FOOD AND AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS
ENVIRONMENTAL RESOURCE ASSESSMENT FOR RURAL LAND USE PLANNING
GCP/YEM/021/NET *Field Document 2*

A FRAMEWORK FOR A NATIONAL SOIL SERIES SYSTEM IN YEMEN

PART 1 EXISTING SERIES

AGRICULTURAL RESEARCH AND EXTENSION AUTHORITY
MINISTRY OF AGRICULTURE AND WATER RESOURCES
DHAMAR, REPUBLIC OF YEMEN

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PART 1 EXISTING SERIES

by

El-Abbas Doka Mohamed Ali
FAO Land Resource Expert

in cooperation with

Wen Ting-tiang
FAO Chief Technical Adviser

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INTRODUCTION

To raise the level of agricultural production in order to secure a higher degree of self sufficiency and improve the quality of life for rural communities, and with virtually no possibilities for horizontal expansion of agricultural land, a more intensive and efficient use of natural resources is the only option to achieve this goal. Considerable scope for higher productivity can be achieved through the following land and water management measures:

- Introduce improved soil and water management packages, in particular on rainfed lands,

- Raise irrigation efficiencies to enhance the productivity of irrigated agricultural systems,

- Direct the limited water resources to the best agricultural lands,

- Grow more water efficient crops, and

- Pay proper attention to land and water conservation to ensure sustainability of these natural resource base without which there can be no agriculture.

Such measures can not be implemented successfully without a reliable soil database that can provide all the soil and land information required for planning and implementing the changes that will result from the above recommendations.

The objective of the present study is to lay out a procedure for organizing, grouping and revising all soil data already produced in Yemen, with the aim of setting up a soil series framework that eventually will lead to the establishment of a national soil series system. Such a system will provide a comprehensive unified base for correlating previous and future soil information, and also serve as a guide for researchers to transfer agricultural technology and research results to areas with similar soils as those on which research was carried out. The national soil series system will also be used to formulate a national soil legend which will help in providing adequate soil and land data required for planning agricultural development in the different regions of the country.

Due to the fact that the quality of previous soil information is rather variable and moreover the available technical capabilities for analyzing soils is limited, while in general the morphological and genetic properties of soils with the best agricultural potential is subdued, it seems that a national soil series system should meet the following criteria:

- provide simple, flexible, and easy to update information which can be understood by a wide range of users (e.g. soil scientists, researchers, extension workers),

- does not require complex data which might be difficult to acquire,

- reflect important soil properties and limitations that affect their suitability for various crops in different agro-climatic zones,

- be compatible to one of the international soil classification systems for easy transfer of technology and future upgrading to international standards

- can be published in the form of a simple booklet for use in the field.

