongly dissected. Mountainsides are rocky, with some soil formation in protected areas. Agriculture is concentrated in valley bottoms, with some terracing on less steep slopes.

KOHLAN AND AMRAN GROUPS

The Jurassic Kohlan group consists of green silty shale and arenaceous sandstone which includes conglomerate lenses. The sandstone is interbedded with and overlies the shale. The sandstone becomes purer in quartz to the north. The Kohlan series is generally unfossiliferous.

The Kohlan group grades into the overlying Jurassic Amran group. The Amran group contains fossiliferous blue and light gray limestone, marl, and calcareous shale and sandstone. The Amran group varies in lithology from



Map 1.5: Generalized geologic map of Yemen.

place to place.

TAWILAH AND MEDJ-ZIR GROUPS

The third group of sedimentary rocks includes the Cretaceous Tawilah and Tertiary Medj-Zir groups. They are cross-bedded, coarse-grained quartz sandstones. They generally contain hematite nodules where they are in contact with volcanic materials. The lower Tawilah group includes conglomerate layers interbedded with red and green shale layers. The Medj-Zir group contains locally fossiliferous layers of calcareous shales.

Tertiary and Quaternary Volcanics

Volcanic rocks which formed in Cenozoic Era are divided into two groups. Igneous rocks of the Tertiary Period are known as the Yemen Volcanics, while any younger volcanic rocks are grouped as Quaternary Volcanics.

YEMEN VOLCANICS

The Yemen Volcanics formation, as defined in Grolier and Overstreet (1978), includes Tertiary volcanic rocks (the Trap Series) and contemperaneous granite laccoliths. The Trap Series (Geukens, 1966) is made up of alternating layers of lava flows, basalts, porphyries and various tuffs. The original volcanic craters are rare. The Trap Series includes sedimentary deposits, which were laid down during volcanically quiet times. These deposits include fossils.

The granite laccoliths included in the Yemen Volcanics are exposed both within and adjacent to the Trap Series, and are also found in the sedimentary rocks north of Sana. They are heavily dissected.

QUATERNARY VOLCANICS

Granites which are younger than the Yemen Volcanics, and volcanoes whose cones are still intact, are present throughout Yemen. The granites contain tourmaline and amphibole crystals. The volcanoes are basaltic and are often enclosed in layers of tuff. The most recent volcanism is located in the Dhamar-Rada area.

Quaternary Alluvial Deposits

Quaternary alluvial deposits are divided on the basis of their mode of transportation into wind-laid (aeolian) and water-laid (fluvial) deposits.

AEOLIAN DEPOSITS

Loess

Loess deposits are found in areas where mountains present a barrier to the wind, causing it to slow down and drop its sediment load. The loess of Yemen probably originated in the Rub Al Khali to the northeast, the direction of the prevailing winds. Many of the loess deposits, particularly in the intermountain plains, have been reworked by alluvial processes.

Dunes

In the survey area, sand dunes are found primarily on the Tihama, where the ground is level. Barchans and some longitudinal dunes are found, indicating that sand supply is the limiting factor of dune formation. The source of the sand is probably the wadi beds and alluvial fans, which receive sand from wadis coming out of the mountains. The great sand seas of the Rub Al Khali are outside of the survey area.

FLUVIAL DEPOSITS

Alluvial Fans

Alluvial fans are deposited where a quick decrease in slope (as at the bottom of a mountain) causes flowing water to slow down and drop its sediment load. Fans are found on the Tihama and on the Wadi Al Jawf, along the mountain fronts.

The fans are made up of coarse-grained material, because the dryness and lack of vegetation allow wind and water to carry away finer particles. Reworked loess material is commonly mixed with the alluvium.

Alluvial Plains

Alluvial plains form in broad, flat areas of low relief on the Tihama and in mountain valleys. The processes of sediment deposition which form alluvial plains are similar to those which form wadis. The sediments, however, are generally finer in texture than those in the active wadi beds and are spread over a much larger area. The source of the sediments is the weathering debris from the highlands mixed with reworked alluvial loess.

Topographic Relationships

Topographic relationships between the landform regions are shown in Figure 1.2.

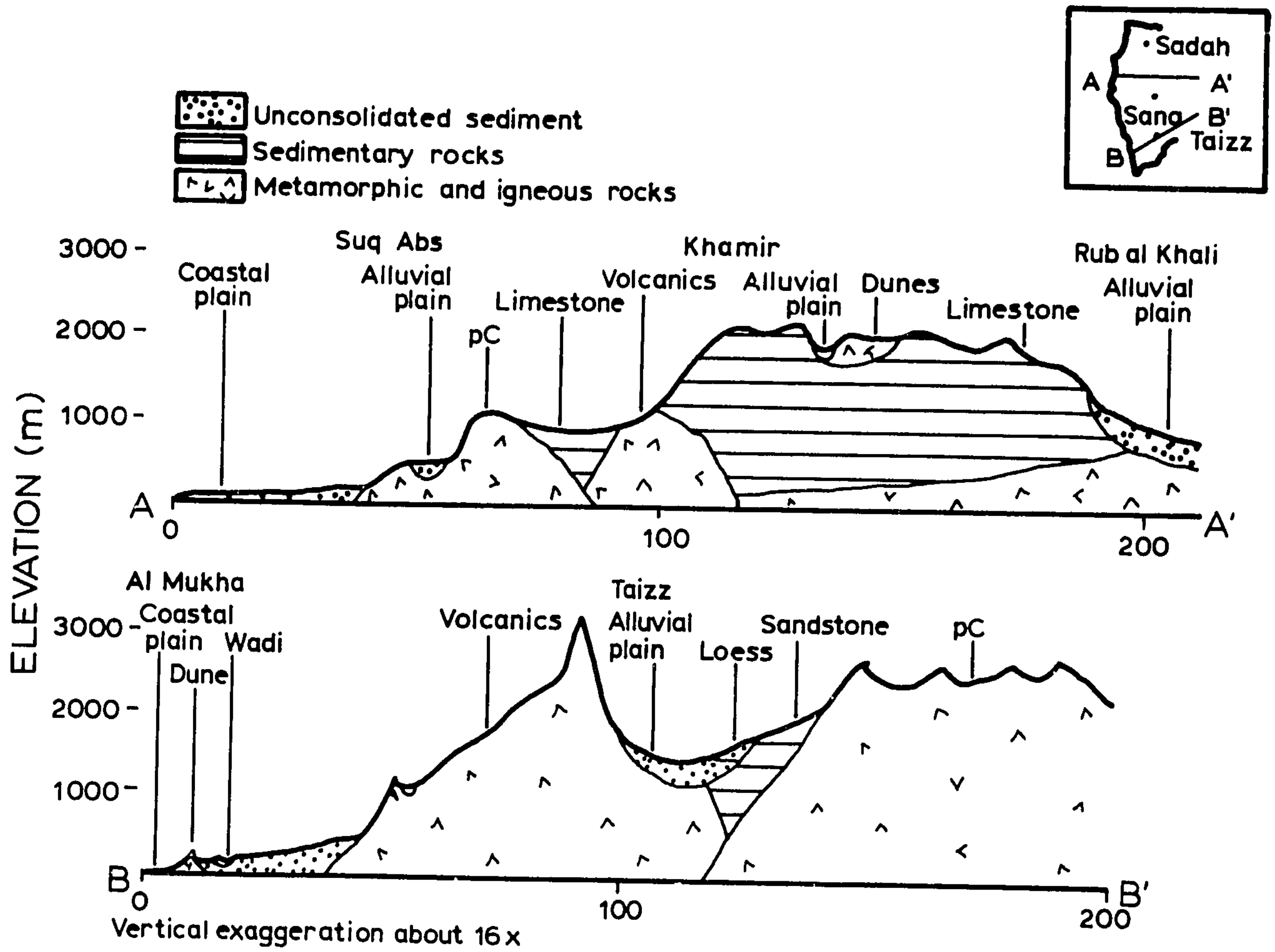


Figure 1.2: Two typical topographic cross-sections for Yemen.

The sources used for the preparation of this figure were the USGS 1:500,000 geologic and geographic maps (Grolier and Overstreet, 1978), which used Landsat imagery as their base. Selected areas were also examined with airphotos at 1:60,000 scale, obtained from the Resource Information Laboratory at Cornell University.

The country was divided into seven areas, with as many subdivisions as necessary. These are: Precambrian shield areas, sedimentary rock areas, the Yemen volcanics area, recent basalt flows, loess deposits, the coastal area, and inland alluvium.

Genesis and Classification of Soils

Genetic Processes Affecting Soil Relationships In Yemen

The genesis of the soils of Yemen is influenced primarily by six natural processes and two man-induced processes. These processes result in the accumulation of soil parent material and in the formation of the soil itself. The natural processes which result in the accumulation of soil parent material are: aeolian deposition, desert sedimentation, colluvial deposition, and combinations of these three processes. The natural processes which affect soil formation in Yemen are: intermittent, low levels of soil leaching and the low level of organic matter accumulation. The man-induced process affecting parent material formation is the accumulation of sediment through terracing and irrigation. The man-induced soil-forming processes are the leaching of soil parent material by irrigation and the accumulation of organic material by cropping.

NATURAL PROCESSES

Parent Material Formation

Parent material formation is the accumulation of inorganic sediments which have the potential to form soils by geologic processes.

Figure 1.3: The Yerim loessal plain.

Aeolian Deposition: Aeolian transport and deposition of soil parent materials has been and still is an important factor of soil genesis in Yemen. The wind has deposited soil parent material in two forms: as loess and as dunes. Large and widespread deposits of loess are observed throughout Yemen. Recent and ancient dunes are a predominant feature of the Tihama coastal area.

Loess: In the mountains most of the aeolian material is silt and clay-size calcareous loess. This loess orginates either locally or from the Rub Al Khali and Sahara deserts.

Field and airphoto observations show that deep loess deposits have accumulated in broad areas of low relief. In steep mountain areas, loess is deposited in valleys at least 2km wide. Larger loess deposits such as the Yerim plain (140km northwest of Taizz) appear to be graben areas filled with thick wind-blown sediments (Figures 1.3 and 1.4). On steep slopes and in wadi flats, the loess is reworked and transported by water. Aeolian-deposited loess layers are not observed on steep topography or in wadi bottoms.

Dunes: On the Tihama, sand and loess from the wadi beds are moved by the wind. Barchan and longitudinal dunes are frequently observed in the areas between wadis. Dunes grow, driven by prevailing winds from the Red Sea. Soil profile development is slow in these areas of shifting sand and loess.

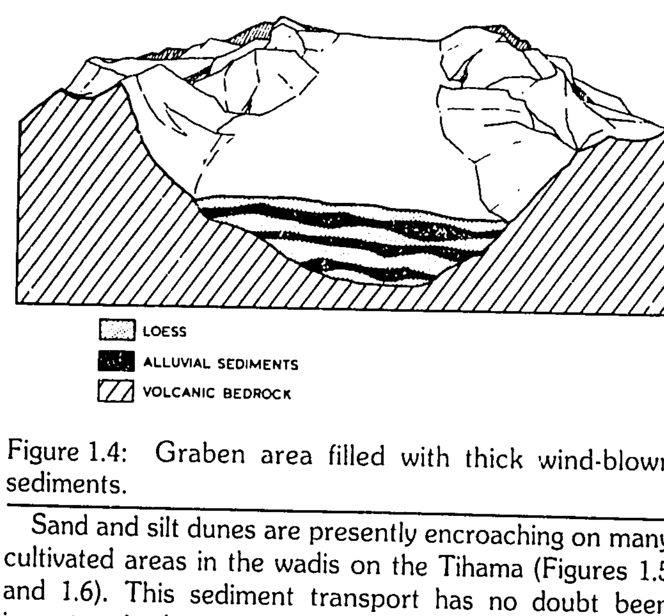


Figure 1.4: Graben area filled with thick wind-blown sediments.

Sand and silt dunes are presently encroaching on many cultivated areas in the wadis on the Tihama (Figures 1.5 and 1.6). This sediment transport has no doubt been important in the past also. Much arable land is lost each year by this encroachment, and local farmers must create new farmland in stabilized areas.

Fluvial Sedimentation: Sedimentation by water is important both along wadis and on intermountain plains.

Wadis: Sedimentary processes are particularly active along wadis. Sedimentation accounts for the layering and thin-bedding of many wadi soils. This is observed at the

Figure 1.5: The Tihama near Wadi Zabid.

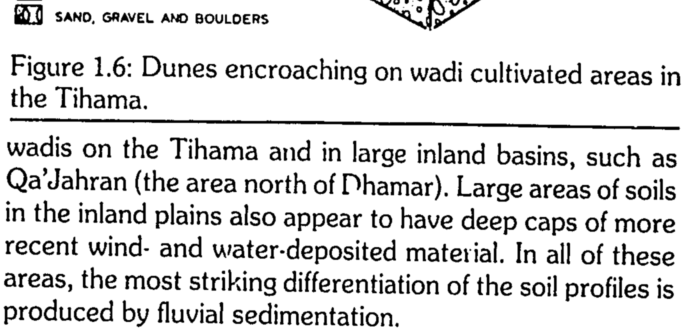


Figure 1.6: Dunes encroaching on wadi cultivated areas in the Tihama.

wadis on the Tihama and in large inland basins, such as Qa'Jahran (the area north of Dhamar). Large areas of soils in the inland plains also appear to have deep caps of more recent wind- and water-deposited material. In all of these areas, the most striking differentiation of the soil profiles is produced by fluvial sedimentation.

In a transect across Wadi Zabid (Figure 1.7) several levels of natural alluvial terraces, each with distinct textural compositions, are observed. The older, more extensive terraces contain less sorted, coarser materials (gravel and small boulders) while younger, less extensive terraces are typically better sorted and finer in texture. Textures of soils near the border of dune fields and wadis are coarse. Textures become finer towards the interior of the wadi.

In an east-west transect along the Wadi Zabid from the volcanic mountains to the Red Sea, another sequence of sediments is observed (Figure 1.8). In general, materials become finer westward from the mountains until a zone of recent sedimentary marine deposits is reached near the Red Sea. This sequence of soil parent materials appears typical for the Tihama as a whole.

Intermountain Plains: In Qa'Jahran (the Dhamar Plain) extensive lacustrine deposits (Acres, 1980) are observed. These deposits suggest a previous wetter climate and/or restricted drainage in the horst and graben landscape. The lacustrine sediments are typically covered with a thin, more recently deposited loess cap (Figure 1.9).

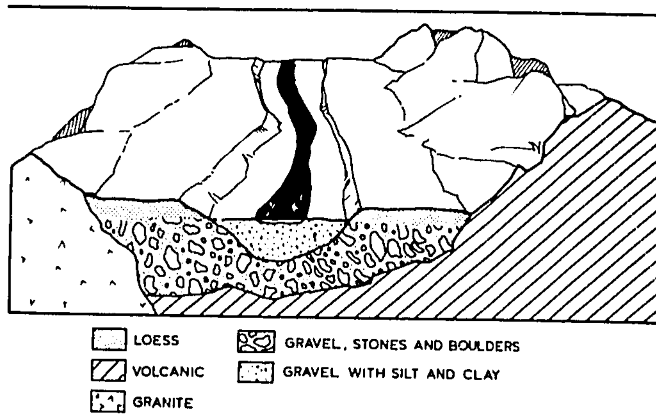


Figure 1.7: A north-south cross-section of Wadi Zabid.

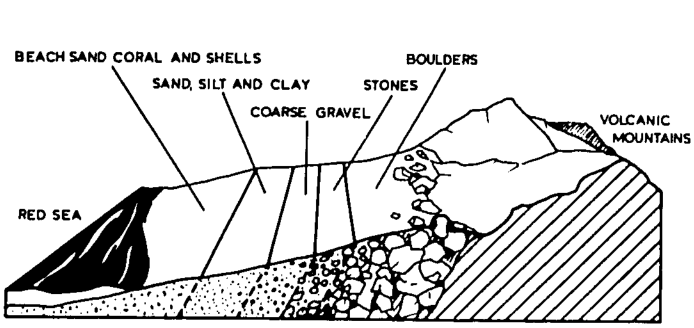


Figure 1.8: An east-west cross-section of Wadi Zabid from volcanic mountains to the Red Sea.

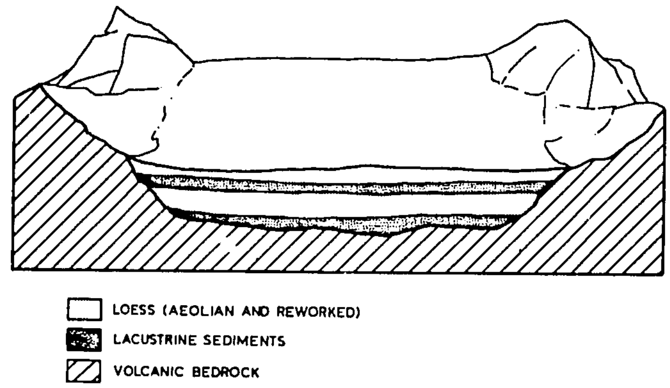


Figure 1.9: Lacustrine sediments covered with aeolian sediments in a graben.

Colluvial Deposition: The extensive colluvial deposits in the Yemen volcanic zone are distinct from the aeolian and alluvial deposits. Characteristically, they occur as moderately sloping pediments at the base of steep volcanic walls or mountainsides (Figure 1.10, see also Figure I.2 in Appendix). The volcanic stones, gravel and boulders in the colluvium are usually sharp and rough-edged. Colluvial pediments in the higher rainfall areas of Ibb are deeper (reach closer to volcanic outcrop summits) and less steep than those in lower rainfall areas, e.g. near Sana.

Combinations of Fluvial, Colluvial, and Aeolian Deposits: Most soil parent material in Yemen accumulates as a result of all three processes of soil parent material formation. Alternating layers of colluvium, alluvium, and loess in any sequence or combination are common. Colluvium mixed with loess is characteristic of many soils of the volcanic highlands.

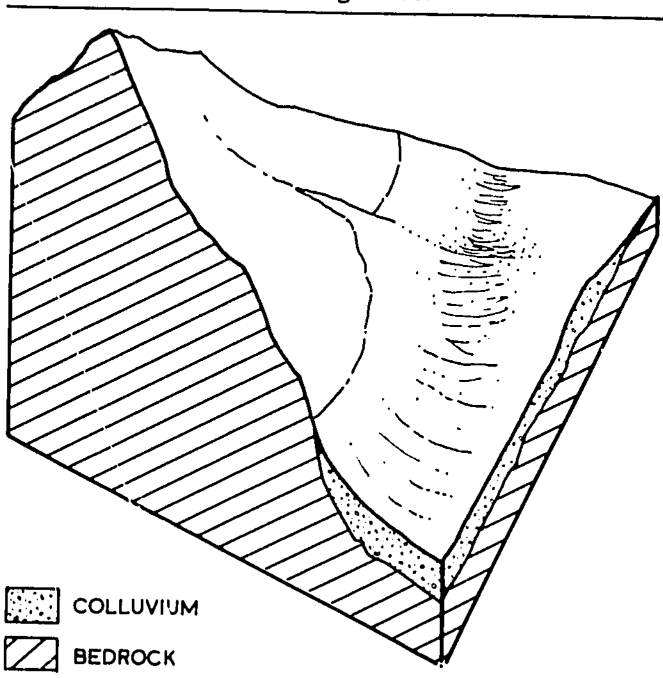


Figure 1.10: Colluvial deposition at the base of a steep volcanic mountainside.

This form of accumulation of parent material often results in a buried soil horizon. On flat to gently rolling broad landscapes, buried soils characterized by dark A1 horizons covered by more recently deposited materials are common (Figure 1.11). These buried soils can be covered by aeolian, colluvial or alluvial materials. For example, at Ibb roadcuts often show alluvial sediments overlain by loess. In these cases, a very abrupt boundary is observed.

Figure 1.11: Ibb loess deposit showing buried dark layer.

Soil-forming Processes

Soil-forming processes are those which act on soil parent material to produce soil horizonation.

Intermittent and Low Levels of Soil Leaching: Large regions of Yemen are in the aridic soil moisture regime. The highest rainfall in the country (near Ibb) may be marginally udic. Leaching of carbonates and other salts is not advanced. As a result of the low level of leaching, soil mineralogy is characterized by a young weathering stage.

The intermittent and low levels of leaching control the location of carbonates and carbonate morphology in the profile. All profiles examined in the field were at least slightly calcareous. Typically, some leaching of carbonates has occurred, so calcareous concretions were formed in B-horizons of some soils. In some areas, where significant water may episodically collect, e.g. plateaus at the bases of steep volcanic mountains, distinct zones of high accumulation of carbonates are present (Figure 1.12).

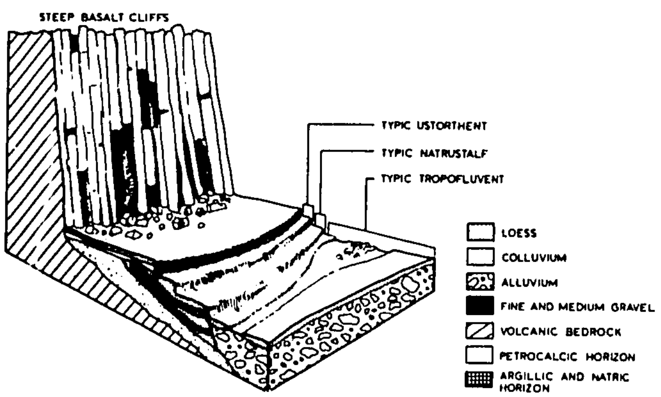


Figure 1.12: A plateau at the base of a steep volcanic mountainside.

Low Levels of Organic Matter Accumulation: In Yemen, as in most arid regions, there is little accumulation of organic matter in soil horizons. Only in areas of higher rainfall (as in the Ibb area), or at water collecting positions in the landscape (lower-slope concave positions) does organic matter accumulate to any great extent in the surface horizons. Mollic epipedons can be found in such positions.

MAN-INDUCED PROCESSES

Parent Material Formation

Man affects soil parent material formation by terracing and irrigation. It has been suggested that men have been constructing terraces in Yemen for at least 2000 years. In the mountainous areas, soil horizonation has been altered significantly by this human influence. Similarly, sedimentary processes have been controlled and modified by farmers building bunds and other barriers along wadis on the Tihama and inland.

Terracing: Terraces retain and collect soil parent material along the mountain slope. The natural process of erosion and movement of soil materials downslope is greatly slowed, and soil is able to form on the accumulated parent material (Figure 1.13). Terracing also results in the sorting of the parent materials because stones are removed from the colluvium and used to build terrace walls.

Two kinds of terraces are recognized in the Yemen volcanic zone: colluvial terraces and loess terraces. All the terraces observed could be classified into one of these two groups.

Colluvial Terraces: Colluvial terraces consist of colluvium from volcanic rocks mixed with some loess. The soil material in colluvial terraces is quite erodable as seen in terraces with broken-down walls. The colluvium itself is gravelly and/or stony and has a lower water-holding capacity than the loess material.

Loess Terraces: Loess terraces have no constructed retaining wall, because loess erodes less easily than colluvial soil parent materials. Loess material is heaped up and a vertical free-standing wall is constructed.

Irrigation: Long periods of irrigation and water control have also affected the deposition of soil parent materials. Spate irrigation on the Tihama has increased sedimentation on the lower, flatter areas. This sedimentation results in formation of terraces often differing in height by several meters.

Soil-forming Processes

Leaching of Soil Parent Materials by Irrigation: Irrigation of some form has been going on perhaps as long as the construction of terraces.

Highland Irrigation: In the highlands, rainwater collection on concave fields by bunds and ridges is the most important form of irrigation. These methods make the small amount of precipitation more effective by reducing runoff. Terracing has the same effect because it also reduces runoff. These processes result in a small increase in leaching of the soil parent materials and soil formation occurs more quickly than it would naturally.

Tihama Irrigation: Along the Tihama spate and well irrigation have been practiced (Figure 1.14). The leaching and reprecipitation of salts must have resulted from this. However, this was not immediately apparent in any of the areas visited, and will need to be confirmed by analytical lab results.

Figure 1.13: Terraced agriculture on volcanics and a wadi south of Dhamar.

Figure 1.14: Bunded terracing for spate irrigation near Wadi Zabid.

Increased Accumulation of Organic Matter: Soils which have been intensively irrigated for cropping for long periods of time have higher amounts of organic matter in their surface horizons. However, organic matter does not generally accumulate sufficiently in this manner to form mollic epipedons.

Taxonomic Soil Classification of the Soils of North Yemen

The mapping units are associations of subgroups (USDA-SCS, 1975). In the legend (Chapter 3), associations are named by the predominant soil order. Each of these predominant soil orders is described below.

ENTISOLS

Most soils in North Yemen are either subject to constant erosion processes or are the product of recent deposition with the result that strongly expressed profile development is rare and the dominant soil order is the Entisol. Orthents dominate in the most arid regions of the country where organic matter decreases uniformly with depth and in mountainous regions where most soils are situated on slopes steeper than 25%.

Fluvents dominate most plains and wadis both because of the irregular distribution of organic matter in the profile and because significant amounts of organic carbon are found at a depth of 1.25m in the profile.

Soil moisture regimes are wet enough in limited areas for some Entisols to be classified as Aquents.

Most Entisols in North Yemen are strongly influenced by alluvial or loessal calcareous silt parent materials but where the parent rocks are sandstone or on the plains where sand has accumulated in dunes, Psamments are common.

Entisols account for approximately 59.8% of all soils in North Yemen.

ARIDISOLS

In arid regions characterized by a stable surface, calcic, and in some instances, gypsic horizons have developed so the soils are classified as Calciorthids or Gypsiorthids. Salic horizons were observed and the soils classified as Salorthids in limited areas where groundwater was both near the surface and saline.

Aridisols account for approximately 8.7% of all soils in North Yemen.

MOLLISOLS

Mollisols are present in the most cool and moist areas of North Yemen. The most extensive Mollisols have a calcic horizon and are classified as Calciustolls. Other Mollisols developing on calcareous parent materials are Petrocalcic Haplustolls, Udic Haplustolls, Vertic Haplustolls (where surface water accumulates), and Typic Haplustolls (with a cambic horizon on the basis of color). Mollisols which develop where the parent rocks are noncalcareous tend to be Typic Hapludolls.

Most Mollisols on the mountain plains of North Yemen are buried soils. Many Mollisols in the mountains have a shallow lithic contact and are used only for grazing.

Mollisols account for approximately 2.4% of all soils in North Yemen.

INCEPTISOLS

Inceptisols are very limited in extent but do occur where soils with a calcic or cambic horizon exist in a region where the moisture regime is not aridic.

Inceptisols account for approximately 4.2% of all soils in North Yemen.

VERTISOLS

Vertisols are the most limited in extent of the major soil orders found in North Yemen. They occur isolated in only a few intermountain basins. They are typically buried under a thin calcareous loess cap.