Chapter 1 MATERIAL AND METHODS

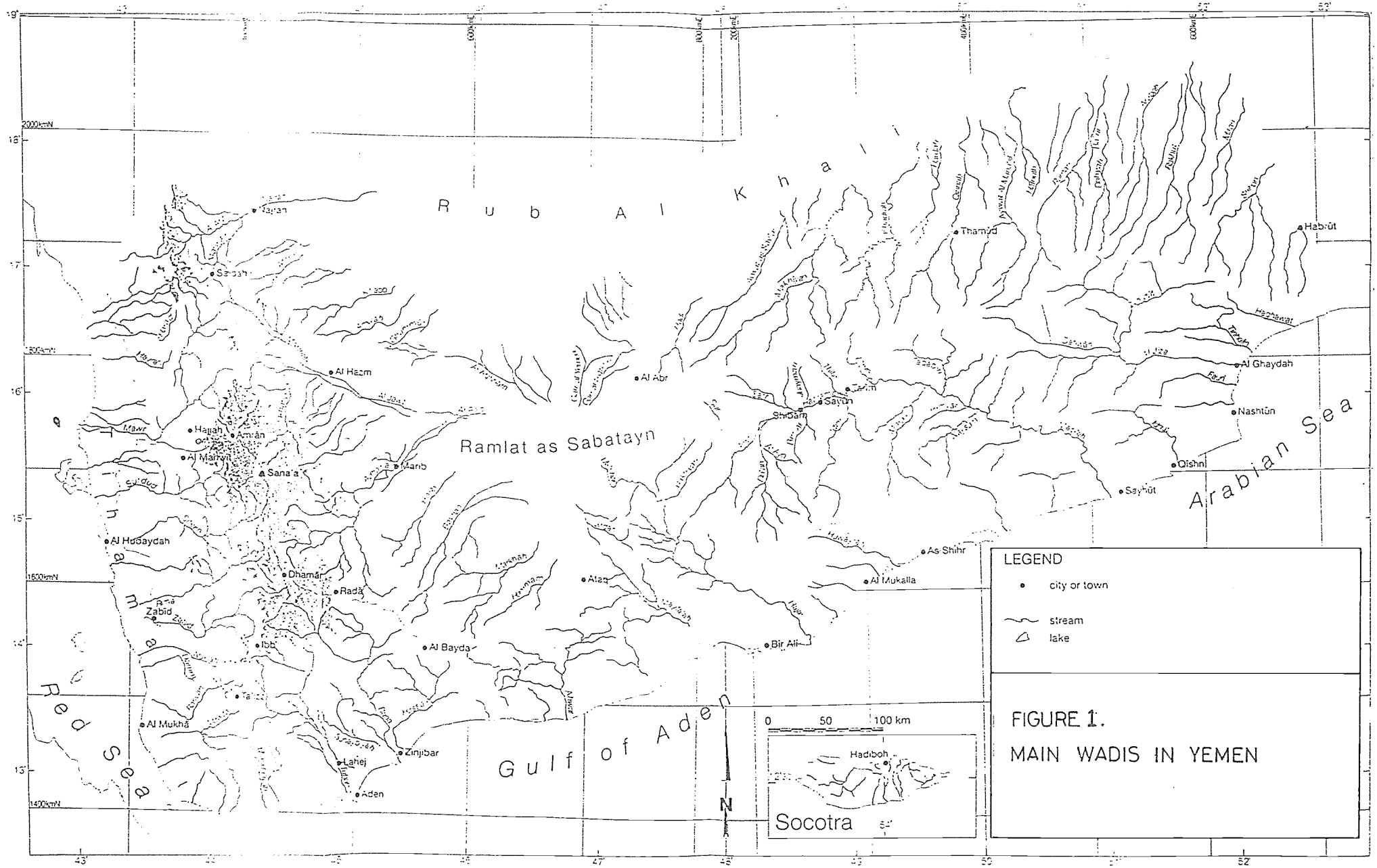
1.1 ENVIRONMENT

The Republic of Yemen lies in the south-western corner of the Arabian Peninsula, between 12°00'- 18°00'N latitude and 42°00'- 53°00'E longitude. The country is divided into nineteen governorates (provinces) with a total area of 547,000 km^2 (approximately 55 million hectares), made up largely of mountains and desert terrain. The total population of Yemen is about 15 million, living mostly in northern governorates. The area of cultivable land is limited and to a large extent exists of man-made terraces built along steep hill and mountain sides. The agricultural production is based on about one million ha of rainfed land, 250,000 ha of land irrigated with pumped groundwater and from springs and streams, and 150,000 ha of spate irrigated areas whereby short-duration floods are diverted to irrigate land adjacent to the wadis. The total land of the country can roughly be divided into the following land use categories :

Irrigated & rainfed cropland	1,026,000 ha	
Fallow	624,000 ha	
Total potential cultivable land		1,650,000 ha
Woodland		1,500,000 ha
Rangeland & pasture		20,550,000 ha
Desert, mountains and urban areas		31,000,000 ha
	total	54,700,000 ha