Vertisols account for approximately 0.4% of all soils in North Yemen.

The remainder of the area, approximately 24.5%, can be characterized as rock outcrops.

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CHAPTER 2

FIELD SURVEY AND LABORATORY METHODS

The soil survey methods were adapted to the 1:500,000 scale of the final map. This scale permitted the delineation of associations of subgroups (USDA-SCS, 1975) of soils which occur in a repeated pattern in the landscape. The map units were recognized on the basis of climate, geology, relief, vegetation, and soil morphology. The extent of the defined units was determined by analyzing satellite and aerial photography imagery.

The survey work included identifying the soils, classified to the subgroup level, which form the major soil associations and delineating these associations on 1:250,000 topographic maps. The field maps were reduced to the final scale of 1:500,000 for publication.

Progress was made by individual sheets, starting from the south and going north. All field operations were completed in eighteen months.

Office Methods

A published geological map at 1:500,000 (Grolier and Overstreet, 1978) and selected airphotos at 1:60,000 were used to define landform regions. These regions are uniform in lithology, climate, and relief.

Some information was available at the beginning of the project for specific areas of the Yemen Arab Republic. A major part of office operational tasks before field operations was compiling and reviewing all the available soils, geological, and climatic data and reports.

Preliminary studies before field operations in Yemen included a search and review of existing soil studies (published and unpublished government consultant's reports) and soil surveys. The Yemen Ministry of Agriculture had commissioned soil reports and surveys of selected areas for possible intensive agricultural development. A listing of these reports and surveys are as follows (Table 2.1).

These reports supplemented field studies for the production of the 1:500,000 soils map. No attempt has been made to duplicate the detailed work done in these areas.

Computer-processed digital Landsat satellite imagery was also used. Three Landsat bands, 4, 5, and 7, were digitally processed into a false-color infrared composite, which was then enlarged to 1:250,000 and 1:100,000. Homogenous areas on the false-color infrared imagery were checked to see if they corresponded with the landform regions previously defined. If necessary, adjustments were made. A general idea of the relief, intensity of vegetation, drainage systems, and lithology was derived from the false-color imagery.

Black and white airphotos (1:60,000) of selected sites were examined for pilot areas to be visited in the field. Relief, drainage, vegetation, soil parent materials, and present agricultural land use were distinguished in greater detail in these photos. The pilot sites estimated the soil pattern in each landscape and were used to select the location of characteristic pits for description and sampling.

Soil descriptions were combined to define a legend of typical soil associations. Profiles were classified to the subgroup level according to *Soil Taxonomy* (USDA-SCS, 1975) and to the family level for the profile descriptions (Appendix). The extent of benchmark soils were estimated for the pilot area.

Areas of similar soil associations were delineated on the satellite imagery. These areas were checked in the field to be sure they conformed to the description of the pilot area. The selection of typical profiles and the extent of association-delineations was revised as further observation and new field information deemed necessary.

Selected profile descriptions and their analytic data are found in the Appendix.

Field Methods

The purpose of mapping the major components of the soil associations at large scales (about 1:25,000) in the pilot areas was to estimate the percentage each individual soil (as classified at the subgroup level) occupied in the association. The methodology followed the guidelines of the USDA *Soil Survey Manual* (1975, draft version). During these field observations, an effort was made to study the correlation between field characteristics, airphotos, and satellite imagery, in order to elaborate an identification key for the interpolation and extrapolation of soils data to inaccessible areas. Another objective of the field studies was to

Table 2.1: Previous Yemen soils reports indexed in Map 4.1.

Acres, B. D. 1978. Landforms and soils of the Dhamar Agricultural Improvement Centre. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, Land Resources Division, Surbiton, Surrey, England.

Acres, B. D. 1980. Soils and land suitability of the Montane Plains and Wadi Rima. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Overseas Development Administration, Land Resources Development Centre, Surbiton, Surrey, England.

Agrar- und Hydrotechnik GmbH. 1980. Development of Wadi Jawf and its tributaries; technical report: soils. Yemen Arab Republic Ministry of Agriculture.

Boros, I. J., I. Szabolcs, and G. Varallyay. 1970. Soil survey in the Tihama lowland (Yemen Arab Republic); I. factors of soil formation; II. soils and land capability classes. *Agrokemia es Talajtan* 19:405-464.

Boros, I. J., and Lesztak, J. 1971. Soil survey in the Tihama lowland (Yemen Arab Republic); III. water management properties of soils. *Agrokemia es Talajtan* 20:217-230.

Egli, E. 1978. *"Landnutzung und landnutzungsveraenderung in der region Wadi Mawr Arabische Republik Jemen." Geographischen Institut der Universtat Zurich.*

Electrowatt Engineering Services, Ltd. 1978. Marib Dam and Irrigation Project; Yemen Arab Republic; annexes I. soil and land classification; III. agriculture; V. geology and geotechniques; VII. hydrology. Government of Abu Dhabi, Presidential Court.

Halcrow, W., and Partners. 1978. Wadi Surdad: Development on the Tihama; vol. 4: soils and land capability; annex C. Yemen Arab Republic Ministry of Agriculture.

Pacheco, R. A. 1978. The application of landsat imagery to soil and land-use mapping in the central region of the Yemen Arab Republic. FAO Seris AGLT, FAO, Rome.

Tesco-viziterv-vituki. 1971. Survey of the agricultural potential of the Wadi Zabid, Yemen Arab Republic, soils and land capability. AGL: SF/YEM 1. Technical Report 8. Budapest.

Western, S. 1972. The classification of arid zone soils; II. the classification of Sedasols in Saudi Arabia. Journal of Soil Science 23:279-297.

Other Reports on Yemen Useful for the Soil Survey

Asmaev, L. R. 1969. Data on soils of the southwestern part of the Arabian peninsula. pp. 249-257. *In* Kovda, V. A., and E. V. Labova (ed.). Geography and classification of soils of Asia. Israel Program for Scientific Translations. pp. 249-257.

Grolier, M. J., G. C. Tibbitts, Jr., and M. M. Ibrahim. 1981. A qualitative appraisal of the hydrology of the Yemen Arab Republic from Landsat images. USGS. Open-file Report 80-565.

Kopp, H. 1975. *Die raumliche differenzierung der agrarlandschaft in der Arabischen Republik Jemen (Nordjemen). Erdkunde* 29:59-68.

Schoch, R. 1977. *Regionale gliederung der Jemenitischen Arabischen Republik mit hilfe von landsat-satellitenbildern. Thesis, Geographischen Institut der Universitat Zurich.*

relate crop production and potential with soil and land characteristics, and to make interpretations for land-use (see Chapter 4). During reconnaisance trips to selected pilot areas, the dominant lithologies and their position in the landscape were noted as well as the presence and position of transported materials: colluvium, alluvium, and aeolian deposits (see Chapter 1). The distribution of the geological formations and the associated transported materials was important for understanding the genesis of the soils (see Chapter 1). This in turn permitted more efficient mapping.

The predominant landscape units such as colluvial slopes, alluvial terraces, man-made terraces, wadis, coastal plains, lake beds, barchan dunes, etc., formed the basis for description and selection of characteristic soil profiles for the pilot area. Traverses were made and soils were augered and examined at different sites along the landscape. Typical surface horizons were noted and checked for uniformity and average depth. The traverses gave an idea of the extent of the various soils in the mapping unit.

Sites for characteristic profiles were selected away from slope breaks and excessive human disturbances (except for man-made terraces). The profiles were described according to *Guidelines for Soil Profile Description* (FAO, 1977). Bulk samples were collected by horizon, as well as other samples for mineralogical, micromorphological, and sedimentalogical studies.

Laboratory Methods

The samples collected during the soil survey were analyzed by the FAO soils laboratory in Aussefeire, Yemen. The analyses were necessary to define the soil characteristics important for classification. Specialized analyses, such as mineralogy and micromorphology, were conducted as needed at the Agronomy Department at Cornell University.

The soil analyses are a complement to the field observations, to confirm and verify the accuracy of the classification. The level of detail is probably not adequate for purposes beyond the objectives of the general survey, such as feasibilty studies of irrigation or other development projects.

Routine analyses of all horizon samples included the following:

1) Particle-size analyses by the pipette method (Day, 1965, pp. 545-562),

2) Ordinary particle-size distribution of sand, silt, and clay by the hydrometer method (Day, 1965, pp. 562-566),

3) Soil pH in 1:1 and 1:5 soil water ratio suspension,

4) Electrical conductivity (EC in mmhos) of a 1:1 soil/water suspension (modification of method by Bower and Wilcox, 1965, pp. 935-940),

5) Cation exchange capacity at pH 8.2 by NaOAc (Chapman, 1965, pp. 899-900),

6) Carbonate by acid-neutralization using hydrochloric acid (Allison and Moodie, 1965, pp. 1387-1388),

7) Organic matter by the Walkley-Black method (Jackson, 1958),

8) Total nitrogen (Bremner, 1965, pp. 1162-1164),

9) Available phosphorus, measured as P soluble in sodium bicarbonate (Olsen and Dean, 1965, pp. 1044-1047).

Some profiles were selected for specialized mineralogical, micromorphological, and sedimentological analyses. These analyses were used to define more clearly the genetic relationships of soils in Yemen. The analyses included:

1) Clay mineralogy by X-ray diffraction (Whittig, 1965, pp. 671-698) and thermal analysis (Barshad, 1965, pp. 699-742),

2) Micromorphological features by petrographic microscope techniques (Cady, 1965, pp. 604-631),

3) Mineralogy of the sand fraction by observation under a 10x microscope.

CHAPTER 3

SOIL MAP LEGEND

The soil map legend (Table 3.1) was defined on the basis of soil genesis concepts and field survey principles discussed previously in Chapters 1 and 2, respectively. Since *Soil Taxonomy* (USDA-SCS, 1975) was the classification used for the map units, it was decided to divide the legend into five parts based on the predominant soil order of each of the individual map units. The predominant soil orders are: 1) Aridisols, 2) Entisols, 3) Inceptisols, and 4) Mollisols. A fifth division was based on those map units which are predominantly rock outcrops. This five-part subdivision of map units groups those units which are most similar.

Individual soil profiles were classified to the family level (see Appendix). Appropriate phases were also designated for the profiles when the phase information was deemed useful for future land use decisions. Phase designations referring mainly to the predominant topography, stoniness, or presence or absence of terraces were also included in the soil map legend.

The importance of soil moisture regimes, which range from aridic to udic, are apparent to anyone with any practical, agricultural experience in Yemen. In the legend, the predominant soil moisture regime is usually given in the soil subgroup name. Further information on the soil moisture regimes for the families and subgroups for agricultural land uses are given in Chapter 5. Soil moisture regimes were estimated from available climatic data (see Chapter 1).

The importance of the soil temperature regime designation may not be as immediately evident as that of the soil moisture designation. This does not in any way, however, diminish its importance for agricultural planning. Yemen is a mountainous country with many small microclimate areas. Air temperature and therefore soil temperature are a direct function of elevation. The warmest soil temperature regimes occur at the lowest elevations and the coolest at the highest elevations. The soil temperature regimes were estimated from known elevations and limited climatic data for several locations in Yemen (see Chapter 1). The dominant soil temperature regime is given in the legend (Table 3.1) for each map unit.

A map at 1:500,000 scale should be useful in determining the approximate areas of different kinds of soils classified at a high level of generalization. The percentage of total area of different subgroups in each map unit is given in the legend. A further breakdown of the areas in square kilometers of each different kind of soil subgroup and soil order has also been determined for planning purposes (Table 3.2). From this table one sees that the map units predominantly Entisols are the most extensive. The second largest area is composed of those map units which are predominantly rock outcrops (this is a particularly large area in the southeastern part of the survey). After these areas the next most predominant are those of Aridisols, followed by Inceptisols, and Mollisols in decreasing order.

Finally, the designation number of the soil profiles characteristic for some of the soil subgroups in the map units is given in the legend (Table 3.1). Full descriptions of eight profiles along with laboratory data are given in the Appendix. A color soils map is enclosed in a pocket on the back cover.

Table 3.1: Soil map units, symbols, phases, temperature regimes, and profiles for soils in the Yemen Arab Republic.

Unit	Symbol	Dominant Phase	Temperature Regime	Percent of Total Area	Profiles
Soils Predominantly Aridisols					
1. Typic Calciorthids	Act	stony to bouldery	isohyperthermic	60%	K7, K9, K36
Typic Torrifluvents		stony to bouldery	isohyperthermic	20%	-
Typic Torriorthents		stony to bouldery	isohyperthermic	20%	K35
2. Typic Gypsiorthids	Agr	stony, mountainous	isohyperthermic	40%	K75, K76
Lithic Torriorthents		stony, mountainous	isohyperthermic	20%	-
Rock Outcrops		stony, mountainous	isohyperthermic	40%	-
3. Typic Salorthids	Asf	flat	isohyperthermic	70%	K46, K49
Tropic Fluvaquents		flat	isohyperthermic	15%	K40
Tropaquents		flat	isohyperthermic	15%	K38
4. Typic Salorthids	Ast	flat	hyperthermic	70%	K59
Typic Torrifluvents		flat	hyperthermic	30%	-
Soils Predominantly Entisols					
5. Typic Torriorthents	Etc	stony, undulating	hyperthermic	40%	K58
Typic Torrifluvents		stony, undulating	hyperthermic	40%	K55
Typic Calciorthids		stony, undulating	hyperthermic	20%	-
6. Typic Torrifluvents	Etu	flat	hyperthermic	60%	-
Typic Udifluvents		flat	hyperthermic	40%	K56
7. Typic Torrifluvents	Ett	flat	isohyperthermic	30%	K37, K41, K42, K48
Typic Torripsamments		flat	isohyperthermic	30%	K39
Typic Torriorthents		flat	isohyperthermic	30%	K50
Typic Calciorthids		flat	isohyperthermic	10%	K47
8. Typic Torriorthents	Ett	flat	isothermic, hyperthermic	50%	K4
Typic Torripsamments		flat	isothermic, hyperthermic	35%	K71
Typic Torrifluvents		flat	isothermic, hyperthermic	15%	K5
9. Typic Torriorthents	Ehu	undulating	iso-, isohyper-,* hyperthermic	20%	F1, K12, K14
Typic Ustifluvents		undulating, terraced	isothermic	20%	K20, K21, K22
Typic Haplargids		undulating	iso-, isohyper-,* hyperthermic	10%	K13
Typic Calciorthids		undulating	isohyperthermic	10%	K18
Typic Ustorthents		undulating	isothermic	10%	K19
Typic Camborthids		mountainous	isothermic	10%	F2
Aquollic Salorthids		flat	isothermic	10%	F3
Typic Fluvaquents		flat	isohyperthermic	10%	K15
10. Typic Torriorthents	Eur	mountainous	isothermic, isohyperthermic	25%	K1, K11
Lithic Torriorthents		mountainous	isothermic, isohyperthermic	25%	-
Typic Ustorthents		mountainous, terraced	isothermic, isohyperthermic	20%	-
Rock Outcrops		mountainous	isothermic, isohyperthermic	30%	-
11. Typic Torripsamments	Est	undulating	isohyperthermic	85%	-
Typic Torrifluvents		undulating	isohyperthermic	15%	-
12. Typic Torripsamments	Ess	undulating	hyperthermic	80%	-
Typic Torrifluvents		undulating	hyperthermic	20%	-

Table 3.1 continued.

Unit		Symbol	Dominant Phase.	Temperature Regime	Percent of Total Area	Profiles
13.	Typic Ustipsamments	Eut	undulating	hyperthermic	85%	-
	Typic Torrifluvents		undulating	hyperthermic	15%	-
14.	Typic Ustifluvents	Euu	almost flat	hyperthermic, isohyperthermic	60%	K10, K28, K30
	Typic Ustorthents		almost flat	hyperthermic, isohyperthermic	20%	-
	Typic Ustipsamments		almost flat	hyperthermic, isohyperthermic	10%	-
	Typic Torrifluvents		almost flat	hyperthermic, isohyperthermic	10%	F6
15.	Typic Ustifluvents	Eup	undulating	isohyperthermic	60%	K72
	Typic Ustipsamments		undulating	isohyperthermic	30%	K73
	Typic Torrifluvents		undulating	isohyperthermic	10%	K74, K77
16.	Typic Ustifluvents	Euo	mountainous, terraced	isothermic, isohyperthermic	60%	-
	Typic Ustorthents		mountainous, terraced	isothermic, isohyperthermic	30%	K16, K17
	Lithic Torriorthents		mountainous	isothermic, isohyperthermic	10%	-
17.	Typic Ustorthents	Eto	mountainous, terraced	iso-, isohyper-,* isomesic	30%	F9, K31
	Typic Ustifluvents		mountainous	iso-, isohyper-,* isomesic	5%	K23, K24
	Tropofluvents		flat	iso-, isohyper-,* isomesic	5%	F11
	Lithic Torriorthents		mountainous	iso-, isohyper-,* isomesic	5%	-
	Typic Torriorthents		mountainous	iso-, isohyper-,* isomesic	5%	-
	Typic Natrustalfs		mountainous	iso-, isohyper-,* isomesic	5%	F10
	Entic Haplustolls		mountainous	isothermic, isomesic	5%	K25
	Typic Argiudolls		mountainous	isothermic, isomesic	5%	K32
	Lithic Ustorthents		mountainous	iso-, isohyper-,* isomesic	5%	K33
	Rock Outcrops		mountainous	iso-, isohyper-,* isomesic	30%	-
18.	Typic Ustifluvents	Eft	flat	isothermic, hyperthermic	60%	K67
	Typic Torrifluvents		flat	isothermic, hyperthermic	30%	-
	Typic Calciorthids		flat	isothermic, hyperthermic	10%	K68
19.	Typic Ustifluvents	Eub	undulating	isothermic	50%	-
	Ustic Torriorthents		rolling	isothermic	10%	K82
	Typic Ustorthents		terraced	isothermic	10%	K87
	Basalt Flow		undulating, rubble land	isothermic	30%	-
20.	Typic Ustorthents	Eoc	undulating	isothermic	50%	K34
	Typic Ustifluvents		undulating	isohyperthermic	30%	K79
	Typic Calciorthids		undulating	isohyperthermic	10%	-
	Typic Torriorthents		undulating	isohyperthermic	10%	K29, K78
21.	Typic Ustorthents	Ehc	mountainous, terraced	isothermic, isomesic	45%	-
	Udic Haplustolls		mountainous, terraced	isothermic, isomesic	10%	K3
	Entic Ustropepts		mountainous	isothermic, isomesic	10%	-
	Petrocalcic Calciustolls		mountainous	isothermic, isomesic	5%	K80
	Typic Calciustolls		mountainous	isothermic, isomesic	5%	F4
	Typic Ustropepts		mountainous, terraced	isothermic, isomesic	5%	F5
	Typic Calciorthids		mountainous	isothermic, isomesic	5%	K81
	Rock Outcrops		mountainous	isothermic, isomesic	15%	-

Table 3.1 continued.

Unit	Symbol	Dominant Phase	Temperature Regime	Percent of Total Area	Profiles
Soils Predominantly Inceptisols					
22. Typic Ustropepts	Iuc	flat	isothermic	55%	-
Ustollic Calciorthids		flat	isothermic	20%	-
Vertic Haplustolls		flat	isothermic	10%	K45
Udic Pellusterts		flat	isothermic	5%	F8
Typic Torrerts		flat	isothermic	5%	F7
Udic Haplustolls		flat	isothermic	5%	K2
23. Typic Ustropepts	Iuu	mountainous, terraced	isothermic	60%	K27
Entic Ustropepts		flat	isothermic	20%	-
Typic Ustifluvents		flat	isothermic	10%	-
Ustollic Camborthids		flat	isothermic	5%	K26
Ustollic Calciorthids		flat	isothermic	5%	K89
Soils Predominantly Mollisols					
24. Typic Calciustolls	Mct	flat, sand cap	isothermic	40%	K62, K66
Typic Calciorthids		flat	isothermic, isohyperthermic	20%	K60, K61, K64, K69, K70
Typic Torriorthents		flat	isothermic	15%	K6
Ustic Torripsamments		flat	isothermic	15%	K63
Typic Haplustolls		flat	isothermic	10%	K65
25. Typic Hapludolls	Mhr	mountainous	isothermic	40%	K44
Entic Hapludolls		mountainous	isothermic	10%	K43
Lithic Torriorthents		mountainous	isomesic	10%	-
Rock Outcrops		mountainous	isomesic	40%	-
26. Vertic Haplustolls	Muh	flat	isothermic	50%	K83, K88
Typic Ustifluvents		flat	isothermic	30%	-
Aridic Haplustolls		flat	isothermic	10%	-
Typic Torriorthents		flat	isothermic	5%	K84
Typic Haplustolls		flat	isothermic	5%	K85
Soils Predominantly Rock Outcrops					
27. Typic Calciorthids	Rcc	stony, mountainous	isothermic, isohyperthermic	20%	K8
Lithic Calciorthids		stony, mountainous	isothermic, isohyperthermic	10%	-
Rock Outcrops		stony, mountainous	isothermic, isohyperthermic	70%	-
28. Lithic Torriorthents	Rtt	mountainous	isohyperthermic	20%	-
Typic Torriorthents		mountainous	isohyperthermic	20%	-
Typic Calciorthids		mountainous	isohyperthermic	10%	-
Rock Outcrops		mountainous	isohyperthermic	50%	-
29. Typic Torriorthents	Rtc	mountainous	hyperthermic	25%	K51
Lithic Torriorthents		mountainous	hyperthermic	10%	K54
Typic Torrifluvents		flat	hyperthermic	5%	K53
Typic Ustifluvents		flat	hyperthermic	5%	K52, K57

Table 3.1 continued.

	Unit	Symbol	Dominant Phase	Temperature Regime	Percent of Total Area	Profiles
	Typic Calciorthids		mountainous	hyperthermic	5%	-
	Rock Outcrops		mountainous	hyperthermic	50%	-
30.	Typic Ustifluvent	Ruo	flat	isothermic	40%	K86
	Rock Outcrops		steep	isothermic	60%	-

*isothermic, isohyperthermic

Table 3.2: Areas of soils in the Yemen Arab Republic by subgroup, map unit, and soil order.

	Unit	Symbol	Areas by Subgroup (km²)	Areas by Map Unit (km²)	Areas by Soil Order (km²)
Soils Predominantly Aridisols					
1.	Typic Calciorthids	Act	950	1582	Aridisols:
	Typic Torrifluvents		316		
	Typic Torriorthents		316		10,097
2.	Typic Gypsiorthids	Agr	160	400	
	Lithic Torriorthents		80		
	Rock Outcrops		160		
3.	Typic Salorthids	Asf	655	935	
	Tropic Fluvaquents		140		
	Tropaquents		140		
4.	Typic Salorthids	Ast	17	24	
	Typic Torrifluvents		7		
Soils Predominantly Entisols					
5.	Typic Torriorthents	Etc	3935	9837	Entisols:
	Typic Torrifluvents		3935		
	Typic Calciorthids		1967		70,223
6.	Typic Torrifluvents	Etu	212	353	
	Typic Udifluvents		141		
7.	Typic Torrifluvents	Ett	1365	4550	
	Typic Torripsamments		1365		
	Typic Torriorthents		1365		
	Typic Calciorthids		455		
8.	Typic Torriorthents	Etf	889	1777	
	Typic Torripsamments		622		
	Typic Torrifluvents		266		

Table 3.2 continued.

Unit	Symbol	Areas by Subgroup (km²)	Areas by Map Unit (km²)	Areas by Soil Order (km²)
9. Typic Torriorthents	Ehu	629	3142	
Typic Ustifluvents		629		
Typic Haplargids		314		
Typic Calciorthids		314		
Typic Ustorthents		314		
Typic Camborthids		314		
Aquollic Salorthids		314		
Typic Fluvaquents		314		
10. Typic Torriorthents	Eur	1458	5831	
Lithic Torriorthents		1458		
Typic Ustorthents		1166		
Rock Outcrops		1749		
11. Typic Torripsamments	Est	1621	1907	
Typic Torrifluvents		286		
12. Typic Torripsamments	Ess	1878	2347	
Typic Torrifluvents		469		
13. Typic Ustipsamments	Eut	1699	1998	
Typic Torrifluvents		299		
14. Typic Ustifluvents	Euu	3415	5691	
Typic Ustorthents		1138		
Typic Ustipsamments		569		
Typic Torrifluvents		569		
15. Typic Ustifluvents	Eup	712	1186	
Typic Ustipsamments		356		
Typic Torrifluvents		118		
16. Typic Ustifluvents	Euo	2020	3366	
Typic Ustorthents		1010		
Lithic Torriorthents		336		
17. Typic Ustorthents	Eto	3364	11,208	
Typic Ustifluvents		560		
Tropofluvents		560		
Lithic Torriorthents		560		
Typic Torriorthents		560		
Typic Natrustalfs		560		
Entic Haplustolls		560		
Typic Argiudolls		560		
Lithic Ustorthents		560		
Rock Outcrops		3364		
18. Typic Ustifluvents	Eft	1101	1834	
Typic Torrifluvents		550		
Typic Calciorthids		183		
19. Typic Ustifluvents	Eub	947	1893	
Ustic Torriorthents		189		
Typic Ustorthents		189		
Basalt Flow		568		

Table 3.2 continued.

Unit	Symbol	Areas by Subgroup (km²)	Areas by Map Unit (km²)	Areas by Soil Order (km²)
20. Typic Ustorthents	Eoc	1380	2760	
Typic Ustifluvents		828		
Typic Calciorthids		276		
Typic Torriorthents		276		
21. Typic Ustorthents	Ehc	416	922	
Udic Haplustolls		92		
Entic Ustropepts		92		
Petrocalcic Calciustolls		46		
Typic Calciustolls		46		
Typic Ustropepts		46		
Typic Calciorthids		46		
Rock Outcrops		138		
Soils Predominantly Inceptisols				
22. Typic Ustropepts	Iuc	2656	4828	Inceptisols:
Ustollic Calciorthids		966		
Vertic Haplustolls		483		4923
Udic Pellusterts		241		
Typic Torrerts		241		
Udic Haplustolls		241		
23. Typic Ustropepts	Iuu	1595	2655	
Entic Ustropepts		531		
Typic Ustifluvents		265		
Ustollic Camborthids		132		
Ustollic Calciorthids		132		
Soils Predominantly Mollisols				
24. Typic Calciustolls	Mct	226	563	Mollisols:
Typic Calciorthids		113		
Typic Torriorthents		84		2809
Ustic Torripsamments		84		
Typic Haplustolls		56		
25. Typic Hapludolls	Mhr	11	26	
Entic Hapludolls		2		
Lithic Torriorthents		2		
Rock Outcrops		11		
26. Vertic Haplustolls	Muh	370	740	
Typic Ustifluvents		222		
Aridic Haplustolls		74		
Typic Torriorthents		37		
Typic Haplustolls		37		

Table 3.2 continued.

Unit	Symbol	Areas by Subgroup (km²)	Areas by Map Unit (km²)	Areas by Soil Order (km²)
Soils Predominantly Rock Outcrops				
27. Typic Calciorthids	Rcc	110	550	Rock Outcrops:
Lithic Calciorthids		55		
Rock Outcrops		385		29,259
28. Lithic Torriorthents	Rtt	1744	8721	
Typic Torriorthents		1744		
Typic Calciorthids		872		
Rock Outcrops		4361		
29. Typic Torriorthents	Rtc	8712	34,848	
Lithic Torriorthents		3485		
Typic Torrifluvents		1742		
Typic Ustifluvents		1742		
Typic Calciorthids		1742		
Rock Outcrops		17,425		
30. Typic Ustifluvent	Ruo	729	1822	
Rock Outcrops		1093		

CHAPTER 4

CRITERIA FOR INTERPRETATIONS AND GENERAL MANAGEMENT CONSIDERATIONS

Soil Limitations and Crop Suitability

The names of the map units in the soil map legend (Chapter 3) are given according to their classification for *Soil Taxonomy* (USDA-SCS, 1975). This system is quite accurate and highly technical. For planning purposes and for making useful interpretations one needs to list the kinds of limiting factors which these highly technical names imply. This section will take the names of the soils at the soil family and subgroup level and list the limiting factors implied by each name. Finally, some interpretations on the suitability of each soil for selected crops will be given.

Limiting Soil Properties in Yemen

In order to make accurate interpretations for specific, proposed agricultural land uses, consideration of possible limiting soil properties must be taken. As a first approximation, a listing is made of all the potentially limiting soil properties as observed in Yemen and as implied by the soil name according to *Soil Taxonomy*. These limiting soil properties are listed as follows (not necessarily in order of importance):

1. Soil moisture regime limitations:
   aridic or torric—irrigation always needed
   ustic—supplemental irrigation occasionally needed
   udic—irrigation not needed, no limitation

2. Micronutrient deficiencies (mainly concerning availability of Fe, Zn, Mn, Cu and Co) as related mainly to the calcareousness of the soil under consideration:
   highly calcareous—need to apply micronutrients
   calcareous—potential micronutrient deficiencies
   slightly to noncalcareous—probably no problem

3. Water-retention capacity as estimated by the family textural classes:
   coarse loamy, sandy skeletal, stony, bouldery—low capacity
   finer loamy and finer (except clayey)—probably adequate capacity

4. High gypsum content:
   possible subsidence from irrigation

5. Shallow to bedrock (lithic):
   low water-holding capacity and shallow rooting depth

6. Topographic limitations as related to erosion hazard or mechanization problems:
   mountainous, steep—severe problem
   undulating—moderate problem
   flat—no problem

7. Flooding hazard:
   soils found on active wadis or floodplains

8. Sodic features:
   high Na content imposes limitations for irrigation use

9. Terraced, mountain soils:
   mountain terraces may restrict many conventional mechanical tillage operations; also rock-walled terraces are more susceptible to erosion and collapse

10. Soil temperature regime limitations:
    isomesic—periods of frost are restrictive
    isothermic—some cool temperature restrictions
    hyperthermic—some seasonal or diurnal cool temperature restrictions; may also be too hot for some crops
    isohyperthermic—some crop restrictions due to prolonged high temperatures

11. Wind erosion hazard:
    blowing and drifting, resulting in the formation of dunes and hummocks

12. Vertic properties:
formation of cracks; shrinking and swelling

The Production of Selected Crops and Some Important Related Soil Limiting Factors

Twelve crops presently or potentially important to Yemeni agriculture were studied. These crops are maize, sorghum, cotton, millet, citrus, date palms, bananas, wheat, chick peas, potatoes, coffee, and alfalfa. Crop soil requirements and soil limiting properties are given for each crop (ILACO B. V., 1981).

1. Maize (*Zea mays*)

moisture —600 to 900mm rain, well distributed; at least ustic soil moisture regime
temperature —if isohyperthermic, grown only in winter
—if isomesic or isothermic, grown in summer
soil properties —ECe* not >5 mmhos/cm

2. Sorghum (*Sorghum vulgare*)

moisture —at least 250mm rainfall; possible in aridic soil moisture regime but better in ustic
temperature —isohyperthermic optimum
—isothermic possible in summer
soil properties —fairly resistant to ECe up to 6 mmhos/cm

3. Cotton (*Gossypium* spp.)

moisture —best grown in an aridic moisture regime with irrigation; if rainfed need at least 450mm or an ustic regime without irrigation
temperature —isohyperthermic optimum
—not possible in isomesic
soil properties —needs good drainage, no aquic regimes; salt-tolerant, ECe up to 10 mmhos/cm

4. Bulrush Millet (*Pennisetum typhoides*)

moisture —needs 200 to 300mm; can be grown in an aridic regime
temperature —isohyperthermic regime optimum; possible for summer in isothermic regime

*Electrical conductivity of the saturation extract.

soil properties —tolerates poor soils but must be well drained, no aquic moisture regimes; fairly salt tolerant

5. Citrus (*Citrus* spp.)

moisture —minimum rainfall of 1,100mm preferably supplemented to an optimum of 1,800 to 2,000mm; udic regime optimum but possibly ustic or aridic with irrigation
temperature —not suitable for isomesic or isohyperthermic regimes
soil properties —needs deep, well drained soils, not suitable in aquic regimes; sensitive to ECe >2.5 mmhos/cm

6. Date Palms (*Phoenix dactylifera*)

moisture —aridic suitable with no rainfall from flowering to ripening but 2,000mm of moisture is needed from groundwater and/or irrigation
temperature —isohyperthermic regime is optimum, hyperthermic is possible
soil properties —prefers sandy soils with groundwater <3m depth, aquic regime preferable; fairly salt tolerant with ECe <8 mmhos/cm

7. Banana (*Musa* spp.)

moisture —udic regime required for 1,500 to 2,000 mm water or intense irrigation
temperature —isohyperthermic regime is optimum; marginal in isothermic; not suitable for isomesic or hyperthermic regimes
soil properties —light, fertile soils with high organic matter and good internal drainage are optimum, not adequate for aquic regimes

8. Wheat (*Triticum aestivum*)

moisture —a minimum of 250mm is needed; optimum for the wetter end of the aridic and the drier end of ustic
temperature —not suitable for isohyperthermic
soil properties —best suited to medium to relatively heavy soils, not suited for coarse loamy families; not suited to aquic regimes; relatively resistant to salinities<7 mmhos/cm

9. Chick Peas (*Cicer arietinum*)

moisture —suitable for aridic and ustic re-

	gimes, not suited for udic regime
temperature	—not suitable for isohyperthermic or hyperthermic, suited to summers in isomesic or isothermic regimes
soil properties	—needs well drained soils, no aquic regimes; prefers heavy soils, not suited to coarse loamy families; very tolerant to salinity (no ECe limit given)

10. Potatoes (*Solanum tuberosum*)

moisture	—100 mm/month needed, no short periods of drought tolerated, udic regime is optimum
temperature	—not suited to isohyperthermic or hyperthermic regimes, better suited to isomesic or isothermic (borderline) in the summer
soil properties	—not suited to heavy soils or aquic regimes; susceptible to high salinity (no ECe limit given)

11. Coffee (*Coffea arabica*)

moisture	—best suited to dry end of udic regime (udic with short dry seasons)
temperature	—not suited to isohyperthermic, hyperthermic, or isomesic regimes, best in isothermic regime
soil properties	—needs good drainage and high organic matter (especially suited to Mollisols); aquic regime not tolerated

12. Alfalfa (*Medicago sativa*)

moisture	—best suited to udic but will tolerate others with irrigation
temperature	—not suited to isomesic, isohyperthermic, or hyperthermic (perhaps borderline) regimes, well suited to isothermic
soil properties	—suited to well drained soils, no aquic regimes; not suited to heavy soils, clayey families; not tolerant to ECe >3 mmhos/cm; moderately tolerant to pH's >6.5

Specific Soil Limitations of Soil Subgroups Included in the Soil Map Legend and Soil Families

As an aid to making useful agricultural interpretations, the limiting soil properties for each soil family listed on the soil map legend (Table 3.1, Chapter 3) is given. These limiting soil properties form the basis for interpreting the suitability of the twelve crops (given above) for the different soil subgroups and families (Table 4.1). This list of limiting soil properties can also form the basis for future interpretations for other crops not cited in this report.

1. Typic Calciorthid, Coarse Loamy, Mixed, Isohyperthermic; Typic Calciorthid, Loamy Skeletal, Mixed, Isohyperthermic; Typic Calciorthid, Coarse Loamy, Mixed, Calcareous, Hyperthermic; Typic Calciorthid, Fine Loamy, Mixed, Isothermic; and Typic Calciorthid, Coarse Loamy, Mixed, Isothermic Families

—Aridic soil moisture regime; needs irrigation
—Isohyperthermic temperature regime; may be too hot for some crops
—Highly calcareous; implying a high potential for micronutrient deficiencies and possible low available P
—Coarse loamy textural class; low water-holding capacity and some possible impediments to mechanical cultivation

2. Typic Torrifluvent, Coarse Loamy, Mixed, Calcareous, Hyperthermic; Typic Torrifluvent, Coarse Loamy, Mixed, Isomegathermic; Typic Torrifluvent, Sandy, Mixed, Calcareous, Isomegathermic; Typic Torrifluvent, Coarse Loamy, Mixed, Calcareous, Isohyperthermic; and Typic Torrifluvent, Coarse Loamy, Mixed Hyperthermic Families

—Aridic soil moisture regime; needs irrigation
—Isomegathermic, isohyperthermic and hyperthermic temperature regimes may be too hot for some crops
—Calcareous; may have some micronutrient deficiencies
—Low organic matter content
—Coarse loamy and sandy textural classes; low water-holding capacity and some possible impediments to mechanical cultivation

3. Typic Torriorthent, Sandy Skeletal, Mixed, Isohyperthermic; Typic Torriorthent, Coarse Loamy, Mixed, Calcareous, Isohyperthermic; Typic Torriorthent, Coarse Loamy, Mixed, Isothermic; Typic Torriorthent, Loamy Skeletal, Mixed, Calcareous, Hyperthermic; Typic Torriorthent, Coarse Loamy, Mixed, Hyperthermic; Typic Torriorthent, Coarse Loamy, Mixed, Isohyperthermic; Typic Torriorthent, Fine Loamy, Mixed, Isohyperthermic; Typic Torriorthent, Coarse Loamy, Mixed, Calcareous, Hyperthermic Families

—Aridic soil moisture regime; needs irrigation
—Isohyperthermic and hyperthermic temperature regimes may be too hot for some crops
—Calcareous; may have some micronutrient deficiencies
—Low organic matter content
—Sandy skeletal and coarse loamy textural classes; very low water-holding capacity and some possible impediments to mechanical cultivation

4. Typic Gypsiorthid, Coarse Loamy, Mixed, Isohyperthermic Family

—Aridic moisture regime; needs irrigation *but* soil will subside with irrigation
—Isohyperthermic temperature regime is too hot for some crops
—Highly gypsiferous; subsidence with irrigation
—Low organic matter content
—Coarse loamy textural class; low water-holding capacity and some possible impediments to mechanical cultivation
—Mountainous; highly erodible and not easily cultivated mechanically

5. Lithic Torriorthents, Coarse Loamy, Mixed, Calcareous, Hyperthermic Family

—Aridic soil moisture regime; needs irrigation
—Isohyperthermic temperature regime is too hot for some crops; isomesic is too cold for others
—Calcareous; may have some micronutrient deficiencies
—Low organic matter content
—Coarse loamy textural class; low water-holding capacity and some possible impediments to mechanical cultivation
—Shallow to bedrock (lithic contact <50cm); highly erodible and major impediments to mechanical cultivation

6. Typic Salorthid, Sandy, Mixed, Isohyperthermic; Typic Salorthid, Coarse Loamy, Mixed, Isohyperthermic; and Typic Salorthid, Coarse Loamy, Mixed, Hyperthermic Families

—Aquic moisture regime; very wet, needs drainage
—Isohyperthermic and hyperthermic temperature regimes may be too hot for some crops
—Very salty; high ECe
—Generally not suitable for any uses presently envisaged, except perhaps extensive grazing

7. Tropic Fluvaquent, Coarse Loamy, Calcareous, Mixed Isomegathermic Family

—Aquic or peraquic soil moisture regime; very wet needs drainage
—Isomegathermic (presently included in isohyperthermic) regime is too hot for some crops
—Some risk of flooding during rainy seasons

8. Tropaquent, Coarse Loamy, Mixed, Isomegathermic Family

—Aquic or peraquic soil moisture regime; very wet needs drainage
—Isomegathermic (presently included in isohyperthermic) regime is too hot for some crops
—Some risk of flooding during rainy seasons

9. Typic Udifluvent, Coarse Loamy, Calcareous, Mixed, Hyperthermic Family

—Hyperthermic temperature regime is too hot for some crops
—Calcareous; may have some micronutrient deficiencies
—Coarse loamy textural class; low water-holding capacity and some possible impediments to mechanical cultivation
—Some risk of flooding during rainy seasons

10. Typic Torripsamment, Mixed, Calcareous, Isomegathermic; and Typic Torripsamment, Mixed, Hyperthermic Families

—Aridic moisture-regime; needs some irrigation
—Isomegathermic and hyperthermic temperature regimes may be too hot for many crops
—Calcareous; may have some micronutrient deficiencies
—Texture implies low water-holding capacity
—Subject to blowing and drifting, formation of shifting dunes

11. Typic Ustifluvent, Coarse Loamy, Mixed, Isothermic; Typic Ustifluvent, Fine Loamy, Mixed, Isothermic; Typic Ustifluvent, Coarse Loamy, Mixed, Isohyperthermic; Typic Ustifluvent, Fine

Loamy, Mixed, Isohyperthermic; and Typic Ustifluvent, Coarse Loamy, Mixed, Calcareous, Hyperthermic Families

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Coarse loamy textural class; low water-holding capacity and some possible impediments to mechanical cultivation
—Terraced areas also impose some restrictions on certain types of mechanical cultivation
—Slight flooding hazard during rainy seasons
—Isohyperthermic and hyperthermic temperature regimes may be too hot for some crops

12. Typic Haplargid, Fine Loamy, Mixed, Hyperthermic Family

—Aridic moisture regime; needs irrigation
—Hyperthermic temperature regime may be too hot for some crops
—Calcareous; may have some micronutrient deficiencies

13. Typic Ustorthent, Sandy Skeletal, Mixed, Isothermic; Typic Ustorthent, Coarse Loamy, Mixed, Isothermic; Typic Ustorthent, Fine Silty, Mixed, Isothermic; Typic Ustorthent, Coarse Loamy, Calcareous, Mixed, Isomesic; and Typic Ustorthent, Fine Loamy, Mixed, Isothermic Families

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiences
—Sandy skeletal and coarse loamy textural classes; low water-holding capacity and some possible impediments to mechanical cultivation
—Isomesic temperature regime may have frosts in winter

14. Typic Camborthid, Loamy Skeletal, Mixed, Isothermic Family

—Aridic moisture regime; needs irrigation
—Calcareous; may have some micronutrient deficiencies
—Loamy skeletal textural class; low water-holding capacity and some possible impediments to mechanical cultivation
—Mountainous; highly erodible and not easily cultivated mechanically

15. Aquollic Salorthid, Fine Clayey, Mixed, Isothermic Family

—Aquic moisture regime; very wet, needs drainage
—Very salty; high ECe
—Generally not suitable for any uses envisaged, except perhaps extensive grazing

16. Typic Fluvaquent, Fine Clayey, Mixed, Isohyperthermic Family

—Aquic moisture regime; very wet, needs drainage
—Isohyperthermic temperature regime; may be too hot for some crops
—Calcareous; may have some micronutrient deficiencies
—Some risk of flooding during rainy seasons

17. Typic Ustipsamments, Mixed, Isohyperthermic Family

—Ustic moisture regime; may need supplemental irrigation
—Hyperthermic and isohyperthermic temperature regimes are too hot for many crops
—Calcareous; may have some micronutrient deficiencies
—Texture implies low water-holding capacity
—Subject to blowing and drifting, formation of sand dunes

18. Tropofluvents (Isohyperthermic)

—Somewhat calcareous; may have potential micronutrient deficiencies
—Isohyperthermic temperature regime may be too hot for some crops; isomesic regime may have frosts in winter
—Some risk of flooding during rainy seasons

19. Typic Natrustalf, Fine Clayey, Mixed, Isothermic Family

—Ustic moisture regime; may need supplemental irrigation
—Somewhat calcareous; may have potential micronutrient deficiencies
—Natric horizon; clay may deflocculate with the application of irrigation water

20. Entic Haplustoll, Coarse Loamy, Mixed, Isomesic Family

—Ustic moisture regime; may need supplemental irrigation

—Calcareous; may have some micronutrient deficiencies
—Isomesic temperature regime may have frosts in winter
—Mountainous; highly erodible and not easily cultivated mechanically

21. Typic Argiudoll, Sandy Skeletal, Mixed, Isomesic Family

—Somewhat calcareous; may have potential micronutrient deficiencies
—Isomesic temperature regime may have frosts in winter
—Mountainous; highly erodible and not easily cultivated mechanically
—Sandy skeletal textural class; low water-holding capacity and some possible impediments to mechanical cultivation

22. Lithic Ustorthent, Sandy Skeletal, Mixed, Isomesic Family

—Ustic moisture regime; may need supplemental irrigation
—Somewhat calcareous; may have potential micronutrient deficiencies
—Isomesic temperature regime may have frosts in winter
—Sandy skeletal textural class; low water-holding capacity and some possible impediments to mechanical cultivation
—Shallow to bedrock (lithic contact <50cm); highly erodible and major impediments to mechanical cultivation

23. Ustic Torriorthent, Fine Loamy, Mixed, Isothermic Family

—Aridic bordering on ustic moisture regime; will need some supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Rolling topography; moderate to high erosion potential

24. Udic Haplustoll, Loamy Skeletal, Mixed, Isothermic; and Udic Haplustoll, Fine Silty, Mixed, Isothermic Families

—Ustic bordering on udic moisture regime; may need some supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Mountainous; highly erodible and not easily cultivated mechanically
—Loamy skeletal textural class; low water-holding capacity and possible impediments to mechanical cultivation
—Terraced areas also impose some restrictions on certain types of mechanical cultivation
—Isomesic temperature regime may have frosts in winter

25. Entic Ustropepts (Isomesic)

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Isomesic temperature regime may have frosts in winter
—Mountainous; highly erodible and not easily cultivated mechanically

26. Petrocalcic Calciustoll, Fine Loamy, Mixed, Isothermic Family

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Low water-holding capacity due to petrocalcic horizon
—Lithic property; shallow to petrocalcic horizon
—Mountainous; highly erodible and not easily cultivated mechanically

27. Typic Calciustoll, Fine Silty, Mixed, Isothermic; and Typic Calciustoll, Coarse Loamy, Mixed, Isothermic Families

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies

28. Typic Ustropept, Fine Silty, Mixed, Isothermic; and Typic Ustropept, Fine Loamy, Mixed, Isothermic Families

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Mountainous; highly erodible and not easily cultivated mechanically
—Terraced areas also impose some restrictions on certain types of mechanical cultivation

29. Ustollic Calciorthid, Fine Loamy, Mixed, Isothermic Family

—Aridic bordering on ustic soil moisture regime; will need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies

30. Vertic Haplustoll, Fine Loamy, Mixed, Isothermic; Vertic Haplustoll, Coarse Silty, Mixed, Isothermic; and Vertic Haplustoll, Fine Loamy, Mixed, Isomesic Families

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Vertic properties; cracking may make it difficult to apply irrigation water evenly
—Isomesic temperature regime may have frosts in winter

31. Udic Pellustert, Fine Clayey, Montmorillonitic, Isothermic Family

—Ustic moisture regime; may need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies
—Fine clayey textural class; restricted water-holding capacity
—Vertic properties; cracking may make it difficult to apply irrigation water evenly

32. Typic Torrert, Fine Clayey, Montmorillonitic, Isothermic Family

—Aridic moisture regime; needs irrigation
—Calcareous; may have some micronutrient deficiencies
—Fine clayey textural class; restricted water-holding capacity
—Vertic properties; cracking may make it difficult to apply irrigation water evenly

33. Ustollic Camborthid, Coarse Loamy, Mixed, Isothermic Family

—Aridic bordering on ustic moisture regime; needs some irrigation
—Very calcareous; may have some micronutrient deficiencies

34. Ustic Torripsamment, Coarse Loamy, Mixed, Isothermic Family

—Aridic bordering on ustic soil moisture regime; needs supplemental irrigation
—Coarse loamy textural class; low water-holding capacity and possible impediments to mechanical cultivation
—Subject to blowing and drifting, formation of sand dunes
—Calcareous; may have some micronutrient deficiencies

35. Typic Haplustoll, Coarse Loamy, Mixed, Isothermic Family

—Ustic soil moisture regime; some supplemental irrigation may be needed
—Calcareous; may have some micronutrient deficiencies

36. Typic Hapludoll, Coarse Loamy, Mixed, Isothermic Family

—Calcareous; may have some micronutrient deficiencies
—Mountainous; highly erodible and not easily cultivated mechanically
—Coarse loamy textural class; low water-holding capacity and possible impediments to mechanical cultivation

37. Entic Hapludoll, Coarse Loamy, Mixed, Isothermic Family

—Calcareous; may have some micronutrient deficiencies
—Mountainous; highly erodible and not easily cultivated mechanically
—Coarse loamy textural class; low water-holding capacity and possible impediments to mechanical cultivation

38. Aridic Haplustolls (Isothermic)

—Ustic bordering on aridic soil moisture regime; will need supplemental irrigation
—Calcareous; may have some micronutrient deficiencies

39. Lithic Calciorthids (Isohyperthermic, Isothermic)

—Aridic soil moisture regime; needs irrigation
—Highly calcareous; may have some micronutrient deficiencies
—Isohyperthermic temperature regime may be too hot for some crops
—Lithic character and stoniness; low water-holding capacity and possible impediments to mechanical cultivation
—Mountainous; highly erodible and not easily cultivated mechanically

40. Rock outcrops or Basalt Flows

—These areas are usually unsuitable for any agriculture except perhaps for very extensive grazing.

The Suitability of Major Soil Families in Yemen for Twelve Important Crops

The ranges of climatic and soil properties optimum for twelve crops have been listed above. Limiting soil properties have also been listed for each soil subgroup and family described in the legend and soil profile descriptions, respectively. Each soil family, and hence subgroup, can now be rated as to its suitability for the cultivation of each of these twelve crops. (A moderate level of inputs—fertilizers, irrigation, pest control, etc.—and management is assumed.) There are three ratings possible. That is, a particular soil (as conceived by the soil family) is either 1-suitable, 2-moderately unsuitable, or 3-unsuitable for a particular crop.