As no permanent rivers, wadis, streams or lakes (except the man-made Marib Dam reservoir) of any importance exist in the country, Yemen's agriculture is highly dependent on rainfall. Annual precipitation ranges from 150 - 450 mm in most parts of the country, but reaches 1200 mm or slightly more in the highland area near Ibb. 90% of the country, however, receives less than 300 mm per annum. Yemen has thus a dry climate with potential evapotranspiration exceeding the monthly precipitation throughout the year in most parts of the country. In some rain-exposed locations on the western escarpment, e.g. the area around Ibb, the rainfall equals or exceeds potential evapotranspiration for about three months per year. Temperature varies greatly with altitude: from the hot, tropical climate of the lowlands to the temperate climate of the mountain areas. Due to the mountainous nature of Yemen numerous wadis are flowing down from highland regions (figure 1). From the western Highlands some wadis flow across the Tihama Coastal plain toward the Red Sea. In the east the wadis flow in the direction of the Empty Quarter. In the South many wadis flow toward the Gulf of Aden and Arabian Sea.

The average annual groundwater recharge is estimated at 1060 million m^3, equivalent to only 35 mm of precipitation. The estimates for groundwater reserves in Yemen range between 0.9 and 2.7 billion m^3 as renewable yield, but an average of 1600 million m^3 is usually reported. The demand is around 2600 million m^3 per annum which is about double the rate of recharge (Hamdallah 1993). The agricultural sector is the principal user of water, amounting to about 91%, while the municipal and industrial sector use the balance.


Rub Al Khali
Ramlat as Sabatayn
Yemen
Red Sea
Gulf of Aden
Arabian Sea
Sa'dah
Al Hazm
Hajjah
Amran
Al Mahwit
Sana'a
Marib
Al Hudaydah
Dhamar
Radda
Zabid
Ibb
Al Bayda
Taiz
Al Mukha
Lahej
Zinjibar
Aden
Al Abr
Thamud
Habrut
Sayun
Shibam
Al Ghaydah
Nashtun
Qishn
Sayhut
As Shihr
Al Mukalla
Ataq
Bir Ali
LEGEND
city or town
stream
lake
0 50 100 km
Hadiboh
Socotra
N
FIGURE 1.
MAIN WADIS IN YEMEN

Yemen can be divided into eight physiographic regions (figure 2) :

1. **The coastal plains (CP):** These are the Western (Tihama) and Southern coastal plains. The Tihama plain (WCP) extends along the Red Sea up to the foot of the mountains in the east, with an elevation ranging from sea level to about 250 m along the foothills. The Southern coastal plain (SCP) extends from east to west along the Gulf of Aden and Arabian Sea for about 1,100 km, with a width of about 70 km. The elevation ranges from sea level to 300 m.

2. **The Western Slopes (WS):** These are the steep side mountains beyond Tihama plain up to the crest of the western escarpment with an elevation ranging from 250 m (west) to 2,200 m (east).

3. **The Highlands (HL):** Extending from north of Sadah southwards through the Midlands mountains to Taiz, with an average elevation ranging from 1,800 to 2,500 m. Composed of a string of intermontane basins, the Highlands can be divided into:

   - Northern Highlands (HLN)
   - Central Highlands (HLC)
   - Southern Highlands (HLS)

4. **The Eastern Slopes (ES):** These are the eastern slopes of the Highland with elevation ranging from 1,200 m in the east to about 1,800 m in the west.

5. **The Midlands (ML):** These are the middle slopes extending from the eastern border of the Highlands towards the Eastern Plains and Ramlat as Saba'atyan. The parts which border the Eastern Slopes stretch towards the east from Ataq till north of Mukalla, and lie enclosed between the Southern Slopes and the Hadramaut Plateau. Elevation ranges from 500 m in the south to 2,500 m in the vicinity of Ibb.