Table 4.1 Suitability Ratings of Major Soil Families in the Yemen Arab Republic for Selected Crops

Key

1: suitable
2: moderately unsuitable
3: unsuitable

Crops and Ratings

Soil Family Name	Maize	Sorghum	Cotton	Bulrush Millet	Citrus	Date Palms	Banana	Wheat	Chick Peas	Potatoes	Coffee	Alfalfa
1. Typic Calciorthid, Coarse Loamy, Mixed, Isohyperthermic	2	1	1	1	3	1	2	3	3	3	3	3
2. Typic Calciorthid, Loamy Skeletal, Mixed, Isohyperthermic	3	1	2	1	3	2	3	3	3	3	3	3
3. Typic Calciorthid, Coarse Loamy, Mixed, Calcareous, Hyperthermic	2	1	1	1	2	2	3	3	3	3	3	2
4. Typic Calciorthid, Fine Loamy, Mixed, Isothermic	2	2	2	2	2	2	2	1	1	2	2	2
5. Typic Calciorthid, Coarse Loamy, Mixed, Isothermic	2	2	2	2	2	2	2	3	3	2	2	1
6. Typic Torrifluvent, Coarse Loamy, Mixed, Calcareous, Hyperthermic	2	1	1	1	2	2	3	3	3	3	3	2
7. Typic Torrifluvent, Coarse Loamy, Mixed, Isomegathermic	2	1	1	1	3	1	2	3	3	3	3	3
8. Typic Torrifluvent, Sandy, Mixed, Calcareous, Isomegathermic	2	1	1	1	3	1	2	3	3	3	3	3
9. Typic Torrifluvent, Coarse Loamy, Mixed, Calcareous, Isohyper thermic	2	1	1	1	3	1	2	3	3	3	3	3
10. Typic Torrifluvent, Coarse Loamy, Mixed, Hyperthermic	2	1	1	1	2	2	3	3	3	3	3	2
11. Typic Torriorthent, Sandy Skeletal, Mixed, Isohyperthermic	3	2	2	2	3	2	3	3	3	3	3	3
12. Typic Torriorthent, Coarse Loamy, Mixed, Calcareous, Isohyperthermic	2	1	1	1	3	1	2	3	3	3	3	3
13. Typic Torriorthent, Coarse Loamy, Mixed, Isothermic	2	2	2	2	2	2	2	3	3	2	2	1
14. Typic Torriorthent, Loamy Skeletal, Mixed, Calcareous, Hyperthermic	3	2	2	2	3	2	3	3	3	3	3	3
15. Typic Torriorthent, Coarse Loamy, Mixed, Hyperthermic	2	1	1	1	3	1	2	3	3	3	3	3
16. Typic Torriorthent, Coarse Loamy, Mixed, Isohyperthermic	2	1	1	1	3	1	2	3	3	3	3	3
17. Typic Torriorthent, Fine Loamy, Mixed, Isohyperthermic	2	1	1	1	3	1	1	3	3	3	3	3
18. Typic Torriorthent, Coarse Loamy, Mixed, Calcareous, Hyperthermic	2	1	1	1	3	1	2	3	3	3	3	3
19. Typic Gypsiorthid, Coarse Loamy, Mixed, Isohyperthermic	3	2	3	2	3	3	3	3	3	3	3	3

	Soil	Maize	Sorghum	Cotton	Bulrush Millet	Citrus	Date Palms	Banana	Wheat	Chick Peas	Potatoes	Coffee	Alfalfa
20.	Lithic Torriorthent, Coarse Loamy, Mixed, Calcareous, Hyperthermic	3	2	3	2	3	3	3	3	3	3	3	3
21.	Typic Salorthid, Sandy, Mixed, Isohyperthermic	3	3	3	3	3	1	3	3	3	3	3	3
22.	Typic Salorthid, Coarse Loamy, Mixed, Isohyperthermic	3	3	3	3	3	1	3	3	3	3	3	3
23.	Typic Salorthid, Coarse Loamy, Mixed, Hyperthermic	3	3	3	3	3	1	3	3	3	3	3	3
24.	Tropic Fluvaquent, Coarse Loamy, Calcareous, Mixed, Isomegathermic	2	2	3	3	3	1	3	3	3	3	3	3
25.	Tropaquent, Coarse Loamy, Mixed, Isomegathermic	2	2	3	3	3	1	3	3	3	3	3	3
26.	Typic Udifluvent, Coarse Loamy, Calcareous, Mixed, Hyperthermic	1	1	1	1	2	1	3	2	3	3	3	2
27.	Typic Torripsamment, Mixed, Calcareous, Isomegathermic	3	2	2	1	3	2	3	3	3	3	3	3
28.	Typic Torripsamment, Mixed, Hyperthermic	3	2	2	1	3	2	3	3	3	3	3	3
29.	Typic Ustifluvent, Coarse Loamy, Mixed, Isothermic	1	2	2	2	1	3	2	2	2	1	1	1
30.	Typic Ustifluvent, Fine Loamy, Mixed, Isothermic	1	2	2	2	1	3	2	1	1	1	1	1
31.	Typic Ustifluvent, Coarse Loamy, Mixed, Isohyperthermic	2	1	1	1	3	1	1	3	3	3	3	3
32.	Typic Ustifluvent, Fine Loamy, Mixed, Isohyperthermic	2	1	1	1	3	1	1	3	3	3	3	3
33.	Typic Ustifluvent, Coarse Loamy, Mixed, Hyperthermic	2	1	1	1	2	2	2	3	3	3	3	3
34.	Typic Haplargid, Fine Loamy, Mixed, Hyperthermic	2	1	1	1	2	3	3	2	3	3	3	3
35.	Typic Ustorthent, Sandy Skeletal, Mixed, Isothermic	2	1	2	1	1	3	3	3	3	1	2	1
36.	Typic Ustorthent, Coarse Loamy, Mixed, Isothermic	2	1	2	1	1	3	3	3	3	1	1	1
37.	Typic Ustorthent, Fine Silty, Mixed, Isothermic	1	1	2	1	1	3	2	1	1	2	1	2
38.	Typic Ustorthent, Coarse Loamy, Calcareous, Mixed, Isomesic	1	3	3	3	3	3	3	2	2	1	3	3
39.	Typic Ustorthent, Fine Loamy, Mixed, Isothermic	1	1	2	1	1	3	2	1	1	2	1	2
40.	Typic Camborthid, Loamy Skeletal, Mixed, Isothermic	3	2	2	2	2	3	3	3	3	3	2	2
41.	Aquollic Salorthid, Fine Clayey, Mixed, Isothermic	3	3	3	3	3	3	3	3	3	3	3	3
42.	Typic Fluvaquent, Fine Clayey, Mixed, Isohyperthermic	3	2	3	3	3	1	3	3	3	3	3	3
43.	Typic Ustipsamments, Mixed, Isohyperthermic	2	1	1	1	3	1	1	3	3	3	3	3
44.	Tropofluvents (Isohyperthermic)	2	1	1	1	3	1	1	3	3	3	3	3
45.	Typic Natrustalf, Fine Clayey, Mixed, Isothermic	2	2	2	2	3	3	2	1	1	2	1	2
46.	Entic Haplustoll, Coarse Loamy, Mixed, Isomesic	2	2	3	3	3	3	3	3	3	1	3	3
47.	Typic Argiudoll, Sandy Skeletal, Mixed, Isomesic	2	3	3	3	3	3	3	3	3	2	3	3
48.	Lithic Ustorthent, Sandy Skeletal, Mixed, Isomesic	3	3	3	3	3	3	3	3	3	3	3	3
49.	Ustic Torriorthent, Fine Loamy, Mixed, Isothermic	1	2	2	2	1	3	2	1	1	2	1	1
50.	Udic Haplustoll, Loamy Skeletal, Mixed, Isothermic	1	2	2	2	1	3	2	3	3	2	1	1

No.	Soil	Maize	Sorghum	Cotton	Bulrush Millet	Citrus	Date Palms	Banana	Wheat	Chick Peas	Potatoes	Coffee	Alfalfa
51.	Udic Haplustoll, Fine Silty, Mixed, Isothermic	1	2	2	2	1	3	2	1	1	2	1	1
52.	Entic Ustropepts (Isomesic)	2	3	3	3	3	3	3	2	2	2	3	3
53.	Petrocalcic Calciustoll, Fine Loamy, Mixed, Isothermic	2	2	3	2	3	3	3	2	2	3	1	2
54.	Typic Calciustoll, Fine Silty, Mixed, Isothermic	1	2	2	2	2	3	2	1	1	2	1	1
55.	Typic Calciustoll, Coarse Loamy, Mixed, Isothermic	1	2	2	2	2	3	3	3	3	2	1	1
56.	Typic Ustropept, Fine Silty, Mixed, Isothermic	1	2	2	2	1	3	2	1	1	2	1	1
57.	Typic Ustropept, Fine Loamy, Mixed, Isothermic	1	2	2	2	1	3	2	1	1	2	1	1
58.	Ustollic Calciorthid, Fine Loamy, Mixed, Isothermic	2	2	2	2	1	3	2	1	1	2	2	2
59.	Vertic Haplustoll, Fine Loamy, Mixed, Isothermic	1	2	2	2	1	3	3	1	1	2	1	1
60.	Vertic Haplustoll, Coarse Silty, Mixed, Isothermic	1	2	2	2	1	3	3	2	2	2	1	1
61.	Vertic Haplustoll, Fine Loamy, Mixed, Isomesic	1	3	3	3	3	3	3	1	1	1	3	3
62.	Udic Pellustert, Fine Clayey, Montmorillonitic, Isothermic	1	2	2	2	2	3	3	1	1	3	2	3
63.	Typic Torrert, Fine Clayey, Montmorillonitic, Isothermic	1	2	2	2	3	3	3	1	1	3	3	3
64.	Ustollic Camborthid, Coarse Loamy, Mixed, Isothermic	2	2	2	2	3	3	3	3	3	3	3	3
65.	Ustic Torripsamment, Coarse Loamy, Mixed, Isothermic	2	2	2	2	3	3	3	3	3	3	3	3
66.	Typic Haplustoll, Coarse Loamy, Mixed, Isothermic	1	2	2	2	1	3	2	3	3	2	1	1
67.	Typic Hapludoll, Coarse Loamy, Mixed, Isothermic	1	2	2	2	1	3	1	3	3	2	1	1
68.	Entic Hapludoll, Coarse Loamy, Mixed, Isothermic	1	2	2	2	1	3	1	3	3	2	1	1
69.	Aridic Haplustolls (Isothermic)	1	2	2	2	1	3	2	2	2	2	1	1
70.	Lithic Calciorthids (Isohyperthermic)	3	2	3	2	3	3	3	3	3	3	3	3
71.	Lithic Calciorthids (Isothermic)	3	2	3	2	3	3	3	2	3	3	3	3
72.	Rock Outcrops and Basalt Flows	3	3	3	3	3	3	3	3	3	3	3	3

Managing the Soils of North Yemen

Soil and Water Conservation

The need for highly developed soil and water conservation practices in Yemen is based on two pervasive factors in Yemeni agriculture. Moisture is most often the limiting factor in crop production and farming is usually practical where there is at least a noticeable gradient and often where slopes are extreme.

Given these conditions there are three soil and moisture conservation methods which Yemeni farmers have practiced for centuries and which have resulted in the presence of deep, well drained, loamy soils in every region of the country. These methods are spate irrigation, water harvesting, and terracing.

In practice these three methods are often used in numerous modifications and combinations, but the net effect is the same. Water runoff is conserved and collected, and with it comes transported soil material, primarily fine sand, silt, and clay. This phenomenon is of great importance in spate irrigation. It is also present in water harvesting and to a lesser extent in terraced agriculture.

SPATE IRRIGATION

Spate irrigation is a system which exploits the seasonally abundant but erratic water resources of the wadis.

Because of the gradient which is characteristic of the mountain wadis and the Tihama Piedmont it is possible by means of simple earthen diversion structures and ancillary canals to divert streams—especially at fullflow or "spate" stage—to fields by using gravity. Typically a canal will conduct silty water from the stream to a series of fields surrounded by bunds. The water is impounded in the Piedmont Tihama, where extensive tracts of land are topographically suited for cultivation and access. Irrigation water is transported several kilometers from the stream by this method. In the mountain wadis the bunds are often only about 50cm high. On the Tihama, where often there is little rainfall to supplement the water obtained by spate irrigation, bunds are sometimes two or more meters high. These soils are deep and have an excellent capacity for moisture storage. A thorough inundation saturates the profile and provides moisture for a crop over a sustained period of time.

WATER HARVESTING

Throughout North Yemen runoff is collected from bare rocky areas and directed by means of low dikes to cultivated fields. The most impressive examples of water harvesting occur in the Central and Northern Highlands. In the Central Highlands arable land is sometimes left fallow for the express purpose of directing the rain water it collects to an adjacent field.

TERRACING

The primary purpose of terracing is to retain, build up, or extend arable lands situated on slopes. It also has the effect of increasing effective rainfall with the result that in many areas of North Yemen where one would expect to find aridic soil moisture regimes, ustic moisture regimes are found instead. There are four types of terraces in North Yemen: steep slope terraces, gentle slope terraces, perched terraces, and basalt flow terraces.

Steep Slope Terraces

For the purposes of this study steep slope terraces are defined as those where the slope between terraces is greater than 25%.

Many steep and gentle slope terraces are positioned to harvest water from surrounding slopes. However, in steep slope terraces this takes on special significance. The presence and positioning of terraces on steep slopes can be grouped in four general classes which, in the absence of climatic data in many areas of the country, serve as indicators of the quantity of effective rainfall.

Class I: No moisture constraint. Terraces extend out of ravines on mountain ridges and high on mountain slopes. The terraces cover the entire face of the mountain, excluding only areas of rock outcrops.

Class II: Moderate moisture constraint. Terraces continue high up on mountain slopes but are limited in extent to the contours of the slope's watershed.

Class III: Serious moisture constraint. Terraces are only at the base of a mountain slope watershed.

Class IV: Severe moisture constraint. No terraces on mountainsides or footslopes.

In high mountains, where there is a wide variation in rainfall and air temperature, the lower slopes of a mountain may be class III or class IV while its upper slopes are class I or class II.

Gentle Slope Terraces

The use of terms like Western Plains, Mountain Plains, and Eastern Plains implies that there are significant amounts of level farm land in North Yemen. In fact this is not the case. Virtually all farm land in North Yemen is situated on topography with a visible slope. This fact, combined with the need to impound water to improve the moisture status of cultivated fields, accounts for the fact that even on the plains virtually all cropped land is terraced. The gentle slope terraces are not as dramatic as steep slope terraces but they do match them in extent.

Gentle slope terraces are the generally broad terraces of footslopes, mountain plains, wadis, and the Piedmont Tihama. With the major exception of some footslope soils, the soils of the gentle slope terraces tend to be deep; some are many meters in depth. In the wadis and the Piedmont Tihama these terraces are usually spate irrigated. By definition the slope of gentle slope terraces is less than 25%. In practice it tends to be much less than that.

An important difference between gentle slope terraces and steep slope terraces is the distances to rock outcrops, which determines the amount of coarse materials in the soil. Gentle slope terraces, as a general rule, are more silty and less sandy and gravelly than steep slope terraces. The presence or absence of rocks to reinforce terraces often serves as an indicator of the dominance of silt in a soil (see section on soil genesis, Chapter 1). Terraced soils with a high silt content often do not need stone reinforcement. Good examples of this are the terraces in the high silt content soils of Ibb, where, in some instances, even steep slope terraces are not reinforced with stone.

Perched Terraces

In terms of slope, perched terraces would also qualify as gentle slope terraces. However, they are different in that they are typical of the extensive exposed bedrock terrain of the Northern Highlands. The name is derived from the fact that the soil of these terraces is seldom more than one-and-a-half meters deep and it is "perched" on bedrock. Often a rock wall is built around a perimeter of bedrock and the inside of the perimeter is filled with transported soil materials.

Perched terraces are also formed by building low rock walls across small ravines and streams—sometimes only a meter or two wide—which are a part of the bedrock topography. Soil is often transported to these terraces, but the entrapment of silt, which is present in the runoff impounded, is also an important constituent of these soils.

Despite their proximity to parent rocks, these terraced soils are predominantly silt with comparatively small amounts of sand or coarser materials.

Basalt Flow Terraces

Again, these are gentle slope terraces in terms of slope. They are the small terraces of widely diverse shapes which have been formed in basalt flows by the combination of picking rocks to clear favorably situated land for cultivation and building walls around the land to preserve it. These terraces are common in large areas of the Central Highlands. The soils of basalt flow terraces are loams and silt loams, but stones and gravel are common. These soils tend to be very strongly calcareous.

Management Considerations of Important Soil Properties

Specific limiting soil properties are reviewed below in terms of their amenability to improved management. Some of these properties were also discussed earlier in relation to specific soil families.

SOIL PERMEABILITY AND MOISTURE RETENTION CHARACTERISTICS

The Fluvents and Orthents which are prevalent in the wadis and terraces of North Yemen are mostly loams which have both good permeability and good moisture retention characteristics. It is these qualities of the soils of Yemen which make agriculture possible in areas of erratic water availability. There are soils with restricted permeability on the highland plains and in the wadis around Taizz but these are of limited extent. More common are sandy and coarse-textured soils which are droughty because of poor moisture retention characteristics. Many of the abandoned terraces in the highlands are more gravelly than those still maintained. The Psamments of the plains also have less favorable water retention characteristics than the Fluvents of the wadis. However, as shown by the widespread presence of dune culture on the Tihama, crops with a vigorous and deep root system can exploit the limited rainfall which percolates quickly and then is stored in the dunes of the Piedmont and mid-Tihama.

DRAINAGE

The soils of North Yemen are generally well drained. The only notable exceptions observed are the restricted drainage soils of the coastal Tihama and Wadi Jawf.

SALINITY AND ALKALINITY

Except for some areas along the Red Sea, in Wadi Jawf, and in a very few areas in the highlands where salts collect in basins and locally the water is abnormally saline, salinity or alkalinity are not problems.

CRUSTING

Although not extremely serious, crusting does exist as a result of the soils' low organic matter content and high silt content. It was particularly noticed that on farms on the Tihama where machinery has been used extensively for four to ten years, poor soil structure and crusting is a problem. A rotation including several years of a sod crop would be the most obvious solution to this problem, if it is economically feasible.

MOISTURE STRESS AND SEDIMENT STRATIFICATION

Random moisture stress, apparently resulting from restricted water penetration due to stratification, was observed, but it is not as widespread as one might expect with the extensive cropping of alluvial soils in North Yemen. Most of these soils are cropped and worked regularly while the sediments making up the soil are deposited. The result of this is apparently the obliteration of any significant stratification at the surface 50cm in most areas. If new lands on the western or eastern plains were brought into production, stratification would very likely be a problem.

STONINESS

The presence of stones in the soil is a limitation for mechanized agriculture on the plains near the mountains. Mountainous, colluvial soils are also typically very stony.

HUMMOCKY SOILS

Due to the effects of wind erosion and deposition, hummocks are common over large areas of the plains and would impede land leveling for bringing new lands under irrigation.

MICRONUTRIENT DEFICIENCIES

Due to the high levels of $CaCO_3$ in the soils of North Yemen, deficiencies of iron, manganese, zinc, or copper would be likely with intensive culture of susceptible crops. However, such deficiences were not noted to be widespread under current agricultural practices.

GLOSSARY

Alluvium: A general term for clay, silt, sand, gravel, or other similar unconsolidated material deposited by a stream or other body of running water on the bed of the stream, its floodplain, or its deltas, or deposited as a cone or fan at the base of a mountain slope.

Argillic horizon: A mineral soil horizon that is characterized by the illuvial accumulation of layer-lattice silicate clays. The argillic horizon has a certain minimum thickness (depending on the thickness of the solum), a minimum quantity of clay in comparison with an overlying eluvial horizon (depending on the clay content of the eluvial horizon), and usually has coatings of oriented clay on the surface of pores, peds, or bridging sand grains. (Soil Sci. Soc. Am., 1978, p. 24).

Aridic: A soil moisture regime that has no moisture available for plants for more than half the cumulative time that the soil temperature at 50cm is above 5°C and has no period as long as 90 consecutive days when there is moisture for plants while the soil temperature is continuously above 8°C. (Soil Sci. Soc. Am., 1978, p. 24).

Barchan: A moving, isolated, crescent-shaped sand dune which forms where sand supply is limited and wind is constant and moderate in speed.

Bunds: Any artificial embankment used to control the flow of water on a river or on irrigated land.

Calcic horizon: A mineral soil horizon of secondary carbonate enrichment that is more than 15cm thick, has a calcium carbonate equivalent of more than 15%, and has at least 5% more calcium carbonate equivalent than the underlying C horizon. (Soil Sci. Soc. Am., 1978, p. 24)

Colluvium: A general term applied to any loose, heterogeneous, incoherent mass of soil material or rock fragments deposited chiefly by mass-wasting, usually at the base of a steep slope or cliff.

False-color infrared composite: Imagery produced from bands 4, 5, and 7 of digital multispectral scanner (MSS) data from the Landsat satellite.

Graben: An elongated, relatively depressed crustal block that is bounded by faults on its long sides.

Horst: An elongated, relatively uplifted crustal block that is bounded by faults on its long sides.

Laccolith: A lens-shaped concordant igneous intrusion less than eight kilometers in diameter.

Lacustrine sediments: Sediments deposited at the bottom of a lake.

Longitudinal dune: A long, narrow, usually symmetrical (in profile) sand dune, oriented parallel to the direction of the prevailing wind responsible for its construction.

Loess: Widespread, unconsolidated, commonly nonstratified deposit of fine-grained, highly calcareous material. Loess is generally believed to be windblown dust of Pleistocene age, but in Yemen loess deposition appears to be currently active. Loess in Yemen may be reworked by water sedimentation.

Marl: Unconsolidated deposits of a mixture of clay and calcium carbonate, formed under marine, or especially freshwater, conditions.

Mollic epipedon: A surface horizon of mineral soil that is dark colored and relatively thick, contains at least 0.6% organic carbon, is not massive and hard or very hard when dry, has a base saturation of more than 50% when measured at pH 7, has less than 250ppm P_2O_5 soluble in 1% citric acid, and is dominantly saturated with bivalent cations. (Soil Sci. Soc. Am., 1978, p. 27)

Petrocalcic horizon: A continous, indurated calcic horizon that is cemented with calcium carbonate and, in some places, with magnesium carbonate. It cannot be penetrated with a spade or auger when dry, it is impenetrable to roots, and its dry fragments do not slake in water. (Soil Sci. Soc. Am., 1978, p. 27)

Sabkhah: Coastal and inland salt flats or playas, built up by deposition of silt, clay, and muddy sand in shallow, sometimes extensive, depressions. The deposits are completely saturated with brine and are often salt encrusted.

Spate irrigation: Irrigation by diversion of water from a sudden flood on a river, caused by heavy rains higher up the valley.

Udic: A soil moisture regime that is neither dry for as long as ninety cumulative days nor for as long as sixty consecutive days in the ninety days following the summer solstice at periods when the soil temperature is above 5°C. (Soil Sci. Soc. Am., 1978, p. 28)

Ustic: A soil moisture regime that is intermediate between the aridic and udic regimes and common in temperate subhumid or subarid regions, or in tropical or subtropical regions with a monsoon climate. A limited amount of moisture is available for plants, but occurs at times when the soil temperature is optimum for plant growth. (Soil Sci. Soc. Am., 1978, p. 28)

Wadi: A stream bed or channel, or a steep-sided bouldery ravine, that is usually dry except during the rainy season. Wadis often form oases. "Wadi" also refers to the stream that runs in the bed. In Arabic, "wadi" can refer to any stream channel, whether it is dry or not.

GENERAL BIBLIOGRAPHY

Abdul-Rahman, Z., and P. G. Bisset. 1982. A comparison of fifteen introduced and two local varieties of barley for summer grain production at three nitrogen levels with irrigation. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 26. Ministry of Overseas Development, London, U. K.

Acres, B. D. (ed.). 1978a. Agricultural development on the Montane Plains. Land Resources Division Project Team, Land Resources Division, Surbiton, Surrey, England; vol. I.

Acres, B. D. 1978b. Landforms and soils of the Dhamar Agricultural Improvement Centre. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Land Resources Division, Surbiton, Surrey, England. YAR-01-36/REP-42/78.

Acres, B. D. 1980a. Soils and land suitability of the Montane Plains. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Land Resources Development Centre, Surbiton, Surrey, England. YAR-01-49/REC-52-80.

Acres, B. D. 1980b. Soils and land suitability of the Montane Plains and Wadi Rima. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Land Resources Development Centre, Surbiton, Surrey, England.

Agrar- und Hydrotechnik GmbH. 1970. *Studie uber den bau von zwei kleinstaudammen im gebiet der hochebene von Sana'a, Jemen bundesstelle fur entwicklungshilfe.* Essen, Federal Republic of Germany.

Agrar- und Hydrotechnik GmbH. 1980. Development of Wadi Jawf and its tributaries; technical report: soils. Essen, Federal Republic of Germany and Yemen Arab Republic Ministry of Agriculture.

Allison, L. E., and C. D. Moodie. 1965. Carbonate. pp. 1379-1396. *In* Black, C. A. (editor-in-chief). Methods of soil analysis; part II. American Society of Agronomy, Inc., Madison, WI, USA.

Anderson, I. P. 1979. Soil survey and irrigation suitability classification of Wadi Rima. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Land Resources Development Centre, Surbiton, Surrey, England.

Anon. 1973. Calcareous soils; report of the FAO/UNDP regional seminar on reclamation and management of calcareous soils. FAO, Rome, Italy.

Anon. 1980. The soil map of the arab countries at 1:1,000,000 scale; the legend. Soil Science Division, The Arab Center for the Studies of Arid Zones and Dry Lands (ASCAD), PO Box 2440, Damascus, Syria.

Arkley, R. J. 1963. Calculation of carbonate and water movement in soil from climatic data. Soil Sci. 96:239-248.

Asmaev, L. R. 1968. Data on soils of the southwestern part of the Arabian peninsula. pp. 249-257. *In* Kovda, V. A. and E. V. Labova (eds.). Geography and classification of soils of Asia; A. Gourevitch, translator. Israel Program for Scientific Translations Press, Jerusalem, Israel. Available from: US Department of Commerce, Clearinghouse for Federal Scientific and Technical Information, Springfield, VA 22151, USA.

Bagnold, R. A. 1951. Sand formations in south Arabia. Geogr. J. 117:78-86

Barshad, I. 1964. Chemistry of soil development. pp. 1-70. *In* Bear, F. E. (ed.). Chemistry of the soil. Reinhold, New York, NY, USA.

Beckingham, C. F., and R. B. Serjent. 1944. A journey by two Jesuits from Dhufar to Sana in 1590. Geogr. J. 93:194-207.

Benfield, A. C. 1975. Notes on the hydrogeology of the Montane Plains, Yemen Arab Republic. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Rep. WD/OS/75/1. Institute of Geological Sciences, London, U. K. YAR-01-15/75.

Bennema, J., J. Boulaine, R. Dudal, I. P. Gerasimov, E. Mockenhausen, and R. W. Simonson. 1968. Soil horizon description and definitions. Soil Sci. Soc. Am. Proc. 32:153-154.

Bernhard, M. (ed. and coordinator). 1979. Proposals for follow-on measures for the Al Boun Project; feasibility study by D. Rethwilm and W. Brandes. German Agency for Technical Cooperation (GTZ), Eschborn, Jemen Arab Republic and Federal Republic of Germany.

Bernhardt, C., R. Hawkins, R. Griffen, D. Hendricks, and M. Norvelle. 1980a. Water planning for Yemen; report of the CID Water Design Team on: —policy and planning;— watershed management practices; —irrigation practices;— appraisal of known information. Draft 2, working draft. [Consortium of International Development, Tucson, AZ, USA.]

Bernhardt, C., R. Hawkins, R. Griffen, D. Hendricks, and M. Norvelle. 1980b. Water policy initiatives for Yemen; recommendations by CID Water Design Team. Consortium for International Development, Tucson, AZ, USA; CID Yemen Report 052-1980-1.

Beyth, M. 1973. Correlation of Paleozoic-Mesozoic sediments in northern Yemen and Tigre, northern Ethiopia. Am. Assoc. Pet. Geologists Bull. 57:2440-2443.

Bidwell, O. W., and F. D. Hole. 1965. Man as a factor of soil formation. Soil Sci. 99:65-72.

Birot, P. 1968. Chapters 1-3, 6, and 7. The cycle of erosion in different climates; C. Ian Jackson and Keith M. Clayton, translators. University of California Press, Berkeley, CA, USA.

Bisset, P. G. 1981. Weather and groundwater levels on the Montane Plains. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 28. Ministry of Overseas Development, London, U. K.

Bisset, P. G. A comparison of seven introduced lentil varieties and the local variety under rainfed conditions on a Montane Plains terrace. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 36. Ministry of Overseas Development, London, U. K.

Bisset, P. G. A comparison of introduced and local varieties of wheat and barley on a rainfed terrace. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 37. Ministry of Overseas Development, London, U. K.

Bisset, P. G. Barley and lentil fertilizer trials on rainfed fields in the vicinity of Bani Saba (Spring 1982). Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 38. Ministry of Overseas Development, London, U. K.

Bisset, P. G., J. Farnworth, and S. A. Said. The response to nitrogen of a perennial/Italian tetraploid ryegrass mixture grown under irrigation. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 22. Ministry of Overseas Development, London, U. K.

Bisset, P. G., J. Farnworth, and S. A. Said. The response to nitrogen of two introduced (Kenyan) and the local variety of maize grown under irrigation. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 23. Ministry of Overseas Development, London, U. K.

Bisset, P. G., J. Farnworth, and S. A. Said. A comparison of two local sorghums with eight USA Sudan Grass and sorghum varieties for forage production under irrigation. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 24. Ministry of Overseas Development, London, U. K.

Bisset, P. G., J. Farnworth, and S. A. Said. The response of Maris Tabard oats to nitrogen when grown for forage or grain under irrigation. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 25. Ministry of Overseas Development, London, U. K.

Bisset, P. G., J. Farnworth, and S. A. Said. A comparison of local red, white, and yellow sorghums for grain production at three nitrogen levels with irrigation. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 26. Ministry of Overseas Development, London, U. K.

Bisset, P. G., and S. Mawly. Rainfall on the Montane Plains 1975-1980. Publ. 14. Dhamar Agricultural Improvement Center, Yemen Arab Republic. Yemen Arab Republic Ministry of Agriculture and U. K. Overseas Development Administration.

Bisset, P. G., and S. A. Said. A trial of 19 tropical grasses and 14 tropical legumes for forage production under irrigated and rainfed conditions of the Montane Plains. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 29. Ministry of Overseas Development, London, U. K.

Black, C. A. (ed. in chief), D. D. Evans, et. al. (associate eds.), and R. C. Dinauer (managing ed.). Methods of soil analysis. American Society of Agronomy, Inc., Madison, WI, USA.

Boros, I. J., and J. Lesztak. 1971. Soil survey in the Tihama lowland (Yemen Arab Republic); III. water management properties of soils. *Agrokem. es Talajtan* 20:217-230.

Boros, I. J., I. Szabolos, and G. Varallyay. 1970. Soil survey in the Tihama lowland (Yemen Arab Republic); I. factors of soil formation; II. soils and land capability classes. *Agrokem. es Talajtan* 19:405-464.

Boustead, P. J. 1975. A market consultancy report to LRD on the MPWR Project, 16 November - 18 December 1974. Rep. R436. Tropical Products Institute, UK Ministry of Overseas Development, London, U. K. YAR-01-14/75.

Bower, C. A., and L. V. Wilcox. 1965. Soluble salts. pp. 933-951. *In* Black, C. A. (editor-in-chief). Methods of soil analysis; part II. American Society of Agronomy, Inc., Madison, WI, USA.

Bremner, J. M. 1965. Total nitrogen. pp. 1149-1178. *In* Black, C. A. (editor-in-chief). Methods of soil analysis; part II. American Society of Agronomy, Inc., Madison, WI, USA.

Brogan, J. C., P. Lemos, and R. E. Carlyle. 1965. A survey of soils laboratories in sixty-four FAO member countries. FAO Soils Bull. 2. FAO, Rome, Italy.

Brown, G. F. 1970. Eastern margin of the Red Sea and the coastal structures in Saudi Arabia. Philos. Trans. R. Soc. London Ser. A: 267:75-87.

Buol, S. W. 1965. Present soil-forming factors and processes in arid and semi-arid regions. Soil Sci. 99:45-49.

Campbell, J. B. 1977. Variation of selected properties across a soil boundary. Soil Sci. Soc. Am. J. 41:578-582.

Carey, J. W., and D. D. Evans (eds.). 1974. Soil crusts. Arizona Exp. Stn. Tech. Bull. 214.

Chapman, H. D. 1965. Total exchangeable bases. pp. 902-904. *In* Black, C. A. (editor-in-chief). Methods of soil analysis; part II. American Society of Agronomy, Inc., Madison, WI, USA.

Chilton, P. J. 1979. Hydrogeology of the Montane Plains and Wadi Rima. Yemen Arab Republic and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-48/

Chilton, P. J. 1980. Hydrogeology of the Montane Plains. Yemen Arab Republic Montane Plains and Wadi Rima project: a land and water resource survey. Not for publication. Land Resources Development Centre, Surbiton, Surrey, England.

Cohen, J. M., M. Hebert, D. B. Lewis, and J. L. Swanson. 1980. Traditional organizations and development: Yemen's local development associations; local organization, participation, and development in the Yemen Arab Republic. Working note 7. Reprint of paper presented to The Annual Rural Sociology Conference, Cornell University. Rural Development Committee, Yemen Research Program, Center for International Studies, Cornell University, Ithaca, NY, USA.

Cohen, J. M., and D. B. Lewis. 1979. Review of literature and analyses of rural development issues in the Yemen Arab Republic; local organization, participation, and development in the Yemen Arab Republic. Working note 6. Reprint of Discussion Paper 52, Harvard Institute for International Development. Rural Development Committee, Yemen Research Program, Center for International Studies, Cornell University, Ithaca, NY, USA.

Day, Paul R. 1965. Particle fractionation and particle-size analysis. pp. 545-567. *In* Black, C. A. (editor-in-chief). Methods of soil analysis; part I. American Society of Agronomy, Inc., Madison, WI, USA.

Deflers, A. 1889. *Voyage au Yemen.* Paris.

Dewis, J., and F. Freitas. 1970. Physical and chemical methods of soil and water analysis. FAO Soils Bull. 10. FAO, Rome, Italy.

DHV Consulting Engineers (PO Box 85, 3800 AB Amersfoort, The Netherlands). 1981. Water resources study in the Tihama Coastal Plain; inception report. Directorate General of International Cooperation (DGIS), Ministry of Foriegn Affairs, Kingdom of the Netherlands, and Yemen Oil and Mineral Corporation, Yemen Arab Republic.

Egli, E. 1978. *Landnutzung und landnutzungsveraenderung in der region Wadi Mawr Arabische Republik Jemen. Geographischen Institut der Universitat Zurich,* Switzerland.

Electrowatt Engineering Services, Ltd. (Zurich, Switzerland) in association with: Hunting Technical Services Ltd. (Herts., England). 1978. Marib Dam and Irrigation Project; Yemen Arab Republic; annexes I. soil and land classification; III. agriculture; V. geology and geotechniques; VII. hydrology. Presidential Court, Government of Abu Dhabi.

FAO. 1973. Calcareous soils. Report of the FAO/UNDP Regional Seminar on Reclamation and Management of Calcareous Soils. FAO of the United Nations, Rome, Italy.

FAO. 1977. Guidelines for soil profile description. 2d ed. Publications Division, FAO, Rome, Italy.

Farnworth, J., and S. A. Said. Publ. 12, 13, 15-19, and 42-78 (42-78 are currently in press). Dhamar Agricultural Improvement Center, Yemen Arab Republic. Yemen Arab Republic Ministry of Agriculture and U. K. Overseas Development Administration.

Farnworth, J., and S. A. Said. The response of Sagla barley to nitrogen when grown for forage under irrigation. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 30. Ministry of Overseas Development, London, U. K.

Farnworth, J., and S. A. Said. A comparison of five USA, two Kenyan, and local Roumi maize under irrigation of the Montane Plains. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 31. Ministry of Overseas Development, London, U. K.

Farnworth, J., and S. A. Said. A comparison of five cultivation techniques for the production of Sagla barley under dryland conditions on the Montane Plains. 2. Summer sowing 1981. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 32. Ministry of Overseas Development, London, U. K.

Farnworth, J., and S. A. Said. The effect of irrigation frequency on local and imported wheat and barley (Spring 1982). Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 34. Ministry of Overseas Development, London, U. K.

Farnworth, J., and S. A. Said. The effect of five irrigation frequencies on Sonalika wheat (Summer 1981). Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 35. Ministry of Overseas Development, London, U. K.

Farnworth, J., S. A. Said, and S. Mawly. Publ. 1-11 and 41 (41 is currently in press). Dhamar Agricultural Improvement Center, Yemen Arab Republic. Yemen Arab Republic Ministry of Agriculture and U. K. Overseas Development Administration.

Farnworth, J., S. A. Said, and S. Mawly. A comparison of nine introduced and two local varieties of alfalfa grown under irrigation on the Montane Plains (first year). Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Publ. 20. Ministry of Overseas Development, London, U. K.

Ferris, Howard J. 1953. Report to the government of Saudi Arabia on reconnaissance soil and land classification of the South Asia Tihama. Rep. 69. FAO, Rome, Italy.

Gerig, Mathias. 1981. *Beitraege zur erforschung der antiken und mittelalterlichen Oase von Ma'rib (Arabische Republik Yemen). Ausgefuhrt im Auftrag des Deutschen Archaologischen Institutes am Geographischen Institut der Universitat Zurich*, Switzerland.

Geukens, F. 1966. Geology of the Arabian peninsula: Yemen. US Geol. Surv. Prof. Pap. 560-B.

Gibb, Sir Alexander, & Partners (Reading, England). 1979. Development of Wadis Bana and Rasyan; stage I. Yemen Arab Republic Ministry of Agriculture.

Gibb, Sir Alexander, & Partners (Reading, England) and Bureau Central D'Etudes pour les Equipements D'Outre- Mer (Paris, France). 1977a. Development of Wadi Al Kharid; stage I preliminary report. Yemen Arab Republic Ministry of Agriculture.

Gibb, Sir Alexander, & Partners (Reading, England) and Bureau Central D'Etudes pour les Equipements D'Outre- Mer (Paris, France). 1977b. Development of Wadi Bana; stage I preliminary report. Yemen Arab Republic Ministry of Agriculture.

Gibb, Sir Alexander, & Partners (Reading, England) and Bureau Central D'Etudes pour les Equipements D'Outre- Mer (Paris, France). 1977c. Development of Wadis Bana, Al Kharid, and Rasyan; inception report. Yemen Arab Republic Ministry of Agriculture.

Gibb, Sir Alexander, & Partners (Reading, England) and Bureau Central D'Etudes Pour Les Equipements D'Outre- Mer (Paris, France). 1977d. Development of Wadis Bana and Rasyan; stage I appendices to preliminary report. Yemen Arab Republic Ministry of Agriculture.

Gibb, Sir Alexander, & Partners (Reading, England) and Bureau Central D'Etudes Pour Les Equipements D'Outre- Mer (Paris, France). 1977e. Development of Wadi Rasyan; stage I preliminary report. Yemen Arab Republic Ministry of Agriculture.

Gile, L. H. 1975a. Causes of soil boundaries in an arid region: I. age and parent materials; II. dissection, moisture and faunal activity. Soil Sci. Soc. Am. Proc. 39:316-330.

Gile, L. H., F. F. Peterson, and R. B. Grossman. 1965. The K horizon: a master soil horizon of carbonate accumulation. Soil Sci. 99:74-82.

Gile, L. H., F. F. Peterson and R. B. Grossman. 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Sci. 101:347-360.

Gillett, J. B. 1941. Plant formations of Western British Somaliland and Harar province of Abyssinia. Kew Bull. 194:37-199.

Gillette, D., and P. A. Goodwin. 1974. Microscale transport of sand-sized soil aggregates eroded by wind. J. Geophys. Res. 79:4080-4084.

Golden, J. P., P. Lemos, R. E. Carlyle, and F. C. R. Freitas. 1966. Guide on general and specialized equipment for soils laboratories. FAO Soils Bull. 3. FAO, Rome, Italy.

Goosen, D. 1967. Aerial photo interpretation in soil survey. FAO Soils Bull. 6. FAO, Rome, Italy.

Grolier, M. J. and W. C. Overstreet. 1978. Geologic map of the Yemen Arab Republic (Sana). U.S. Geological Survey Miscellaneous Investigations Series Map I-1143-b.

Grolier, M. J., G. C. Tibbitts, Jr., and M. M. Ibrahim. 1981. A qualitative appraisal of the hydrology of the Yemen Arab Republic from landsat images. Open-file rep. 80-565. USGS, Reston, VA, USA.

Hain, W. 1969. Initial agricultural development of the Yemeni Tihama. *Beitr. Trop. Subtrop. Landwirtsch. Tropenveterinaermed.* 7:241-251.

Halcrow, Sir William, and Partners. 1978. Soils and land capability; vol. 4, annex C. *In* Wadi Surdad: development on the Tihama. Yemen Arab Republic Ministry of Agriculture.

Hebert, M. 1981. Preliminary field report: socio-economic conditions and development; Maghlaf, Hodeidah Governorate; working note 8. Local organization, participation, and development in the Yemen Arab Republic. Rural Development Committee, Yemen Research Program, Center for International Studies, Cornell University, Ithaca, NY, USA.

Hendy, C. 1979. Livestock production in the Montane Plains. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-41/REC-29/79.

Henry, P. W. T. 1976. Forestry on the Montane Plains. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-26/ REC -11/76.

Hepper, F. N. 1977. Outline of the vegetation of the Yemen Arab Republic. Publ. Cairo Univ. Herb. 7 & 8:307-322.

Holm, D. A. 1960. Desert geomorphology in the Arabian peninsula. Science 132:1369-1379.

ILACO, B. V. International Land Development Consultants (Arnhem, The Netherlands). 1981. Agricultural compendium for rural development in the tropics and subtropics. Commissioned by the Ministry of Agriculture and Fisheries, The Hague, The Netherlands. Elsevier Scientific Publishing Co., Amsterdam, Oxford, New York.

Italconsult (Rome). 1975. Water supply and sewerage systems for Sana'a and Hodeida (phase II); Sana'a sewerage system master plan. United Nations Development Programme, WHO (executing agency), and Yemen Arab Republic Ministry of Public Works (government cooperating agency); vol. II appendices A-E.

Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Englewood Cliffs, NJ, USA.

Japanese Master Plan Study Team. n. d. Study for Hajjah Province integrated rural development in the Yemen Arab Republic; S. Inove, leader. No information available.

Kilmer, Victor J. (ed.). 1982. Handbook of soils and climate in agriculture. CRC Press, Boca Raton, FL, USA.

Kopp, H. 1975. *Die raumliche differenzierung der agrarlandschaft in der Arabischen Republik Jemen (Nordjemen). Erdkunde* 29:59-68.

Le Houerou, H. N. 1976. An ecological assessment of the project areas with special reference to sand stabilization in Wadi Rima and prospects for fodder shrubs and trees. The Montane Plains and Wadi Rima Project: a land and water resource survey. MPWR Project, PO Box 1287, Sana'a, Yemen Arab Republic.

LRD Project Team. 1975. Outline proposals for investment in rural roads and village water supplies. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-18/REP-5/75.

LRD Project Team. 1978. Agricultural development on the Montane Plains; B. D. Acres (ed.). Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-31/REP-18/77.

LRD. 1979. Montane Plains and Wadi Rima project report. Surbiton, Surrey, England.

Makatari, A. M. A. 1971. Water rights and irrigation practices in Lahj: a study of the applications of customary and Saharian law in southwest Arabia. pp. 3-45.

Mandaville, J. P. 1977. Plants. pp. 229-267. *In* Scientific results of the Oman fauna and flora survey, 1975. J. Oman Studies Spec Rep.

Melton, F. A. 1940. A tentative classification of sand dunes—its application to dune history in the southern high plains. J. Geol. 48:113-145.

Merabet, Zohra. 1980. A survey of water activities under foreign assistance in the Yemen Arab Republic. Prepared under the USAID/YEMEN Contract No. 279-80-589.

Morton, J. 1980. Agricultural marketing in the Yemen Arab Republic with special reference to the Montane Plains and Wadi Rima. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-45/REC-35/79.

Nasir, Ghazi. 1966. *Naturliche voraussetzungen for die landwirtschaftiche produktion in Jemen und ihre asunutzung. Institut fur Tropische und Subtropische Landwirtschaft. Zum landwirtschaftlichen diplomexamen vorgelegt an der Landwirtschaftlichen Fakultat der Karl-Marx-Universitat, Leipzig.*

Naval Weather Services. 1974. Worldwide airfield summaries.

Newhall, F. 1972. Calculation of soil moisture regimes from the climatic record; rev. 4. Mimeographed, 17 pages, 3 tables, 7 figures. Soil Conservation Service, USDA, Washington, D. C., USA.

Olsen, S. R., and L. A. Dean. 1965. Phosphorus. pp. 1035-1049. *In* Black, C. A. (editor-in-chief). Methods of soil analysis; part II. American Society of Agronomy, Inc., Madison, WI, USA.

Pacheco, R. A. 1978. The application of landsat imagery to soil and land-use mapping in the central region of the Yemen Arab Republic. FAO Series AGLT. FAO, Rome, Italy.

Petterssen, S. 1940. Weather analysis and forecasting. McGraw-Hill Book Co., Inc., New York, USA.

Philby, H. St. J. B. 1938. The land of Sheba. Geogr. J. 92:1-21.

Popov, G. B., and W. Zeller. 1963. Ecological survey report on the 1962 survey in the Arabian Peninsula. Unpubl. rep. ref. UNSF/DL/ES/6. FAO, Rome, Italy.

Powers, R. W., L. F. Ramirez, C. D. Redmond, and E. L. Elberg. 1966. Geology of the Arabian peninsula: sedimentary geology of Saudi Arabia. US Geol. Surv. Prof. Pap. 560-D.

Pratt, D. J. (ed.). 1976. Initial development prospects; vol. 1, Montane Plains; vol. 2, Wadi Rima. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-23/REP-1/764.

Rechcigl, M., Jr. (ed.). 1982. Handbook of agriculture productivity. CRC Press. Boca Raton, FL, USA; vol. I, II.

Reilly, P. M. (comp.). 1974. Land resource bibliography—Yemen. Unpublished draft. Land Resources Division, Surbiton, Surrey, England.

Richards, L. A. (ed.). 1954. Saline and alkali soils. USDA Agriculture Handbook 60. US Government Printing Office, Washington, DC, USA.

Robinsons. 1980. Results of groundwater drilling. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-43a/RFC-33/80.

Ross, L. A., in consultation with J. M. Cohen. 1981. An informal banking system: the remittance agents of Yemen; working note 12. Local organization, participation, and development in the Yemen Arab Republic. Rural Development Committee, Yemen Research Program, Center for International Studies, Cornell University, Ithaca, NY, USA.

Schematic Soil Map. anon. n. d. Land Management Department of the Ministry of Agriculture and Water, Kingdom of Saudi Arabia.

Schoch, R. 1977. *Regionale gliederung der Jemenitischen Arabischen Republik mit hilfe von landsat-satellitenbildern Thesis, Geographischen Institut der Universitat Zurich,* [Switzerland].

Schoch, R. 1978. Land evaluation and classification from landsat-imagery in the Yemen Arab Republic. Swiss Technical Co-operation Service, Zurich, Switzerland.

Shantz, H. L. 1956. History and problems of arid lands development. pp. 3-25. *In* White, G. F. (ed.). The future of arid lands. American Association for the Advancement of Science 43.

Shokri, N. M. 1955. Petrography of the alkaline volcanic rocks of Yemen. *Bull. Inst. Egypte* 36:165-175.

Shokri, N. M., and E. Z. Basta. 1955. A classification of the pyroclastic rocks of Yemen. *Bull. Inst. Egypte* 36:129-164.

Smith, G. D. 1973. Soil moisture regimes and their use in soil taxonomies. *In* Field soil water regimes. Soil Sci. Soc. Am. Spec. Pub. Ser. 5.

Smith, G. D., F. Newhall, L. H. Robinson, and D. Swanson. 1964. Soil temperature regimes: their characteristics and predictabilty. SCS-TP-144. Soil Conservation Service.

Smith, R. M., P. C. Twiss, R. K. Krauss, and M. J. Brown. 1970. Dust deposition in relation to site, season, and climatic variables. Soil Sci. Soc. Am. Proc. 34:112-117.

Smyth, A. J. 1970. The preparation of soil survey reports. FAO Soils Bull. 9. FAO, Rome, Italy.

Sogreah Consulting Engineers (Grenoble, France). 1979. Wadi Siham feasibility study; interim report. Tihama Development Authority, Ministry of Agriculture, Yemen Arab Republic.

Soil Science Society of America. 1978. Glossary of soil science terms. Soil Science Society of America, 677 South Segoe Road, Madison, WI 53711, USA.

Soil Survey Staff. 1951. Soil survey manual. Agricultural Handbook 18. Soil Conservation Service, USDA, Washington, D. C. For sale by Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402, USA.

Soil Survey Staff. 1975. Soil taxonomy; a basic system of soil classification for making and interpreting soil surveys. Agricultural Handbook 436. Soil Conservation Service, USDA, Washington, D. C. USA.

Speece, M. (comp.). 1982. Environmental report on Yemen (Yemen Arab Republic). Revised draft. National Park Service Contract No. CX-0001-0-0003 with US Man and the Biosphere Secretariat, Department of State, Washington, DC. Prepared by Arid Lands Information Center, Office of Arid Lands Studies, University of Arizona, Tucson, AZ, 85721, USA.

Steele, J. G. 1967. Soil survey interpretation and its use. FAO Soils Bull. 8. FAO, Rome, Italy.

Swanson, J. C. 1981. Preliminary field report: socio-economic conditions & development; Bani'awwam, Haaja Governorate; working note 9. Local organization, participation, and development in the Yemen Arab Republic. Rural Development Committee, Yemen Research Program, Center for International Studies, Cornell University, Ithaca, NY, USA.

Syers, J. K., M. L. Jackson, V. E. Beiheiser, R. N. Clayton, and R. W. Rex. 1969. Eolian sediment influences on pedogenesis in the Quaternary. Soil Sci. 107:421-427.

Tan, K. 1970. Agricultural problems in south Arabia. World Crops 22:397-400.

Tesco-viziterv-vituki. 1971. Survey of the agricultural potential of the Wadi Zabid, Yemen Arab Republic, soils and land capability. Technical rep. 8. Budapest, Hungary. AGL:SF/YEM 1.

Thesiger, W. 1946. A new journey in southern Arabia. Geogr. J. 108:129-145.

Thesiger, W. 1948. Across the empty quarter. Geogr. J. 111:1-21.

Tipton and Kalmbach, Inc. 1979. Development of Wadi Mawr; part II, appendicies A and B. Denver, CO, USA.

Tombs, J. M. C., and K. E. Rollin. 1976. Geophysical surveys to assist hydrogeological investigations in the Yemen Arab Republic. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Rep. 35. Applied Geophysics Unit, UK Institute of Geological Sciences. Ministry of Overseas Development, London, U. K. YAR-01-28/76.

Tuskegee Institute, The Carver Research Foundation, Office of International Programs (Alabama). 1981a. Tropical and subtropical fruit improvement project; final report, parts I and II. Yemen Arab Republic Contract Number 279-0024.

United States Soil Conservation Service. 1972. Soil survey laboratory methods and procedures for collecting soil samples. USDA Soil Surv. Invest. Rep. 1. U.S. Government Printing Office, Washington, DC, USA.

Vesey-Fitzgerald, D. F. 1955. Vegetation of the Red Sea coast south of Jeddah, Saudi Arabia. J. Ecol. 43:477-489.

Wegener, G. 1957. The water supply in Yemen. *Wasserwirtsch. Wassertech.* 7:241-242.

Wernstedt, F. 1972. World climatic data. Climatic Data Press, Lemont, PA, USA.

Western, S. 1972. The classification of arid zone soils; II. the classification of Sedasols in Saudi Arabia. J. Soil Sci. 23:279-297.

Westinga, E., and D. C. P. Thalen. 1980. A survey and problem analysis of the rangelands in the Rada' District. Rada' Integrated Rural Development Project Tech. Note 5. ILACO, Netherlands. 4.08.034.

Wickens, G. E. 1976. The flora of J. Marra. London H.M.S.O.

Williams, J. B. 1976. Climatic data, 1974-75. Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resource survey. Ministry of Overseas Development, London, U. K. YAR-01-21/REC-8/76.

Wissmann, H. von. 1972. *Die Juniperus-Gebirgswalder in Arabien. Erdwiss. Forsch.* 4:157-176.

Wood, J. R. I. 1982. Report for the Erosion Control and Afforestation Project in the Haraz region. G.T.Z., Eschborn, German Federal Republic.

Wood, J. R. I. 1983a. A handbook of the Yemen flora. Routledge, Kegan, & Paul, London, U. K.

Wood, J. R. I. 1983b. The vegetation of the Tihama in the report of the 1982 Tihama Expedition. London, U. K.

World Bank. 1979. Yemen Arab Republic. Development of a traditional economy.

Yaalon, D. H., and E. Ganor. 1973. The influence of dust on soils during the Quaternary. Soil Sci. 116:146-155.

Yaalon, B., and B. Yaron. 1966. Framework for man-made soil changes—an outline of metapedogenesis. Soil Sci. 102:272-277.

Yemen Arab Republic, Sana [Geographic]. n. d. USGS. USGS Misc. Invest. Ser. Map I-1143-A.

Yemen Arab Republic, Sana [Geologic]. 1978. M. J. Grolier and W. C. Overstreet. USGS Misc. Invest. Ser. Map I-1143-b.

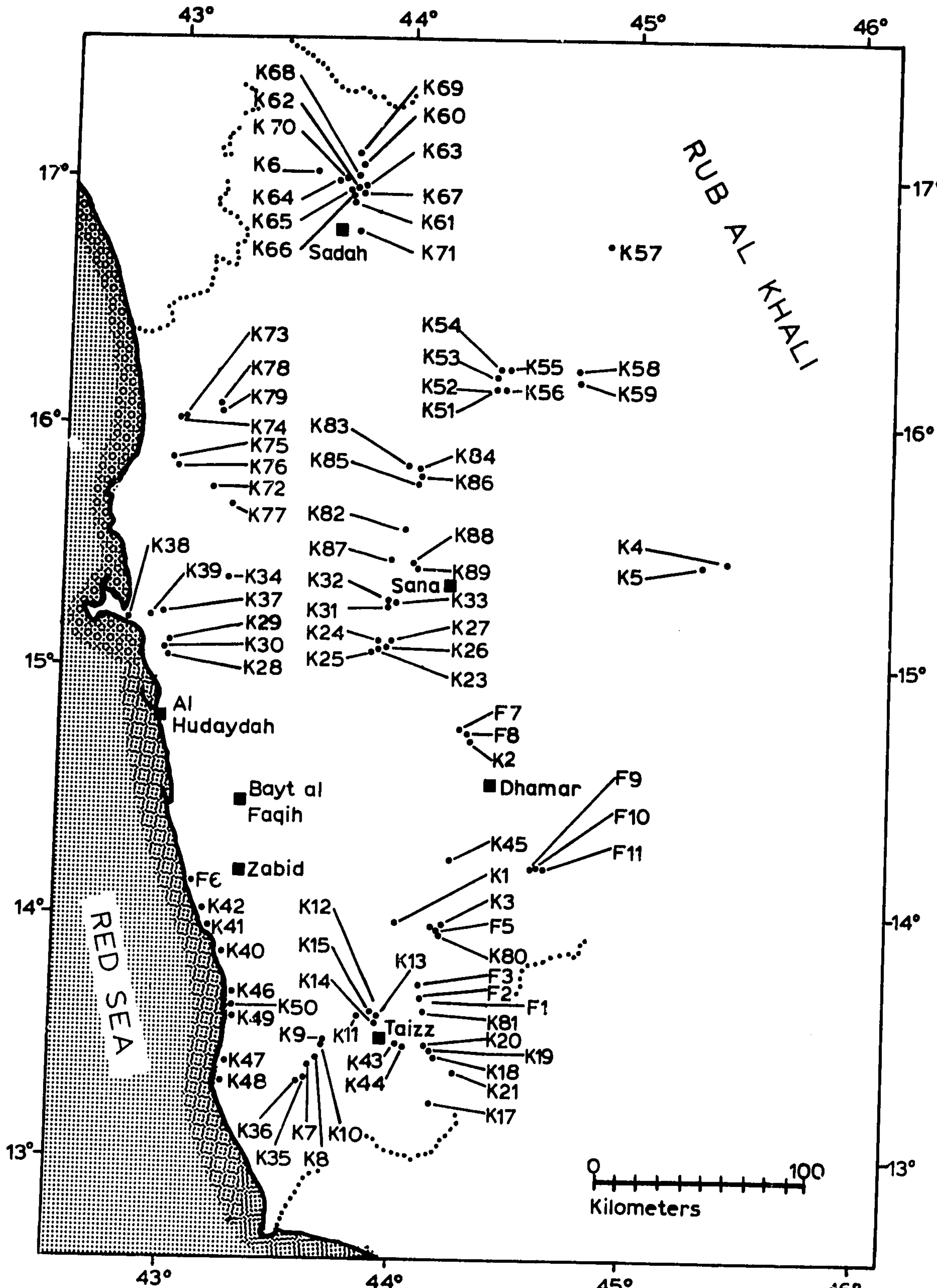
Young, F. W., M. Hebert, and J. C. Swanson. 1981. The ecological context of local development in Yemen; working note 13. Local organization, participation, and development in the Yemen Arab Republic. Rural Development Committee, Yemen Research Program, Center for International Studies, Cornell University, Ithaca, NY, USA.