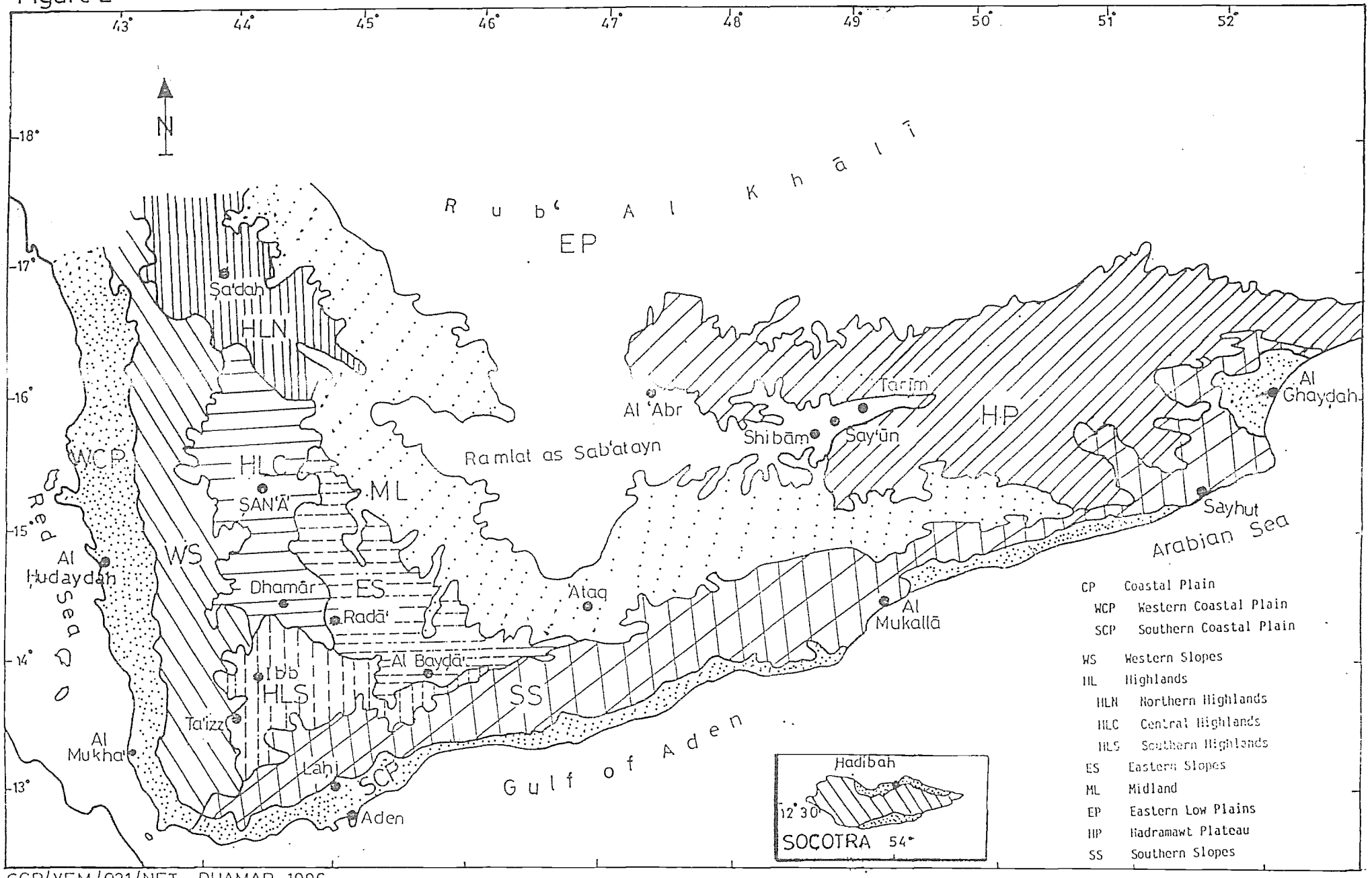
6. **The Eastern Plains (EP):** Lowland from the foot of the highlands and from western half of the southern slopes to join at Foyer El-Batin with an elevation of 200 m.

7. **Hadramaut Plateau (HD):** It lies east of the Eastern Plains and to the north of the Southern coastal plains. The elevation ranges from 600 m in the wadis to 1600 m in high watershed areas. The plateau slopes down gently towards the north where it becomes covered by thick alluvial sediments.

8. **The Southern slopes (SS):** Extend from the Red Sea in the west to the borders of Oman in the east. It consists of group of wadis, plains, mountain and it drains into the Arabian Sea. The elevation ranges from 300 m to 2,000 m.

MAIN PHYSIOGRAPHIC REGIONS OF YEMEN

Figure 2



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1.2 MATERIAL

1.2.1 Previous soil surveys in Yemen

Since the early seventies numerous soil surveys have been carried out in different parts of Yemen. Table 1 provides an overview of all major soil surveys hitherto conducted in the country. An early description of soil surveys undertaken in the (former) Yemen Arab Republic was given by Gewaifel and Al-Thor (1984). Rhebergen and Al-Meshriky (1990) updated the information on previous soil surveys. A bibliography, containing among others a full list of all publications on soils in northern and southern Yemen, was recently published (Wen ting-tiang, 1995).

These surveys, carried out by various foreign bodies, often through bilateral aid, were undertaken at different levels of intensity and according to different classification systems. As they were invariably carried out within the framework of agricultural and rural development, the main purpose of these soil surveys was to provide the necessary information required for assessing the land potential for crop production. Consequently, much effort went into the characterization and mapping of soils for land capability evaluation, and relatively little attention was paid to the classification and correlation of soils, which in some instances was totally neglected. The latter might have been due to the following factors:

1. Most soil classification systems depend on some chemical, physical and pedological data which were not always collected or determined.

2. Absence of national soil classification standards to guide the soil surveys undertaken in Yemen.

3. International soil classification systems may not always have been appropriate for separating soils at the scale of mapping used, and more simple parameters may have been used to separate the soil types observed.

Within the soil surveys carried out so far, hundreds of profiles have been described. These profiles have either been classified according to one or both of the two most common soil classification system (i.e. USDA Soil Taxonomy or FAO-Unesco Soil Map of the World Legend), or were classified according to local criteria. Some described profiles have therefore not been correlated with one of the international soil classification systems.

1.2.2 Soil classification in previous soil survey reports

Reviewing the soil survey data in Yemen from late sixties to date it was realized that from the over thirty published soil surveys only eighteen include detailed information on soil classification. The Soil Taxonomy (compiled by the Soil Survey Staf of the U.S. Soil Conservation Service) and the Legend, Soil Map of the World (FAO/Unesco, 1974) were both used, but at different taxonomic levels. The FAO/Unesco Legend was generally used up to second or unit level, while the Soil Taxonomy was used from subgroups down to the soil series level. Table 1 indicates which soil survey has been classified according to what system.