Zohary, M. 1973. Geobotanical foundations of the Middle East. 2 vols. Stuttgart, Germany.

APPENDIX—BENCHMARK SOILS DATA

Eight profile descriptions and laboratory data were selected from the entire soil survey of the Yemen Arab Republic for inclusion in the benchmark soils data. The profiles were selected mainly because they were considered to be good examples of the most typical soils encountered during the soil survey. All soil profile sites are shown on Map I.1.

In these eight descriptions and data only three were completely characterized by the National Soil Survey Laboratory in Lincoln, Nebraska. The other five profiles were analyzed, as were the bulk of the Yemen soil samples, by the Agricultural Research Laboratory at Ausseifere (Taizz). Staff, equipment and budget limitations at Ausseifere did not permit all the detailed analyses as were produced for the three profiles sent to Lincoln.



Map I.1: Soil profile sites of the Yemen soil survey.

Soil Profile Site F1

Site Information

Classification: TYPIC TORRIORTHENT, COARSE LOAMY, MIXED, CALCAREOUS, ISOTHERMIC FAMILY
Date and time described: April 13, 1981, 2 PM
Authors: T. Forbes and J. King
Location: 5 km southwest of Al Ganed
Elevation: 1420 m
Physiographic position: convex slope, plain
Topography of surrounding country: undulating
Microtopography: gullies, tussacks
Slope: 4%
Land use: *Acacia arabica* present, surrounding areas used for sorghum, corn and wheat
Climate: Estimated as Aridic (rainfall about 200 mm/yr)

Soil Information

Parent Material: Alluvium and colluvium from volcanic rocks of hillcrest. Large addition of loess.
Drainage class: Well-drained
Moisture conditions: Dry down to one meter, then slightly moist.
Depth to groundwater: unknown
Surface stones or outcrops: Fine gravel partially covering surface; hillcrest very rocky.
Evidence of erosion: Severe sheet and gully erosion, possible wind erosion.
Salt content: No apparent salt or alkali
Human influence: Heavy grazing

Profile Description

C1 0-20 cm F1	Light yellowish brown 10YR 6/4 (dry); silt loam; weak coarse to fine subangular blocky structure; non-sticky, non-plastic, very friable (moist); soft (dry); common, very fine discontinuous, horizontal, inped, tubular, closed pores; calcareous; common fine roots; clear, broken boundary.
2C 20-31 cm F2	Brown, 10YR 5/3 (moist); slightly gravelly silt loam; weak coarse to fine subangular blocky structure; non-sticky, non-plastic, very friable (moist); few, very fine, discontinuous, random, inped, tubular, closed pores; calcareous; frequent mineral fragments- basalt rock; few small roots; clear, broken boundary.
3C 31-41 cm F3	Yellowish brown, 10YR 5/4 (moist); silt loam; weak to moderate, coarse to fine subangular blocky structure; slightly sticky (wet); slightly plastic, very friable (moist); few, micro, discontinuous, random, inped, tubular, closed pores; calcareous; few fine to very fine roots; clear, wavy boundary.
4C 41-69 cm F4	Yellowish brown, 10YR 5/4 (moist); gravelly silt loam; moderate coarse to fine subangular, blocky structure; slightly sticky (wet); slightly plastic, very friable (moist); few very fine, discontinuous, random, inped, tubular, closed pores; calcareous; few gravels, angular to sub-angular fresh basalt rock fragments; few ostracod shells; very few fine roots; clear wavy boundary.
5C 69+ cm F5	Yellowish brown 10YR 5/4 (moist); silt loam; weak to moderate, coarse to fine, subangular blocky structure; slightly plastic and slightly sticky (wet); very friable (moist); few, very fine, discontinuous, random, inped, tubular, closed pores; calcareous; very few coarse and fine roots.

Note: Gravel layer thickness and depth is quite variable for polypedon.

See Figure I.1.

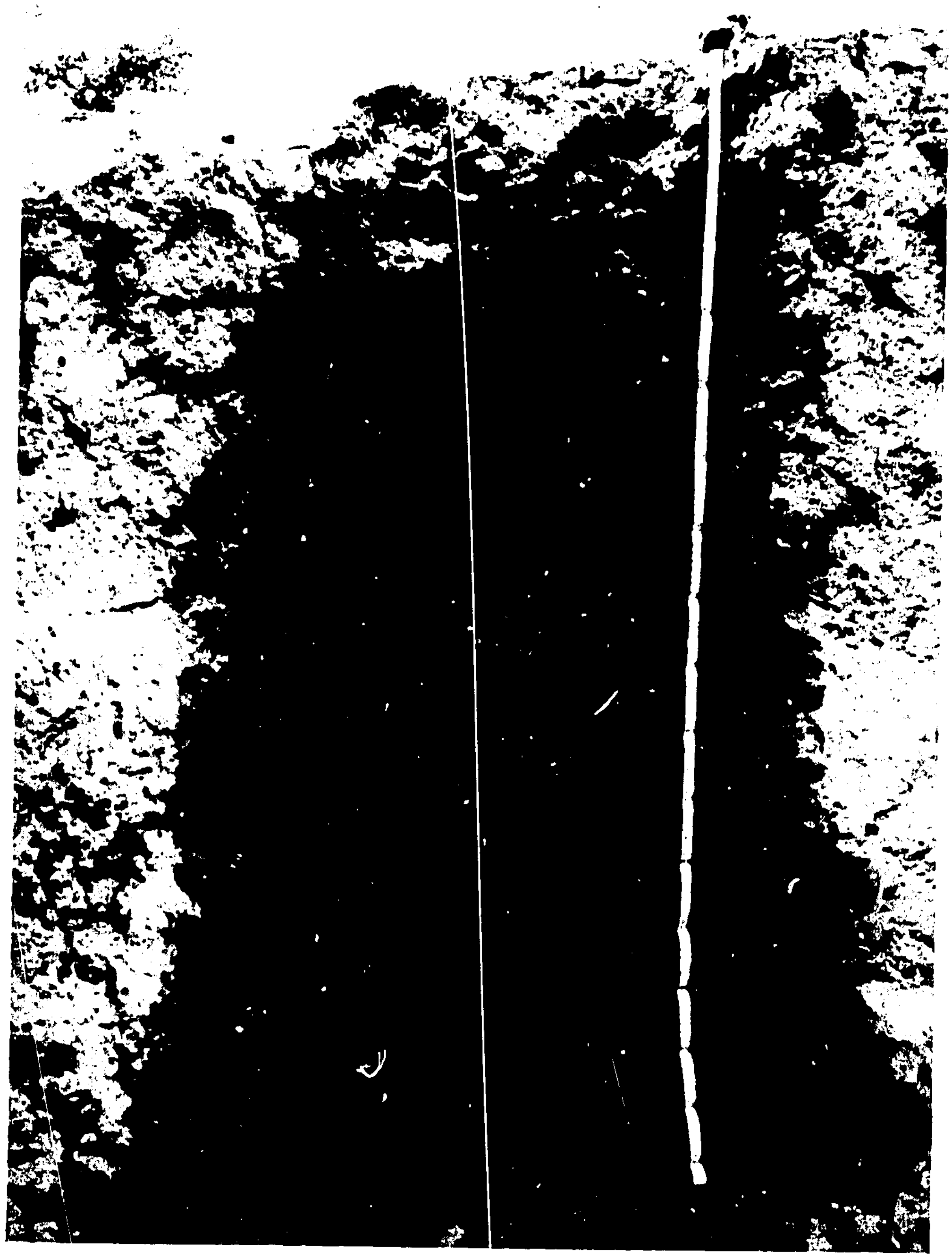


Figure I.1: Soil profile at site F1.

ANALYTICAL DATA FOR SITE F1
Taizz Laboratory

Sample No.	Depth (cm)	Horizon	Coarse Frag. >2 mm *	Size Coarse Frag. **	Total Sand 2-.05 mm	Total Silt .05-.002mm	Total Clay <.002 mm	Texture Class <2 mm ***
					(-----------	Pct	-----------)	
F1	0-20	C	vf	g	13.1	77.5	9.4	sil
F2	20-31	2C	fr	g	27.3	63.2	9.5	sil
F3	31-41	3C	vf	-	11.6	77.1	11.3	sil
F4	41-69	4C	f	g	31.2	59.6	9.2	sil
F5	69+	5C	vf	-	27.4	61.7	10.8	sil

Sample No.	Very Coarse Sand 2-1mm	Coarse Sand 1-.5 mm	Medium Sand .5-.25 mm	Fine Sand .25-0.1mm	Very Fine Sand 0.1-.05mm	Coarse Silt .05-.02mm	Medium Silt .02-.005mm	Fine Silt .005-.002mm
	(------------------			Pct				------------------)
F1	2.1	0.4	0.3	1.2	9.1	60.9	12.8	3.7
F2	11.2	3.2	1.5	3.6	7.8	50.6	9.2	3.4
F3	1.1	0.8	0.5	1.8	7.4	59.2	13.1	4.8
F4	13.5	3.4	4.2	2.5	7.6	50.0	6.2	3.3
F5	6.9	1.8	0.8	2.7	15.3	44.5	12.5	4.7

Sample No.	pH 1:5	pH 1:1	EC mmhos /cm	Avail. P (ppm)	$CaCO_3$ (%)	Organic Matter (%)	Total N (%)	CEC meq/100g
F1	9.0	7.8	0.22	8.74	18.4	0.6	0.062	19.9
F2	8.8	7.7	0.87	8.51	20.6	0.38	0.056	17.2
F3	8.7	7.9	0.56	7.82	21.2	0.63	0.042	21.3
F4	9.0	7.9	0.9	7.82	17.8	0.21	0.021	16.6
F5	9.0	7.9	0.8	3.7	17.6	0.30	0.018	18.8

*vf-very few (<5% by volume)
f-few (5-15% by volume)
fr-frequent (15-40% by volume)
vfr-very frequent (40-80% by volume)

**g-gravel (2-75 mm)
s-stones (75-250 mm)
b-boulders (>250 mm)

(from *Guidelines for Soil Profile Description*, FAO, 1977)

***c-clay   si-silt
l-loam   s-sand

Soil Profile Site F2

Site Information

Classification: USTOLLIC CAMBORTHID, LOAMY-SKELETAL, MIXED, ISOTHERMIC FAMILY
Date and time described: April 14, 1981, 11 AM
Authors: T. Forbes and J. King
Location: Al Thhran—5 miles southeast of Al Ganed
Elevation: 1350 m
Physiographic position: Colluvial footslope, convex slope
Topography of surrounding country: Steep, dissected slope
Microtopography: Layer of cobbles on slope surface
Slope: 43–44%
Land use: Not used for cultivation
Climate: Unknown

Soil Information

Parent Material: Colluvium from basalt and limestone
Drainage class: Well drained
Moisture conditions: Surface moisture
Depth to groundwater: Unknown
Surface stones or outcrops: Stones, gravels and some boulders
Evidence of erosion: Some sheet erosion
Salt content: No alkali or calcium salts on rocks
Human influence: None

Profile Description

A1 0–13 cm F6	Dark reddish brown, 5YR 3/4 (moist); stony, slightly gravelly, loam; weak, coarse to fine subangular blocky structure; slightly sticky and slightly plastic (wet); loose to very friable (moist); many micro to medium, discontinuous, random, inped, interstitial open and closed pores; very frequent volcanic and limestone stones; strongly calcareous; many coarse medium and fine roots; clear, wavy boundary.
B 13–70 cm F7	Reddish brown, 5YR 4/4 (moist); stony and gravelly loam; very weak, medium to fine subangular blocky and crumb structure; very slightly sticky, slightly plastic (wet); loose to very friable (moist); many micro to some coarse discontinuous, random, interstitial, inped, open and closed pores; calcareous; many fine and some coarse roots; very frequent volcanic and limestone gravel; gradual, irregular boundary.
Cca 70+ cm F8	Brown, 7.5 YR 4/4 (dry); stony and gravelly loam; very weak, medium fine, subangular blocky and granular structure; slightly sticky and slightly plastic (wet); loose (dry); many micro to coarse, discontinuous, random, inped, interstitial, open and closed pores; very frequent volcanic and limestone stones and gravel; very few fine roots; strongly calcareous.

See Figures I.2 and I.3.

Figure I.2: Landscape at site F2.

Figure I.3: Soil profile at site F2.

ANALYTICAL DATA FOR SITE F2
Taizz Laboratory

Sample No.	Depth (cm.)	Horizon	Coarse Frag. >2 mm *	Size Coarse Frag. **	Total Sand 2-.05 mm	Total Silt .05-.002mm	Total Clay <.002 mm	Texture Class <2 mm ***
					(-----------	Pct	-----------)	
F6	0–13	A1	vfr	s	36.7	44.6	18.7	l
F7	14–70	B	vfr	g	46.7	36.2	17.1	l
F8	70+	Cca	vfr	s,g	44.5	37.7	17.8	l

Sample No.	Very Coarse Sand 2–1mm	Coarse Sand 1-.5 mm	Medium Sand .5-.25 mm	Fine Sand .25-0.1mm	Very Fine Sand 0.1-.05mm	Coarse Silt .05-.02mm	Medium Silt .02-.005mm	Fine Silt .005-.002mm
	(-------------			Pct				-------------)
F6	9.5	7.7	5.4	8.2	5.9	24.8	16.9	2.9
F7	13.1	10.3	7.5	10.9	4.8	19.3	14.2	2.7
F8	14.7	11.0	6.8	8.5	3.6	15.0	14.6	8.1

Sample No.	pH 1:5	pH 1:1	EC mmhos /cm	Avail. P (ppm)	$CaCO_3$ (%)	Organic Matter (%)	Total N (%)	CEC meq/100g
F6	8.6	7.8	0.4	5.3	8.4	1.54	0.068	34.9
F7	8.5	7.6	2.3	5.8	10.8	1.18	0.058	29.6
F8	8.4	7.6	4.1	6.7	16.0	0.91	0.049	29.1

*vf-very few (<5% by volume)
f-few (5–15% by volume)
fr-frequent (15–40% by volume)
vfr-very frequent (40–80% by volume)
(from *Guidelines for Soil Profile Description*, FAO, 1977)

**g-gravel (2–75 mm)
s-stones (75–250 mm)
b-boulders (>250 mm)

***c-clay
l-loam
s-sand
si-silt

Soil Profile Site K27

Site Information

Classification: TYPIC USTIFLUVENT, FINE LOAMY, MIXED, ISOTHERMIC FAMILY
Date and time described: October 29, 1981
Authors: J. King and A. E. Abu Ghanem
Location: One kilometer southeast of the Sana-Al Hudaydah road, 1.5 km southeast of village of Bait Radam 44° 06′ E 15° 12′ N
Elevation: 2643 m
Physiographic position: Near low point of gently sloping broad valley
Topography of surrounding country: Very gently undulating plain between mountainous areas
Microtopography: Broad, low terraces
Slope: Between terraces 1-2%; almost flat
Land use: Barley, wheat and beans
Climate: 1. Annual rainfall: 300mm, 2. Soil moisture regime: Ustic, 3. Soil temperature regime: Isothermic.

Soil Information

Parent material: Fine silty material, mostly alluvial
Drainage class: Class 3, moderately well drained
Moisture conditions: Slightly moist beneath 19 cm
Depth to groundwater: Unknown, no effect on profile
Surface stones or outcrops: Class 0, very few stones
Evidence of erosion: None
Salt content: Calcareous
Human influence: Low terracing, cropping

Profile Description

Ap 0-10cm K109	Dark brown, 7.5 YR 4/4 (moist); brown, 7.5 YR 4/4 (dry); sandy clay loam; moderate fine crumb structure; slightly sticky, slightly plastic, very friable, soft slightly calcareous; frequently very fine roots; clear wavy boundary.
C 10-37cm K110	Dark brown, 7.5YR 3/4 (moist); brown, 7.5YR 5/4 (dry); silt loam; moderate coarse prismatic to weak medium subangular blocky structure; non-sticky, slightly plastic, friable, slightly hard, few very fine tubular pores; slightly calcareous; few very fine roots; abrupt, smooth boundary.
A11b 37-50cm K111	Dark brown, 7.5YR 4/2 (moist); strong brown, 7.5YR 4/6 (dry); loam; strong medium prismatic to strong medium angular blocky structure; some slickensides in the top of the horizon; non-sticky, slightly plastic, friable, hard; few very fine tubular pores; moderately calcareous; common calcareous mycelium; few very fine to fine roots on the outside of the peds; clear, smooth boundary.
A12b 50-65cm K112	Black, 10YR 2/1 (moist); very dark grayish brown, 10YR 3/2 (dry); loam; strong medium prismatic to strong medium angular blocky structure; sticky, plastic, friable, very hard, few very fine tubular pores; moderately calcareous; common calcareous mycelia; few very fine to fine roots; clear, smooth boundary.
B 65-115cm K113	Dark yellowish brown, 10YR 4/3 (moist); dark yellowish brown, 10YR 4/3 (dry); loam; strong medium prismatic to strong medium angular blocky structure; slightly sticky, plastic, friable, very hard, few very fine tubular pores; slightly calcareous; no roots; gradual, smooth boundary.
C1 115-140cm K114	Dark yellowish brown, 10YR 4/3 (moist); brown, 10YR 5/3 (dry); sandy loam; massive structure; slighty sticky, slightly plastic, friable, very hard; common very fine tubular pores; strongly calcareous; common mycelia; no roots; clear, wavy boundary.
C2ca 140-150+cm K115	Dark yellowish brown, 10YR 4/4 (moist); yellowish brown, 10YR 5/4 (dry); silt loam; strong coarse prismatic with some lenses of coarse platy structure; slightly sticky, non-plastic, friable, very hard; many very fine tubular pores; slightly calcareous; no roots.

See Figure I.4.

Figure I.4: Landscape at site K27.

ANALYTICAL DATA FOR SITE K27

U. S. Department of Agriculture
Soil Conservation Service
National Soil Survey Laboratory
Lincoln, Nebraska

Depth (cm)	Horizon	Clay < .002	Silt .002 -.05	Sand .05 -2	Fine .002 -.02	Coarse .02 -.05
		(------------ Pct of <2mm				------------)
0- 10	Ap	32.2	46.3	21.5	25.0	21.3
10- 37	C	29.1	45.5	25.4	22.7	22.8
37- 50	A11B	33.2	39.1	27.7	19.1	20.0
50- 65	A12B	40.6	40.6	18.8	22.2	18.4
65-115	B	29.6	45.1	45.2	11.3	18.3
115-140	C1	16.2	24.7	59.1	7.5	17.2

Hzn	(------ Sand (mm)				------)	(Coarse Fractions (mm))				(>2mm)
	VF	F	M	C	VC	(------ Weight			------)	Wt
	.05 -.10	.10 -.25	.25 -.50	.5 -1	1 -2	2 -5	5 -20	20 -75	.1- 75	Pct of Whole Soil
	(------ Pct of <2mm				------)	(------ Pct of <75mm			------)	
Ap	17.7	1.9	0.9	0.7	0.3	1	1	-	6	2
C	19.7	2.2	1.2	1.2	1.1	1	1	4	11	6
A11B	16.7	3.8	2.8	2.8	1.6	1	1	1	14	3
A12B	15.0	2.2	0.8	0.4	0.4	tr	tr	-	4	-
B	32.7	7.7	2.7	1.3	0.7	tr	tr	-	12	tr
C1	34.8	10.3	5.0	4.9	4.1	3	1	13	37	17

Hzn	Orgn C	Total N	(Ratio/Clay) CEC	15 Bar	(Bulk Density) 1/3 Bar	Oven Dry	Cole Whole Soil	(Water Content) 1/3 Bar	15 Bar	Wrd Whole Soil
	(Pct of <2mm)				(---g/cc---)		cm/cm	(Pct of <2mm)		cm/cm
Ap	0.43	0.041	1.03	0.45					14.4	
C	0.36	0.033	1.04	0.45	1.30	1.44	0.034	24.9	13.2	0.15
A11B	0.56	0.045	1.04	0.49	1.43	1.68	0.054	25.9	16.3	0.14
A12B	1.37	0.101	0.95	0.42	1.36	1.65	0.066	29.4	17.1	0.17
B	0.32		0.88	0.49	1.50	1.72	0.047	23.0	14.5	0.13
C1	0.18		1.34	0.67	1.50	1.57	0.014	19.2	10.8	0.11

Hzn	Ca	Mg	Na	K	Sum Bases	(CEC) NH_4-OAc	Sat- NH_4 OAc	CO_3 as $CaCO_3$	Cond. Mmhos/ cm	pH $CaCl_2$ .01m 1:2	pH H_2O 1:1
	(NH_4OAc Extractable Bases				)						
	(Meq / 100 g)						(Pct)				
Ap	39.8	4.1	0.1	0.8	44.8	33.2	100	tr	0.18	7.4	8.0
C		3.7	0.2	0.6		30.4		1	0.14	7.8	8.3
A11B	38.7	3.9	0.3	0.4	43.3	34.6	100	tr	0.14	7.6	8.2
A12B	40.1	4.2	0.3	0.4	45.0	38.6	100	tr	0.15	7.6	8.1
B	27.9	3.1	0.2	0.4	31.6	26.1	100	tr	0.14	7.7	8.1
C1	21.0	2.7	0.2	0.4	24.3	21.7	100	tr	0.12	7.5	8.1

Hzn	Mineralogy — Clay — X-ray — <2u — Relative Amounts				DTA <2u (Pct)	VFS Total Res (Pct)	VFS Dominant Weatherable (Pct)
C	MT 3	KK 2	MI 1	CL 1	KK14	58	FK21
A11B	MT 3	KK 2	MI 1		KK15	59	FK24
A12B	MT 2	KK 2	MI 1		KK10	62	FK20

Mmhos/cm of 1:2 Water Extract for Layers 1, 2, 3, 4, 5, 6
Analyses: All on Sieved <2mm Basis
Mineralogy: Kind of Mineral- MT Montmorillonite, MI Mica, CL Chlorite, FK Potassium-feldspar

Relative Amount: 6 Indeterminate, 5 Dominant, 4 Abundant, 3 Moderate, 2 Small, 1 Trace

Hzn	FA	RE	Mineralogy — Optical — Sand/Silt (percent)								
C	VFS	60	QZ55	FK21	FP 6	AR 4	BT 4	EP 3	HN 3	OP 2	MS 1
A11B	VFS	61	QZ54	FK24	FP 7	EP 4	OP 3	BT 3	AR 2	RA 2	HN 2
A12B	VFS	63	QZ55	FK20	FP 6	RA 4	AR 3	OP 3	HN 3	EP 3	BT 2

Hzn	Mineralogy — X-ray — Clay — Relative Amounts				DTA Clay	Total Analyses K_2O (Pct)	Total Analyses Fe (Pct)
C	MT 3	KK 2	MI 1	CL 1	KK14	1.4	6.9
A11B	MT 3	KK 2	MI 1		KK15	1.3	7.2
A12B	MT 2	KK 2	MI 1		KK10	1.6	7.0

Analyses: All on Sieved <2mm Basis
Mineralogy: FA = Fraction Analyzed, RE = Resistant
Kind of Mineral: OP = Opaques, QZ = Quartz, AR = Weathered Aggregates, BT = Biotite, CL = Chlorite, EP = Epidote, FK = Potassium Feldspar, FP = Plagioclase Feldspar, HN = Hornblende, MI = Mica, MS = Muscovite, MT = Montmorillonite, KK = Kaolinite, RA = Resistant Aggregates
Relative Amount: 6 Indeterminate, 5 Dominant, 4 Abundant, 3 Moderate, 2 Small, 1 Trace

Soil Profile Site K39

Site Information

Classification: TYPIC TORRIPSAMMENT, MIXED, ISOMEGATHERMIC FAMILY
Date and time described: December 9, 1982
Authors: J. King and A. E. Abu Ghanem
Location: North of Hudaydah, 11km east of Org which is on the Red Sea coast, 15° 13' N, 42° 54' E
Elevation: 40 m
Physiographic position: Plain
Topography of surrounding country: Flat
Microtopography: Sandy hummocks up to one meter in height
Slope: 1°, 2%
Land use: Sagebrush, light grazing
Climate: 1. Annual rainfall: <100 mm, 2. Soil moisture regime: Aridic, 3. Soil temperature regime: Isomegathermic.

Soil Information

Parent material: Wind blown sand and calcareous silt and clay
Drainage class: Class 4, well drained
Moisture conditions: Dry throughout
Depth to groundwater: Not known, but no effect on profile
Surface stones or outcrops: None
Evidence of erosion: Hummocks resulting from combined effects of wind erosion and deposition
Salt content: Calcareous
Human influence: None

GENERAL DESCRIPTION OF THE PROFILE: A light-textured soil with four horizons differentiated by slight changes in color and texture.

Profile Description

A1 0–10cm K176	Dark brown, 10YR 3/3 (moist) and brown 10YR 5/3 (dry); sand; structureless; nonsticky, nonplastic (wet); very friable (moist); loose (dry); moderately calcareous; clear, smooth boundary.
2C 10–26cm K177	Very dark grayish brown 10YR 3/2 (moist) and grayish brown 10YR 5/2 (dry); loamy sand; weak very thin platey structure; slightly sticky, nonplastic (wet); very friable (moist); soft (dry); moderately calcareous; few fine to medium roots; abrupt smooth boundary.
3C 26–102cm K178	Dark brown, 10YR 3/3 (moist) and brown 10YR 4/3 (dry); loamy sand; moderate medium to very coarse subangular blocky structure; slightly sticky, non-plastic (wet); very friable (moist); soft (dry); many fine tubular pores; moderately calcareous; very few fine roots; abrupt smooth boundary.
4C 102–155+cm K179	Dark brown, 10YR 3/3 (moist) and brown 10YR 4/3 (dry); sand; moderate medium to very coarse subangular blocky structure; slightly sticky, non-plastic (wet); very friable (moist); soft (dry); many fine tubular pores; moderately calcareous; very few fine roots.

See Figure I.5.