Table 1 Soil surveys carried out in Yemen

AREA	GOVERNORATE	YEAR	SURVEY INTENS.	MAP SCALE	EXTENT (HA)	CLASSIFI-CATION
WADI MAWR	AL HUDAYDA	1972	SD	1: 40 000	72 000	-
WADI SURDUD	AL HUDAYDA	1978	SD	1: 40 000	14 000	-
WADI SIHAM	AL HUDAYDA	1981	REC SD	1: 50 000	200 000 (38000)	F
WADI RIMA	AL HUDAYDA	1980	SD	1: 65 000	64 000	S, ST, FAO
WADI ZABID	AL HUDAYDA	1971	SD	1: 20 000	20 000	parent mat.
WADI RASYAN	AL HUDAYDA	1977	REC	1: 65 000	210 000	parent mat.
MONTANE PLAINS	DHAMAR - IBB	1981	SD	1: 50 000	280 000	S, ST, FAO
AL MAHWIT	AL MAHWIT	1983	SD	1:100 000	233 000	ST
SANA'A BASIN	SANA'A	1986	REC	1:100 000	325 000	physiogr.,R
HAJJAH	HAJJAH	1980	EXP	1:500 000	959 000	physiogr.,R
AL JAWF	AL JAWF	1980	REC SD	1:100 000 1: 20 000	76 000 (29000)	-
MARIB DAM	MARIB	1977 1978	REC SD	1: 50 000 1: 50 000	50 000 22 500	ST texture
AL BAWN	SANA'A	1978	REC	1: 50 000	26 400	ST
SADAH	SADAH	1985	REC	1: 50 000	45 000	ST
KHAWLAN	SANA'A	1977	EXP	1:500 000	347 384	-
QUMAYSHAH FARM	AL HUDAYDA	1975	D	1: 10 000	50	texture
WADI TUBAN	LAHJ	1973	SD	1: 25 000	16 730	-
WADI HADRAMAWT	HADRAMAWT	1981	REC SD	1:100 000 1: 20 000	47 000 20 000	F, FAO, ST
MUDIYAH	ABYAN	1977	SD	1: 5 000	7 000	texture
WADI MARKHAH AND WADI KHAWRAN	SHABWAH	1984	SD	1:100 000 1: 20 000	21 700	ST
AL KAWD AL KAWD	ABYAN	1978 1975	D SD	1: 3 000 1: 10 000	200 175	S, ST S, ST
ABYAN DELTA W.BANA & ABYAN DELTA	ABYAN	1974 1984	SD SD	1: 25 000 1: 25 000	52 300 (35000)	S, ST S, ST
WADI BAYHAN	SHABWAH	1978	SD	1: 20 000	11 000	F
DHAMAR	DHAMAR	1983	D	1: 10 000	1 000	depth, text.
NISSAB AREA	SHABWAH	1982	REC	1:100 000	30 800	S, ST
WADI RABWAH	LAHJ	1990	SD	1: 25 000	10 000	R
AHWAR AREA	SHABWAH	1967 1990	SD SD	1: 20 000 1: 25 000	102 000 (13 200)	S R
NUQUB AREA	SHABWAH	1967	SD	1: 20 000	7 600	S
AL ARAYIS FARM	ABYAN	1978	D	1: 5 000	200	S
SUWAYRI	ABYAN	1978	D	1: 2 500	300	S
WADI HAJAR	HADRAMAWT	1984	D	1: 10 000	2 500	FAO
WADI MAYFA'AH	HADRAMAWT	1976	SD	1: 35 000	13 000	FAO
YEMEN ARAB REPUBLIC	ALL GOVERNORATES	1983	EXP	1:500 000	200 000 km^2	ST

EXPLANATION OF ABBREVIATIONS:

Survey intensity	D	-	detailed	REC	-	reconnaissance
	SD	-	semi-detailed	EXP	-	exploratory
Classification	ST	-	Soil Taxonomy	R	-	Russian system
	FAO	-	FAO/Unesco legend	S	-	soil series
	F	-	French system			

The following of these surveys and reports contain sufficient information to be used for this study (see figure 3 for their location) :

1. Report on soil survey and land classification of Nuqub (Beihan) area 1967

2. Report on soil survey and land classification of Ahwar area 1967

3. Soil survey and irrigation suitability classification. of wadi Rima'. YAR Montane Plains and wadi Rima' Project: A land and water resource survey. 1979