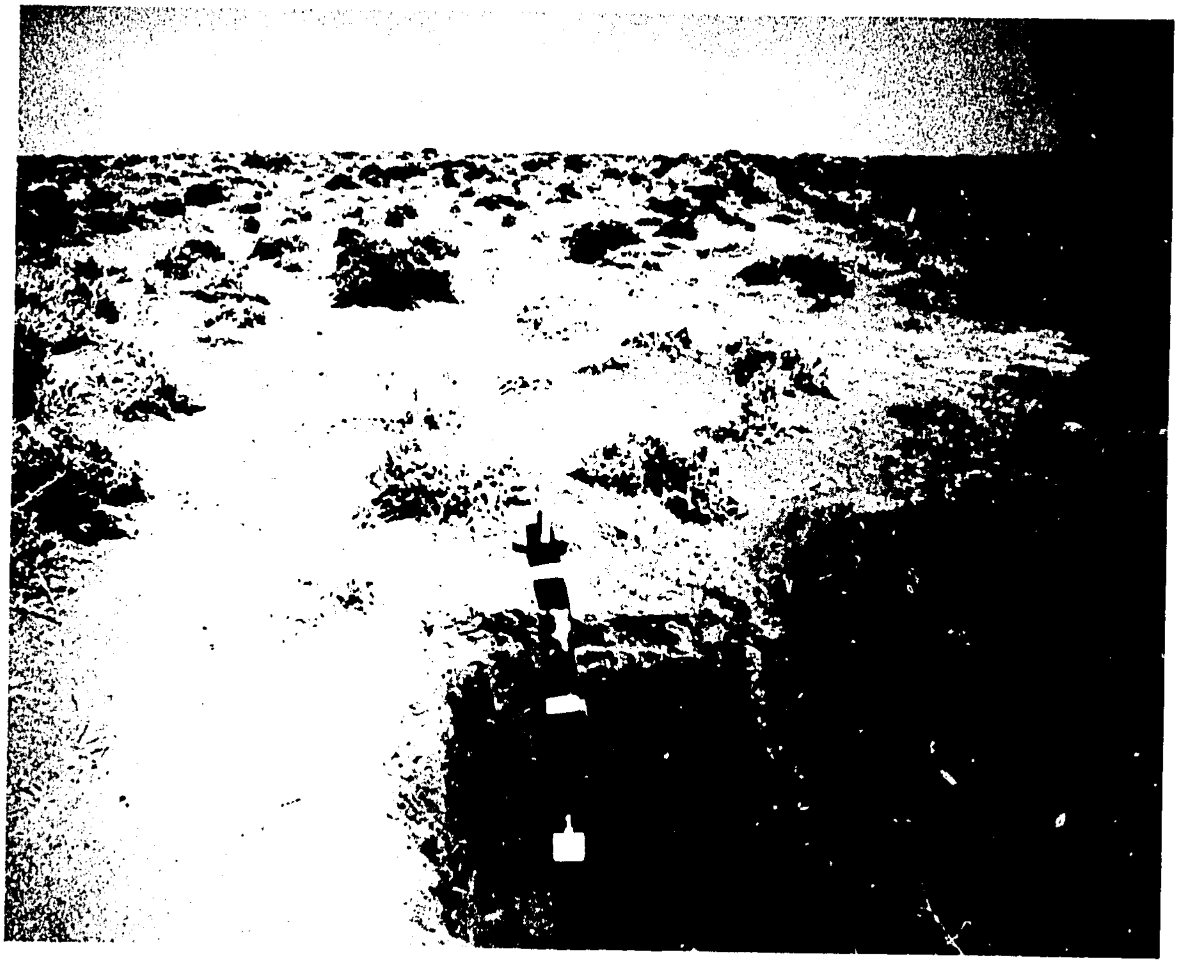


Figure I.5: Landscape at site K39.

ANALYTICAL DATA FOR SITE K39

Taizz Laboratory

Sample No.	Depth (cm.)	Horizon	Coarse Frag. >2 mm *	Size Coarse Frag. **	Total Sand 2-.05 mm	Total Silt .05-.002mm	Total Clay <.002 mm	Texture Class <2 mm ***
					(-----------	-Pct-	----------)	
K176	0-10	A1	-	-	89	7	4	s
K177	10-26	2C	-	-	87	7	6	ls
K178	26-102	3C	-	-	87	7	6	ls
K179	102+	4C	-	-	89	7	4	s

Sample No.	pH 1:1	EC mmhos /cm	Organic Matter (%)	$CaCO_3$ (%)	Avail. P (ppm)
K176	8.4	0.96	0.55	5.1	11.9
K177	8.2	0.19	0.38	4.4	11.9
K178	8.2	0.21	0.20	3.9	9.2
K179	8.2	0.41	0.18	3.7	11.9

*vf-very few (<5% by volume)
f-few (5-15% by volume)
fr-frequent (15-40% by volume)
vfr-very frequent (40-80% by volume)
(from *Guidelines for Soil Profile Description*, FAO, 1977)

**g-gravel (2-75mm)
s-stones (75-250mm)
b-boulders (>250mm)

***c-clay s-sand
l-loam silt

Soil Profile Site K43

Site Information

Profile number: S-82-YE-965-002 (SCS-USDA)
Classification: TYPIC HAPLUDOLL, FINE LOAMY, MIXED, ISOTHERMIC FAMILY
Date and time described: January 10, 1982
Authors: A. Van Wambeke, J. King, A. E. Abu Ghanem
Location: Road cut 0.35km from radio relay station on summit of Jabal Sabir on road to Taizz
Elevation: 2840 m
Physiographic position: Slightly convex slope
Topography of surrounding country: Mountainous
Microtopography: None
Slope: 40% steep, convex
Land use: grazing
Climate: Udic moisture regime

Soil Information

Parent material: Acidic igneous rock
Drainage class: Class 4, well drained
Moisture conditions: Dry throughout
Depth to groundwater: Not known, no effect on profile
Surface stones or outcrops: Rubble land, rock outcrops and boulders cover 90% of the land
Evidence of erosion: Bare rocks, small hummocks would indicate some water erosion.
Salt content: None
Human influence: None

GENERAL DESCRIPTION OF THE PROFILE: The profile is dark brown throughout with two clear differences in structure. The two top horizons appear granular and the lowest horizon appears more massive.

Profile Description

A1 0-20cm K199	Black, 10YR 2/1 (moist) on aggregate, very dark brown, 10YR 2/2 (dry); silt loam; moderate, medium, subangular blocky to crumb structure; slightly sticky, slightly plastic; friable; soft to slightly hard; many very fine tubular pores; very few fresh slightly angular stones; non calcareous; frequent fine to coarse roots; gradual wavy boundary.
2A1 20-35cm K200	Very dark brown, 10YR 2/2 (moist) and very dark grayish brown, 10YR 3/2 (dry); sandy loam; moderate, coarse, subangular blocky to weak crumb structure; slightly sticky, slightly plastic; friable; soft to slightly hard; common very fine tubular and few coarse tubular pores; very fine horizontal cracks; few fresh slightly angular gravel mineral fragments; non calcareous; common fine to coarse roots; clear, wavy boundary.
C 35-87cm K201	Very dark brown, 10YR 2/2 (moist) and very dark grayish brown, 10YR 3/2 (dry); loam; moderate, coarse, subangular blocky to crumb structure; slightly sticky, slightly plastic; friable; soft to slightly hard; few very fine tubular pores; few fresh slightly angular stones; non-calcareous; common fine to coarse roots.

See Figure I.6.

Figure I.6: Soil profile at site K43.

ANALYTICAL DATA FOR SITE K43

U. S. Department of Agriculture
Soil Conservation Service
National Soil Survey Laboratory
Lincoln, Nebraska

Depth (cm)	Hzn	Total: Clay < .002	Total: Silt .002 -.05	Total: Sand .05 -2	Silt: Fine .002 -.02	Silt: Coarse .02 -.05	Sand (mm): VF .05 -.10	Sand (mm): F .10 -.25	Sand (mm): M .25 -.50	Sand (mm): C .5 -1	Sand (mm): VC 1 -2
		Pct of <2mm									
0-20	A1	19.7	33.4	46.9	12.9	20.5	9.2	9.9	10.4	9.0	8.4
20-35	2A1	17.5	26.5	56.0	9.7	16.8	8.6	11.7	12.7	11.9	11.1
35-85	C	21.0	30.6	48.4	10.7	19.9	8.5	8.9	9.6	10.1	11.3

Hzn	Coarse Fractions (mm) Weight: 2 -5	5 -20	20 -75	.1- 75	(>2mm) Wt Pct of Whole Soil	Orgn C	Total N	Ratio/Clay: CEC	Ratio/Clay: 15 Bar
	Pct of <75mm					Pct of <2mm			
A1	11	7	-	49	18	4.45	0.329	1.61	0.88
2A1	11	8	3	59	22	3.64	0.270	1.46	0.86
C	10	5	5	52	20	2.22		1.15	0.62

Hzn	Bulk Density: 1/3 Bar	Bulk Density: Oven Dry	Cole Whole Soil	Water Content: 1/3 Bar	Water Content: 15 Bar	Wrd Whole Soil
	g/cc		cm/cm	Pct of <2mm		cm/cm
A1					17.3	
2A1	1.23	1.36	0.030	21.1	15.0	0.07
C	1.38	1.50	0.025	20.6	13.0	0.09

Hzn	NH₄OAc Extractable Bases: Ca	Mg	Na	K	Sum Bases	Acidity	CEC: Sum Cats	CEC: NH₄-OAc	Exch Na	SAR	Base Saturation: Sum	Base Saturation: NH₄OAc
	Meq / 100 g								Pct		Pct	
A1	29.1	3.4	0.1	0.4	33.0	5.1	38.1	31.7	tr	tr	87	100
2A1	23.3	2.7	tr	0.3	26.3	5.3	31.6	25.6			83	100
C	19.7	3.1	tr	0.2	23.0	5.5	28.5	24.2			81	95

Hzn	Carbonate as $CaCO_3$ <2mm (Pct)	(--------pH--------) Sat. Paste	$CaCl_2$ .01M 1:2	H_2O 1:1
A1	tr	6.8	6.7	7.0
2A1			6.4	6.9
C			6.3	6.7

Hzn	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	H_2O	Total Salts Est.	Elec. Cond. Mmhos /cm
	(------------------Water Extracted From Saturated Paste------------------)											
	(----------------------Meq/Liter----------------------)									(----Pct----)		
A1	7.5	1.7	0.3	0.1	-	6.5	0.5	0.8	-	70.6	tr	0.79
2A1												0.20
C												0.14

Hzn	(-----Mineralogy----- Clay X-ray <2u Relative Amounts)				(---DTA---) (---<2u---)	(---VFS--- Pct) Total Res	Dominant Weatherable
2A1	MT 2	KK 2	VC 2	MI 1		42	FK45
C	MT 3	KK 2	VC 2	MI 1	KK14	47	FK41

Mmhos/cm of 1:2 Water Extract for Layers 2, 3
Analyses: All on Sieved <2mm Basis
Mineralogy:
Kind of Mineral: MT=montmorillonite, KK=Kaolinite, VC=Vermiculite-Chlorite, MI=Mica, FK=Potassium-Feldspar

Relative Amount: 6 Indeterminate, 5 Dominant, 4 Abundant, 3 Moderate, 2 Small, 1 Trace

(------Mineralogy------ Optical ------ Sand/Silt (percent)------)

Hzn	FA	RE									
A1											
2A1	VFS	43	FK45	QZ37	FP 6	OP 4	BT 3	AR 2	HN 2	EP 1	RA 1
C	VFS	48	FK41	QZ41	FP 6	OP 5	EP 2	BT 2	HN 2	RA 1	MS 1

Hzn	Mineralogy						
	X-ray				DTA	(Tot Analyses)	
	Clay						
						K_2O	Fe
	Relative Amounts				Pct		
2A1	MT 2	KK 2	VC 2	MI 1		1.2	5.8
C	MT 3	KK 2	VC 2	MI 1	KK14	1.2	6.7

Analyses: All on Sieved <2mm Basis

Mineralogy: FA = Fraction Analyzed, RE = Resistant

Kind of Mineral: OP = Opaques, QZ = Quartz, RA = Resistant Aggregates, AR = Weathered Aggregates, BT = Biotite, EP = Epidote, FK = Potassium Feldspar, FP = Plagioclase Feldspar, HN = Hornblende, MI = Mica, MT = Montmorillonite, VC = Vermiculite-Chlorite, KK = Kaolinite, MS = Muscovite

Relative Amount: 6 Indeterminate, 5 Dominant, 4 Abundant, 3 Moderate, 2 Small, 1 Trace

Soil Profile Site K45

Site Information

Profile number: S82-YE-965-003(SCS-USDA)
Classification: VERTIC HAPLUSTOLL, FINE, MONTMORILLONITIC, ISOTHERMIC FAMILY
Date and time described: January 17, 1982
Authors: J. King, A. Van Wambeke and Abdul Elah Abu Ghanem
Location: Intermountain plains, 75 m from north corner of milking parlor at the Rabat dairy farm
Elevation: 2450 m
Physiographic position: Area of slight depression on broad intermountain plain
Topography of surrounding country: Almost flat
Microtopography: None
Slope: 1° or 2%
Land use: Light cover of short grass
Climate: 290 mm, Ustic moisture regime

Soil Information

Parent material: Fine alluvium
Drainage class: Class 3, moderately well drained
Moisture conditions: Moist below 29 cm
Depth to groundwater: 3 m
Surface stones or outcrops: None
Evidence of erosion: None
Salt content: None
Human influence: None

Profile Description

Ap 0-9cm K208	Very dark grayish brown, 10YR 3/2 (moist) and dark grayish brown 10YR 4/2 (dry); clay; fine subangular blocky to crumb structure with only crumb structure at the surface; slightly sticky, plastic; friable; no pores; no mineral fragments or nodules; strongly calcareous; frequent medium to fine roots; clear, smooth boundary.
A1 9-29cm K209	Very dark gray 10YR 3/1 (moist) and dark grayish brown 10YR 4/2 (dry); silty clay loam; strong medium to fine subangular structure; sticky, very plastic; friable; slightly hard; no pores; no mineral fragments or nodules; moderately calcareous; many medium to fine roots; clear, smooth boundary.
A3 29-42cm K210	Very dark gray 10YR 3/1 (moist) and gray 10YR 5/1 and grayish brown 10YR 5/2 (dry); silty clay; strong coarse to fine subangular blocky structure with oblique 1 cm cracks; sticky, very plastic; friable; slightly hard; few fine interstitial pores; very few gravel and stones and few small hard irregular white nodules; moderately calcareous; common fine roots; gradual smooth boundary.
Cca 42-68cm K211	Very dark grayish brown 10YR 3/2 (moist) and grayish brown 10YR 5/2 (dry); silty clay loam; strong coarse to fine subangular blocky structure; oblique vertical 1 cm cracks to 55 cm; sticky, plastic; friable; hard; no pores; few small hard irregular white nodules; moderately calcareous; few fine roots; gradual smooth boundary.
2C 68-115cm K212	Dark grayish brown 10YR 5/2 (moist) and brown 10YR 5/3 and grayish brown 10YR 5/2 (dry); silty clay; strong coarse to fine subangular blocky structure; sticky, plastic; friable; very hard; few fine interstitial pores; few small hard irregular white nodules; non-calcareous; few fine roots; clear smooth boundary.
3C 115+cm K213	Grayish brown 10YR 5/2 (moist) and light brownish gray 10YR 6/2 and brown 10YR 5/3 (dry); silty clay; strong, medium prismatic to strong medium to fine subangular blocky structure; sticky, very plastic; friable; very hard; few fine interstitial pores; few small hard irregular white nodules; non calcareous; few fine roots.

ANALYTICAL DATA FOR SITE K45

U. S. Department of Agriculture
Soil Conservation Service
National Soil Survey Laboratory
Lincoln, Nebraska

Depth (cm)	Horizon	Total Clay .002	Total Silt .002 -.05	Total Sand .05 -2	(Clay) CO_3 .002	Silt Fine .002 -.02	Silt Coarse .02 -.05
(Pct of 2mm)							
0- 9	Ap	43.8	43.9	12.3	tr	18.8	25.1
9- 29	A1	48.7	40.6	10.7	1	18.3	22.3
29- 42	A3	49.2	39.9	10.9	-	20.2	19.7
42- 69	Cca	42.5	48.4	8.9		29.5	18.9
68-115	2C	36.9	50.4	12.7		31.3	19.1

Hzn	Sand (mm) VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	Coarse Fractions (mm) Weight 2 -5	5 -20	20 -75	.1- 75	(>2mm) Wt Pct of Whole Soil
	(Pct of <2mm)					(Pct of <75mm)				
Ap	11.2	0.8	0.4	0.2	-	-	-	-	1	-
A1	9.1	0.8	0.6	0.2	-	tr	tr	-	2	tr
A3	8.3	0.8	0.5	0.7	0.6	1	1	-	5	2
Cca	6.2	0.9	0.5	0.6	0.7	1	1	2	7	4
2C	6.7	1.5	1.2	1.4	1.9	2	5	-	13	7

Hzn	Orgn C	Total N	(Ratio/Clay) CEC	15 Bar	(Bulk Density) 1/3 Bar	Oven Dry	Cole Whole Soil	(Water Content) 1/3 Bar	15 Bar	Wrd Whole Soil
	(Pct of <2mm)				(---g/cc---)		cm/cm	(Pct of <2mm)		cm/cm
Ap	5.92	0.569	0.93	0.66					29.1	
A1	3.61	0.378	0.89	0.63	1.18	1.58	0.102	36.4	30.5	0.07
A3	1.33		0.90	0.64	1.13	1.70	0.145	40.0	31.6	0.09
Cca	0.43		1.06	0.58	1.26	1.80	0.124	34.5	24.7	0.12
2C	0.33		1.12	0.62	1.33	1.77	0.096	32.2	22.9	0.12

Hzn	(NH$_4$OAc Extractable Bases Ca	Mg	Na	K	) Sum Bases	(CEC) NH$_4$-OAc	Exch Na	SAR	Base Saturation NH$_4$OAc	CO$_3$ as CaCO$_3$ <2mm	Res. Ohms /cm
	(Meq/100 g					)	Pct		(Pct)	(Pct)	
Ap		6.1	0.2	2.2		40.7	tr	tr		13	
A1		7.7	0.6	1.0		43.1	1	1		10	
A3		8.4	1.8	0.8		44.4	3	3		2	
Cca	37.3	8.6	2.5	0.7	49.1	45.2	5	4	100	tr	
2C	33.8	7.9	1.9	0.8	44.4	41.5	4	3	100	tr	1300

Hzn	(--------pH--------) Sat. Paste	CaCl$_2$ .01M 1:2	H$_2$O 1:1
Ap	7.5	7.6	7.7
A1	7.4	7.8	7.9
A3	7.5	7.9	8.0
Cca	7.5	7.7	8.1
2C	7.4	7.5	7.8

Hzn	(------Water Extracted From Saturated Paste------) Ca	Mg	Na	K	HCO$_3$	Cl	SO$_4$	H$_2$O	Total Salts Est.	Elec. Cond.
	(--------Meq/Liter						--------)	(----Pct	----)	/cm
Ap	7.9	1.6	0.5	0.5	7.5	1.3	1.3	85.5	tr	0.93
A1	5.8	1.4	1.9	0.1	7.0	0.7	0.8	81.3	tr	0.77
A3	2.2	0.7	3.5	tr	4.7	0.5	0.8	80.5	tr	0.55
Cca	1.3	0.4	3.7	tr	3.0	0.7	1.4	75.0	tr	0.50
2C	2.6	0.8	4.0	0.1	2.1	2.0	2.7	68.4	tr	0.74

Hzn	(---Clay---) (---X-ray---) (---<2u---) (---Relative Amounts			---)	(---DTA---) (---<2u---)	(---VFS---) Total Res	Dominant Weatherable
						(------Pct	------)
A1	MT 5	KK 2	MI 2	CL 1		56	FK28
A3							
Cca	MT 4	KK 2	MI 1		KK13	54	FK29
2C							

Analyses: All on Sieved <2mm Basis

Mineralogy: Kind of Mineral- MT=Montmorillonite, KK=Kaolinite, MI=Mica, CL= Chlorite, FK=Potassium-Feldspar

Relative Amount: 6 Indeterminate, 5 Dominant, 4 Abundant, 3 Moderate, 2 Small, 1 Trace

Hzn	FA	RE	Mineralogy Optical Sand/Silt Pct								
Ap											
A1	VFS	57	QZ53	FK28	HN 3	BT 3	CA 3	EP 2	RA 2	FP 2	CB 2
A3											
Cca	VFS	55	QZ50	FK29	FP 10	RA 3	AR 3	BT 2	EP 2	OP 1	CL<1
2C											

Hzn	Mineralogy X-ray Clay Relative Amounts				Mineralogy DTA Clay Pct	Tot Analyses K₂O Pct	Tot Analyses Fe Pct
Ap							
A1	MT 5	KK 2	MI 2	CL 1		1.6	6.9
A3							
Cca	MT 4	KK 2	MI 1		KK13	1.4	7.9
2C							

Analyses: All on Sieved <2mm Basis
Mineralogy: FA = Fraction Analyzed, RE = Resistant
Kind of Mineral: QZ = Quartz, RA = Resistant Aggregates, BT = Biotite, CA = Calcite, CB = Carbonate Aggregates, CL = Chlorite, EP = Epidote, FK = Potassium Feldspar, FP = Plagioclase Feldspar, HN = Hornblende, MI = Mica, MT = Montmorillonite, KK = Kaolinite, OP = Opaques, AR = Weathered Aggregates
Relative Amount: 6 Indeterminate, 5 Dominant, 4 Abundant, 3 Moderate, 2 Small, 1 Trace

Soil Profile Site K47

Site Information

Classification: USTOLLIC CALCIORTHID, COARSE LOAMY, MIXED, ISOHYPERTHERMIC FAMILY
Date and time described: March 10, 1982
Authors: J. King and Abdul Elah Abu Ghanem
Location: Near Al Mukha
Elevation: 122 m
Physiographic position: Plain formed by wadis, plain with shallow wadi cuts
Topography of surrounding country: Flat with volcanic mountains within a half kilometer
Microtopography: None
Slope: 2° or 5%
Land use: Sagebrush, Accacia, light grazing
Climate: Aridic soil moisture regime

Soil Information

Parent material: Coarse alluvium of mixed origin
Drainage class: Well drained
Moisture conditions: Dry throughout
Depth to groundwater: No effect on profile
Surface stones or outcrops: Gravelly to stony desert pavement covers the surface of the soil, stones just cover it enough to make it a Class 1 (fairly stony) surface
Evidence of erosion: Some wind-blown sand
Salt content: Profile is calcareous throughout
Human influence: None

GENERAL DESCRIPTION OF THE PROFILE: This is a coarse alluvial soil which is calcareous throughout. It has a horizon of maximum calcium accumulation from 39-74cm.

Profile Description

A1 0-2.5cm K217	Brown 10YR 4/3 (moist) and pale brown 10YR 6/3 (dry); very gravelly to stony sandy loam; no structure; slightly sticky, slightly plastic (wet); very friable (moist); soft (dry); numerous very fine pores giving a honeycombed appearance; very frequent, angular to rounded weathered gravel to stones; strongly calcareous; no roots; clear smooth boundary.
B11 2.5-39cm K218	Brown 10YR 4/3 (moist) and yellowish brown 10YR 5/4 (dry); very gravelly to bouldery sandy loam; no structure; slightly plastic (wet); very friable (moist); loose (dry); few very fine tubular pores; very frequent, angular to rounded weathered gravel, stones and boulders; strongly calcareous; common fine roots; gradual smooth boundary.
B12 39-74cm K219	Yellowish brown 10YR 5/4 (moist) and pale brown 10YR 6/3 (dry); very gravelly to bouldery sandy loam; no structure; non-sticky, non-plastic (wet); very friable (moist); loose (dry); few very fine tubular pores; very frequent, angular to rounded weathered gravel to stones; strongly calcareous; few fine roots; abrupt smooth boundary.
C 74-86cm K220	Brown 10YR 4/3 (moist) and pale brown 10YR 6/3 (dry); very gravelly to stony loamy sand; no structure; non-sticky, non-plastic (wet); very friable (moist); loose (dry); very few, very fine tubular pores; very frequent, angular to rounded weathered gravel to stones; strongly calcareous; very few fine roots; clear wavy boundary.
2C 86-100cm K221	Brown 10YR 4/3 (moist) and pale brown 10YR 6/3 (dry); very gravelly to bouldery sandy loam; fine weak subangular blocky structure; non-sticky, non-plastic (wet); very friable (moist); soft (dry); common very fine tubular pores; very frequent, angular to rounded weathered gravel, stones to boulders; strongly calcareous; very few fine roots; gradual wavy boundary.
3C 100-150+cm K222	Brown 10YR 4/3 (moist) and light grey, 10YR 7/2 (dry); very gravelly to bouldery sandy loam; no structure; non-sticky, non-plastic (wet); very friable (moist); loose (dry); no pores; very frequent, angular to rounded weathered gravel, stones and boulders; strongly calcareous; no roots.

See Figure I.7.

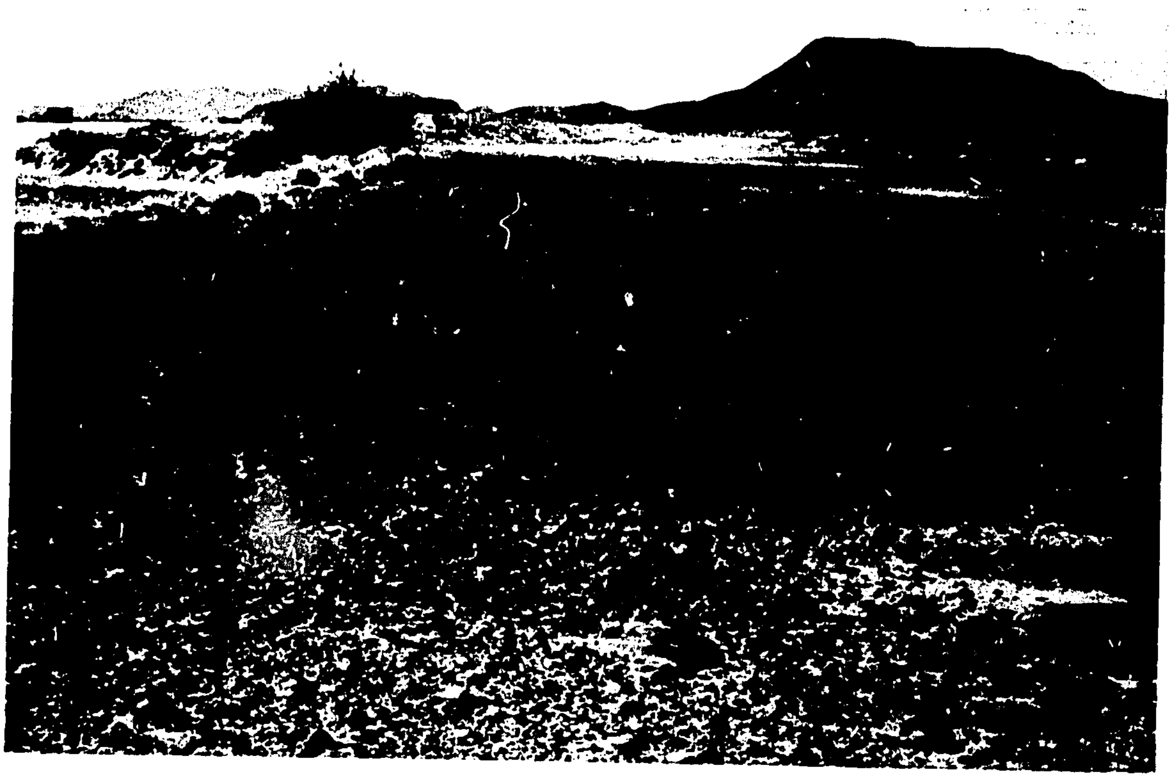


Figure I.7: Landscape at site K47.

ANALYTICAL DATA FOR SITE K47
Taizz Laboratory

Sample No.	Depth (cm)	Horizon	Coarse Frag. >2 mm *	Size Coarse Frag. **	Total Sand 2-.05 mm	Total Silt .05-.002mm	Total Clay <.002 mm	Texture Class <2 mm ***
					(-----------	Pct	-----------)	
K217	0-2.5	A1	-	-	68	28	4	sl
K218	2.5-39	B11	-	-	68	28	4	sl
K219	39-74	B12	-	-	70	20	10	sl
K220	74-86	C	-	-	88	8	4	ls
K221	86-100	2C	-	-	72	20	8	sl
K222	100-150	3C	-	-	80	12	8	sl

Sample No.	pH 1:1	EC mmhos /cm	Organic Matter (%)	$CaCO_3$ (%)	Avail. P (ppm)	C E C meq/100g
K217	7.2	31.0	1.63	12.4	9.0	12.4
K218	6.9	17.5	1.52	15.2	3.0	14.3
K219	7.2	5.9	1.48	20.0	8.0	12.8
K220	7.4	3.7	1.10	9.5	1.0	10.4
K221	7.0	5.1	1.25	16.7	3.0	12.4
K222	7.3	4.9	1.41	12.2	3.0	9.8

*vf-very few (<5% by volume)
f-few (5-15% by volume)
fr-frequent (15-40% by volume)
vfr-very frequent (40-80% by volume)

**g-gravel (2-75mm)
s-stones (75-250mm)
b-boulders (>250mm)

(from *Guidelines for Soil Profile Description*, FAO, 1977)

***c-clay s-sand
l-loam silt

Soil Profile Site K53

Site Information

Classification: TYPIC TORRIFLUVENT, COARSE LOAMY, MIXED, CALCAREOUS, HYPERTHERMIC FAMILY, HUMMOCKY PHASE
Date and time described: April 23, 1982
Authors: J. King and A. E. Abu Ghanem
Location: At A.H.T. tent camp for measuring flow of Wadi Grdud, approximately 5km southwest from Al Shanan town, in Al Jawf Province, 16° 12'N, 44° 23'E
Elevation: 1150 m
Physiographic position: Plain
Topography of surrounding country: Flat
Microtopography: Hummocks 3 m high, covering about 50% of the surface
Slope: 1° or 2%
Land use: Used for light grazing
Climate: 1. Annual rainfall: 100mm, 2. Soil moisture regime: Aridic, 3. Soil temperature regime: Hyperthermic.

Soil Information

Parent material: Calcareous silty alluvium
Drainage class: Well drained
Moisture conditions: Profile dry throughout
Depth to groundwater: No effect on profile
Surface stones or outcrops: None
Evidence of erosion: Severe gully erosion which has transformed the surface into a hummocky configuration, some wind erosion
Salt content: None, profile calcareous throughout
Human influence: None

GENERAL DESCRIPTION OF THE PROFILE: Stratified, dominantly silty alluvium of uniform light brown color throughout. This is the hummocky phase of the series found close to the mountains, rather than in the plains. The hummocky phase is assumed to be caused by water erosion.

Profile Description

C 0-29cm K254	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown (dry); silt loam; moderate medium subangular blocky and weak medium platey structure; sticky and plastic (wet); friable (moist); soft (dry); no pores; strongly calcareous; very few very fine roots; abrupt, wavy boundary.
2C 29-46cm K255	10YR 4/4 dark yellowish-brown (moist) and 10YR 7/4 very pale brown (dry); silt loam; moderate coarse to medium subangular blocky structure; slightly sticky and plastic (wet); friable (moist); hard (dry); common fine tubular pores; very few common very fine calcareous pseudomycelia, strongly calcareous; no roots; abrupt, smooth boundary.
3C 46-55cm K256	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown (dry); sandy loam; weak medium to fine subangular blocky structure; slightly sticky and slightly plastic (wet); friable (moist); slightly hard (dry); few fine tubular pores; strongly calcareous; no roots; abrupt, wavy boundary.
4C 55-72cm K257	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown and 10YR 7/4 very pale brown (dry); silt loam; strong coarse angular blocky structure; nonsticky and slightly plastic (wet); friable (moist); hard (dry); common fine, few medium tubular or vesicular pores; common very fine pseudomycelia, strongly calcareous; no roots; abrupt, smooth boundary.
5C 72-129cm K258	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown (dry); loam; moderate medium to fine angular blocky structure; nonsticky and plastic (wet); friable (moist); soft (dry); no pores; strongly calcareous; no roots; abrupt smooth boundary.
6C 129-142cm K259	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown (dry); sandy loam; moderate coarse to medium angular blocky structure; nonsticky and plastic (wet); friable (moist); slightly hard (dry); no pores; strongly calcareous; no roots; abrupt, smooth boundary.
7C 142-152cm K260	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown (dry); silt loam; moderate coarse to medium subangular blocky structure; nonsticky and nonplastic (wet); friable (moist); soft (dry); few medium tubular pores; strongly calcareous; no roots; abrupt, smooth boundary.
8C 152-164cm K261	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown (dry); sandy loam; moderate medium to fine subangular blocky; nonsticky and slightly plastic (wet); friable (moist); slightly hard (dry); few very fine tubular pores; strongly calcareous; no roots; abrupt, smooth boundary.
9C 164-180cm K262	10YR 5/4 yellowish-brown (moist) and 10YR 6/4 light yellowish-brown (dry); sandy loam; weak medium subangular blocky structure; nonsticky and slightly plastic (wet); friable (moist); soft (dry); no pores; strongly calcareous; no roots.

See Figures I.8 and I.9.

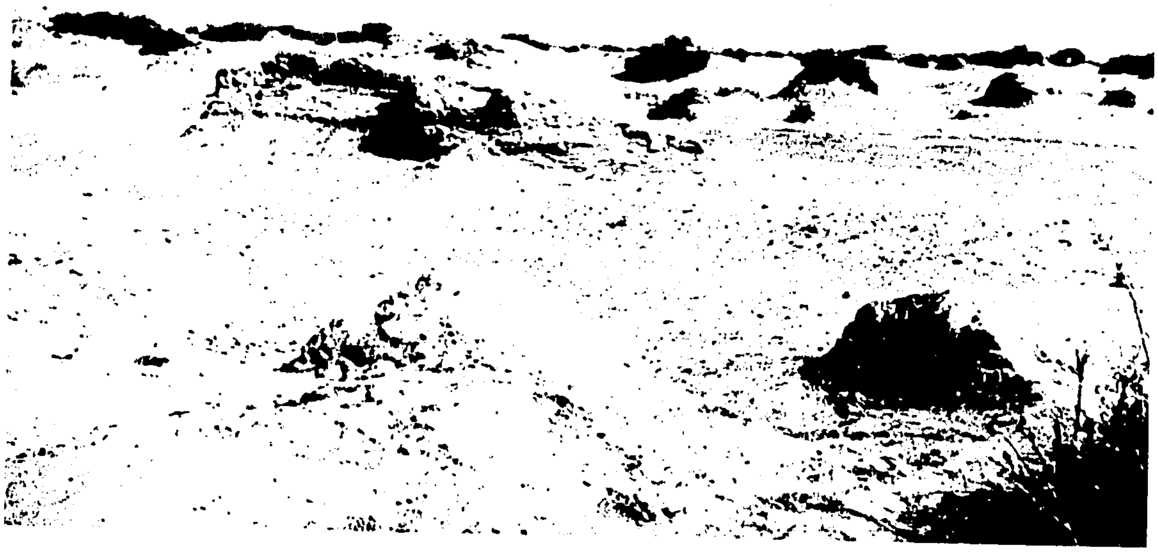


Figure I.8: Landscape at site K53.

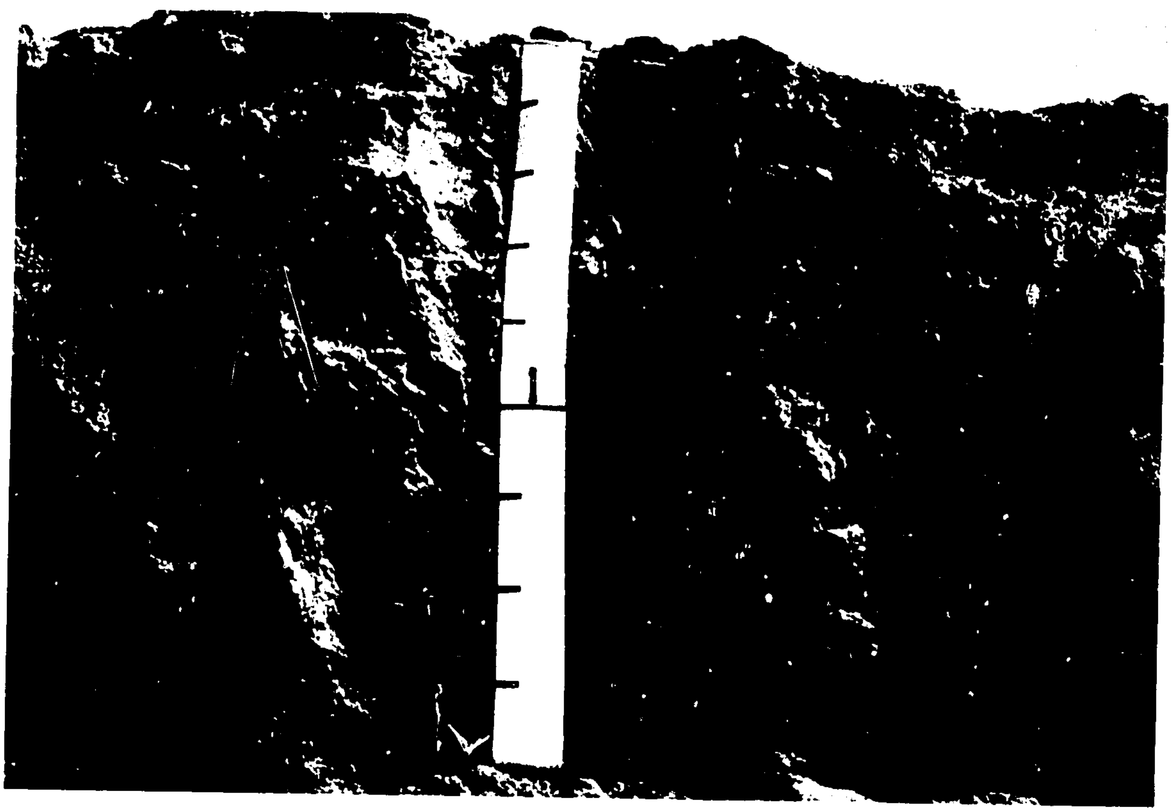


Figure I.9: Soil profile at site K53.

ANALYTICAL DATA FOR SITE K53
Taizz Laboratory

Sample No.	Depth (cm)	Horizon	Coarse Frag. >2 mm *	Size Coarse Frag. **	Total Sand 2-.05 .mm	Total Silt .05-.002mm	Total Clay <.002 mm	Texture Class <2 mm ***
					(-----------	Pct	-----------)	
K254	0-29	C	-	-	30	68	2	sil
K255	29-46	2C	-	-	34	60	6	sil
K256	46-55	3C	-	-	44	48	8	sl
K257	55-72	4C	-	-	30	60	10	sil
K258	72-129	5C	-	-	48	42	10	l
K259	129-142	6C	-	-	56	36	8	sl
K260	142-152	7C	-	-	31	52	17	sil
K261	152-164	8C	-	-	63	78	9	sl
K262	164-180	9C	-	-	53	38	9	sl

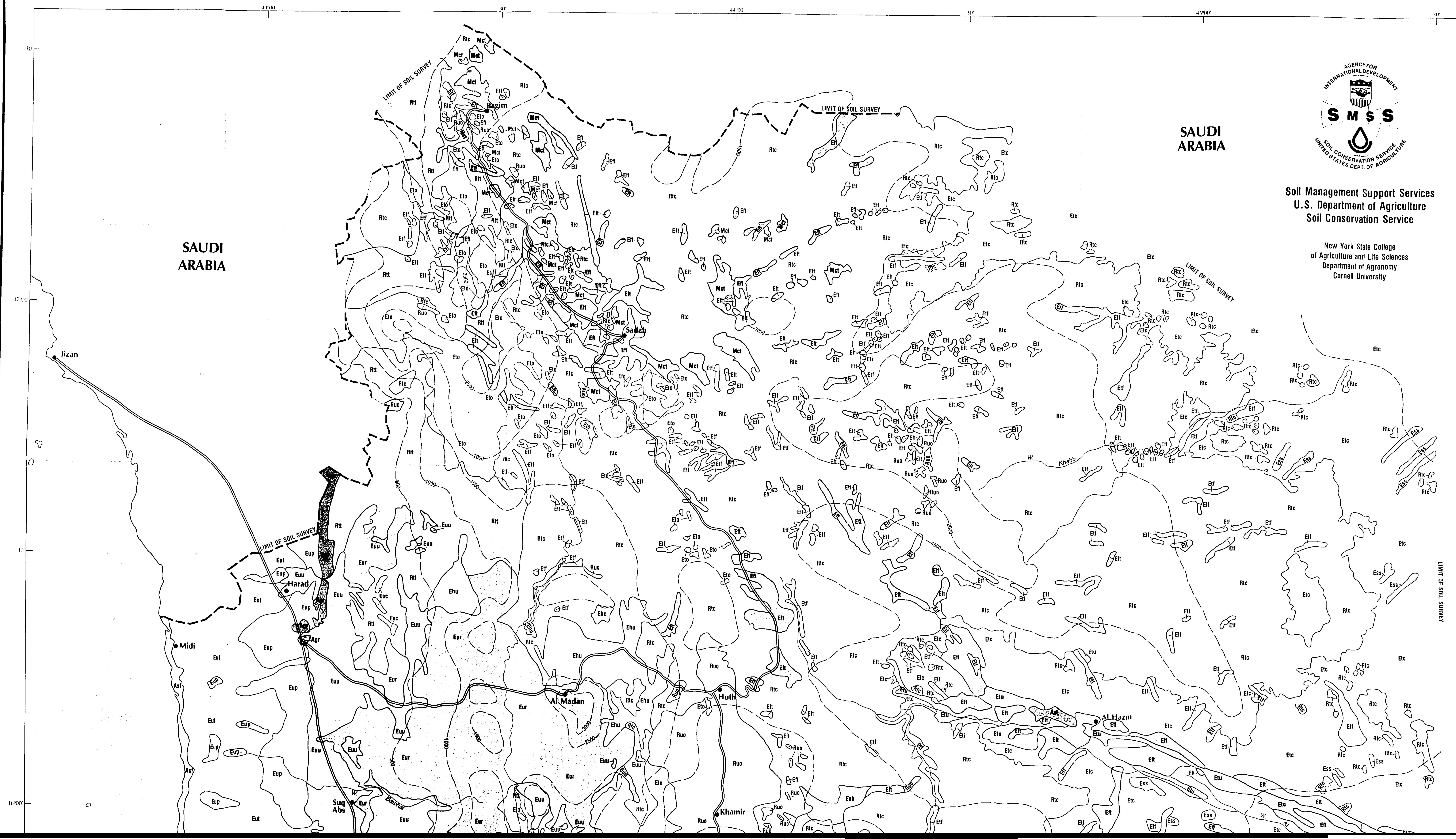
Sample No.	pH 1:1	EC mmhos /cm	Organic Matter (%)	$CaCO_3$ (%)	Avail. P (ppm)	C E C meq/100g
K254	6.9	27.0	1.67	24.6	18.0	8.0
K255	7.5	8.5	1.60	23.0	16.6	24.0
K256	7.0	14.8	1.44	22.0	15.0	9.0
K257	7.1	15.1	1.90	21.0	18.0	16.0
K258	7.4	8.6	1.48	20.0	11.6	9.8
K259	7.9	6.5	1.33	20.0	15.0	9.0
K260	7.9	9.7	1.52	19.8	16.6	20.0
K261	8.1	6.7	.29	19.7	11.6	8.0
K262	8.0	7.8	1.22	18.0	12.6	8.5

*vf-very few (<5% by volume)
f-few (5-15% by volume)
fr-frequent (15-40% by volume)
vfr-very frequent (40-80% by volume)
(from *Guidelines for Soil Profile Description*, FAO, 1977)

**g-gravel (2-75mm)
s-stones (75-250mm)
b-boulders (>250mm)

***c-clay s-sand
l-loam silt

YEMEN GENERAL SOIL MAP



Soil Management Support Services
U.S. Department of Agriculture
Soil Conservation Service

New York State College
of Agriculture and Life Sciences
Department of Agronomy
Cornell University

SOIL MAP LEGEND

MAP UNITS	SYMBOL	PHASE	DOMINANT TEMP. REGIME	PERCENT OF TOTAL AREA
SOILS PREDOMINANTLY ARIDISOLS				
Typic Calciorthids	Act	stony to bouldery	isohyperthermic	60%
Typic Torrifluvents		stony to bouldery	isohyperthermic	20%
Typic Torriorthents		stony to bouldery	isohyperthermic	20%
Typic Gypsiorthids	Agr	stony, mountainous	isohyperthermic	40%
Lithic Torriorthents		stony, mountainous	isohyperthermic	20%
Rock Outcrops		stony, mountainous	isohyperthermic	40%
Typic Salorthids	Asf	flat	isohyperthermic	70%
Tropic Fluvaquents		flat	isohyperthermic	15%
Tropaquents		flat	isohyperthermic	15%
Typic Salorthids	Ast	flat	hyperthermic	70%
Typic Torrifluvents		flat	hyperthermic	30%
SOILS PREDOMINANTLY ENTISOLS				
Typic Torriorthents	Etc	stony, undulating	hyperthermic	40%
Typic Torrifluvents		stony, undulating	hyperthermic	40%
Typic Calciorthids		stony, undulating	hyperthermic	20%
Typic Torrifluvents	Etu	flat	hyperthermic	60%
Typic Udifluvents		flat	hyperthermic	40%
Typic Torrifluvents	Ett	flat	isohyperthermic	30%
Typic Torripsamments		flat	isohyperthermic	30%
Typic Torriorthents		flat	isohyperthermic	30%
Typic Calciorthids		flat	isohyperthermic	10%
Typic Torriorthents	Etf	flat	isothermic, hyperthermic	50%
Typic Torripsamments		flat	isothermic, hyperthermic	35%
Typic Torrifluvents		flat	isothermic, hyperthermic	15%
Typic Torriorthents	Ehu	undulating	iso-, isohyper-, *hyperthermic	20%
Typic Haplargids		undulating	iso-, isohyper-, *hyperthermic	10%
Typic Ustifluvents		undulating, terraced	isothermic	20%
Typic Calciorthids		undulating	isohyperthermic	10%
Typic Ustorthents		undulating	isothermic	10%
Typic Camborthids		mountainous	isothermic	10%
Aquollic Salorthids		flat	isothermic	10%
Typic Fluvaquents		flat	isohyperthermic	10%
Typic Ustorthents	Eur	mountainous, terraced	isothermic, isohyperthermic	20%
Typic Torriorthents		mountainous	isothermic, isohyperthermic	25%
Lithic Torriorthents		mountainous	isothermic, isohyperthermic	25%
Rock Outcrops		mountainous	isothermic, isohyperthermic	30%
Typic Torripsamments	Est	undulating	isohyperthermic	85%
Typic Torrifluvents		undulating	isohyperthermic	15%
Typic Torripsamments	Ess	undulating	hyperthermic	80%
Typic Torrifluvents		undulating	hyperthermic	20%
Typic Ustipsamments	Eut	undulating	hyperthermic	85%
Typic Torrifluvents		undulating	hyperthermic	15%
Typic Ustifluvents	Euu	almost flat	hyperthermic, isohyperthermic	60%
Typic Ustorthents		almost flat	hyperthermic, isohyperthermic	20%
Typic Ustipsamments		almost flat	hyperthermic, isohyperthermic	10%
Typic Torrifluvents		almost flat	hyperthermic, isohyperthermic	10%
Typic Ustifluvents	Eup	undulating	isohyperthermic	60%
Typic Ustipsamments		undulating	isohyperthermic	30%
Typic Torrifluvents		undulating	isohyperthermic	10%
Typic Ustifluvents	Euo	mountainous, terraced	isothermic, isohyperthermic	60%
Typic Ustorthents		mountainous, terraced	isothermic, isohyperthermic	30%
Lithic Torriorthents		mountainous	isothermic, isohyperthermic	10%
Typic Ustifluvents	Eto	mountainous	iso-, isohyper-, *isomesic	5%
Typic Tropofluvents		mountainous	iso-, isohyper-, *isomesic	5%
Typic Ustorthents		mountainous, terraced	iso-, isohyper-, *isomesic	30%
Lithic Torriorthents		mountainous	iso-, isohyper-, *isomesic	5%
Typic Torriorthents		mountainous	iso-, isohyper-, *isomesic	5%
Typic Natrustalfs		mountainous	iso-, isohyper-, *isomesic	5%
Entic Haplustolls		mountainous	isothermic, isomesic	5%
Typic Argiudolls		mountainous	isomesic	5%
Lithic Ustorthents		mountainous	iso-, isohyper-, *isomesic	5%
Rock Outcrops		mountainous	iso-, isohyper-, *isomesic	30%
Typic Ustifluvents	Eft	flat	isothermic, hyperthermic	60%
Typic Torrifluvents		flat	isothermic, hyperthermic	30%
Typic Calciorthids		flat	isothermic, hyperthermic	10%
Typic Ustifluvents	Eub	undulating	isothermic	50%
Basalt Flow		undulating, rubble land	isothermic	30%
Ustic Torriorthents		rolling	isothermic	10%
Typic Ustorthents		terraced	isothermic	10%
Typic Ustorthents	Eoc	undulating	isothermic	50%
Typic Ustifluvents		undulating	isohyperthermic	30%
Typic Calciorthids		undulating	isohyperthermic	10%
Typic Torriorthents		undulating	isohyperthermic	10%
Typic Ustorthents	Enc	mountainous, terraced	isothermic, isomesic	45%
Udic Haplustolls		mountainous, terraced	isothermic, isomesic	10%
Entic Ustropepts		mountainous	isothermic, isomesic	10%
Petrocalcic Calciustolls		mountainous	isothermic, isomesic	5%
Typic Calciustolls		mountainous	isothermic, isomesic	5%
Typic Ustropepts		mountainous, terraced	isothermic, isomesic	5%
Typic Calciorthids		mountainous	isothermic, isomesic	5%
Rock Outcrops		mountainous	isothermic, isomesic	15%
SOILS PREDOMINANTLY INCEPTISOLS				


RED SEA
JABAL
ZUQAR
ISLAND
Bayt
Al Faqih
Zabid
Hays
Dhamar
Yerim
Rada
Juban
Al Bayda'
Lawdar
LIMIT OF SOIL SURVEY
14°00'

SOILS PREDOMINANTLY INCEPTISOLS

Udic Pellusterts	Iuc	flat	isothermic	5%
Typic Torrerts		flat	isothermic	5%
Typic Ustropepts		flat	isothermic	55%
Ustollic Calciorthids		flat	isothermic	20%
Vertic Haplustolls		flat	isothermic	10%
Udic Haplustolls		flat	isothermic	5%
Typic Ustropepts	■	mountainous, terraced	isothermic	60%
Entic Ustropepts		flat	isothermic	20%
Typic Ustifluvents		flat	isothermic	10%
Ustollic Camborthids		flat	isothermic	5%
Ustollic Calciorthids		flat	isothermic	5%

SOILS PREDOMINANTLY MOLLISOLS

Typic Haplustolls	Mct	flat	isothermic	10%
Typic Calciustolls		flat, sand cap	isothermic	40%
Typic Calciorthids		flat	isohyperthermic, isothermic	20%
Typic Torriorthents		flat	isothermic	15%
Ustic Torripsamments		flat	isothermic	15%
Entic Hapludolls	Mhr	mountainous	isothermic	10%
Typic Hapludolls		mountainous	isothermic	40%
Lithic Torriorthents		mountainous	isomesic	10%
Rock Outcrops		mountainous	isomesic	40%
Vertic Haplustolls	Muh	flat	isothermic	50%
Typic Ustifluvents		flat	isothermic	30%
Aridic Haplustolls		flat	isothermic	10%
Typic Torriorthents		flat	isothermic	5%
Typic Haplustolls		flat	isothermic	5%

SOILS PREDOMINANTLY ROCK OUTCROPS

Typic Calciorthids	Rcc	stony, mountainous	isothermic, isohyperthermic	20%
Lithic Calciorthids		stony, mountainous	isothermic, isohyperthermic	10%
Rock Outcrops		stony, mountainous	isothermic, isohyperthermic	70%
Lithic Torriorthents	Rtt	mountainous	isohyperthermic	20%
TypicTorriorthents		mountainous	isohyperthermic	20%
Typic Calciorthids		mountainous	isohyperthermic	10%
Rock Outcrops		mountainous	isohyperthermic	50%
Typic Torrifluvents	Rtc	flat	hyperthermic	5%
Typic Ustifluvents		flat	hyperthermic	5%
Typic Torriorthents		mountainous	hyperthermic	25%
Lithic Torriorthents		mountainous	hyperthermic	10%
Typic Calciorthids		mountainous	hyperthermic	5%
Rock Outcrops		mountainous	hyperthermic	50%
Typic Ustifluvent	Ruo	flat	isothermic	40%
Rock Outcrops		steep	isothermic	60%

• isothermic, isohyperthermic

This map is for general planning. It shows only the major soils and does not contain sufficient detail for operational planning.

Contour intervals 500 meters
The delineation of international boundaries on this map must not be considered authoritative.

Base map information adapted from the British Topographic Series, Director of Military Survey Ministry of Defence, U.K. 1974.

Produced by the Department of Agronomy of the New York State College of Agriculture and Life Sciences at Cornell University in cooperation with the Yemen Arab Republic Ministry of Agriculture and the United States Agency for International Development USAID/YAR-MOA Contract #279-0042 Completed 1983