4. Abyan Delta Project, Definite Plan Report. 1974
   Annex IV - Soil and Land Classification

5. National programme of tomato production for processing 1975

   5.1 Study of soil and water in selected areas
   5.2 Soil survey of El Kod experimental farm 1975

6. Detailed soil survey of three demonstration and research farms 1978

   6.1 El-Kod Agricultural Demonstration and Research farm
   6.2 Al-Araise farm
   6.3 Suweri farm (Seiyun)

7. Marib Dam and Irrigation Project 1978
   Annex I : Soils
   Annex II : Soil and Land Classification

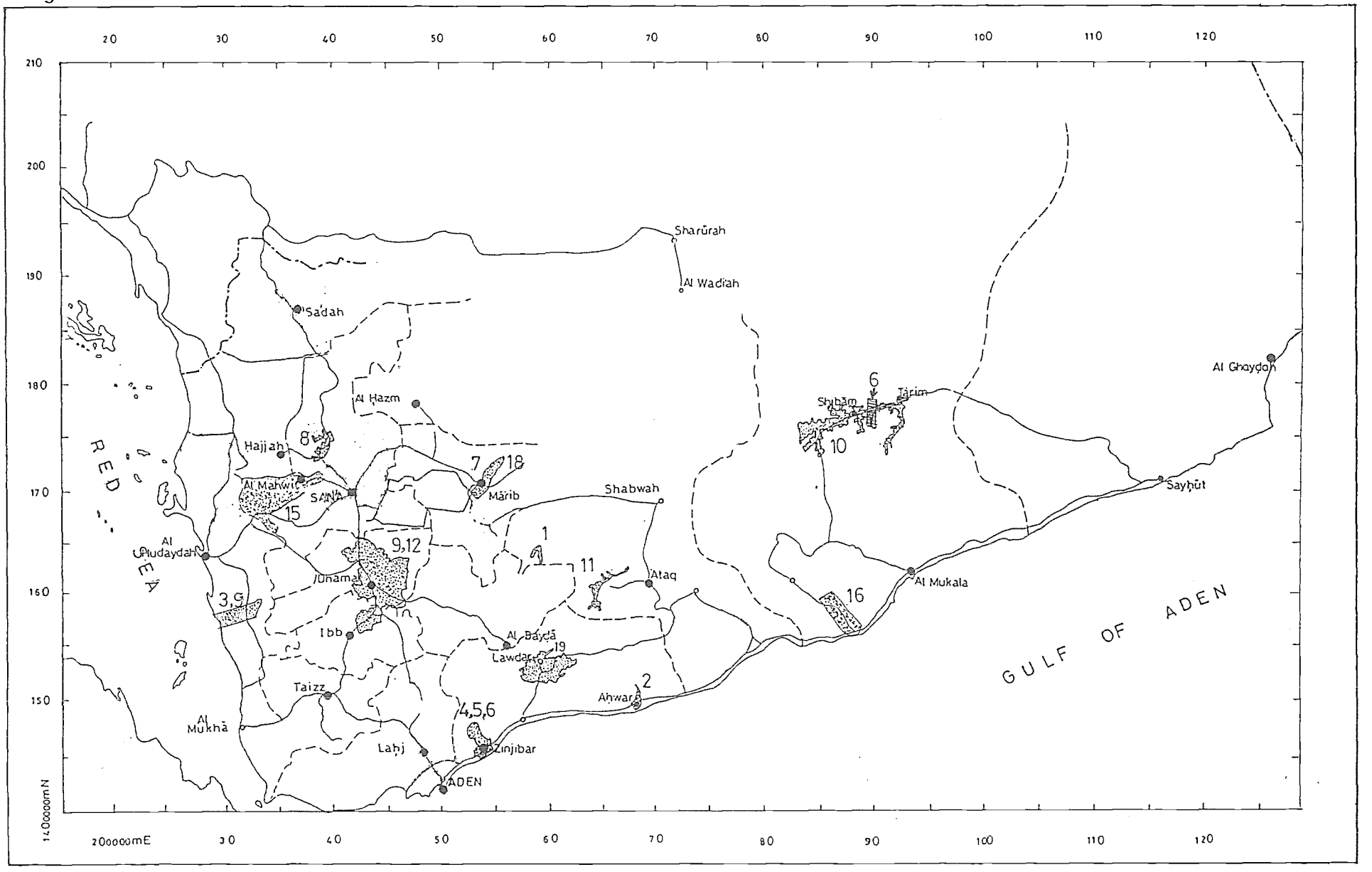
8. Proposals for follow-on measures for Al-Boun Project Feasibility Study 1979

9. Soils and land suitability of the Montane Plains and Wadi Rima'. YAR. Montane plains and Wadi Rima' Project : A land and water resource survey. 1979

10. Wadi Hadramout feasibility study. Final report 1981
    Vol. 1. Specific Study. Vol. 2. Soil Survey and Land Classification.

11. Hydrological survey of Nissab region. Final report 1982
    (Water and Soil resources). Vol. 2. Appendix VI. Soil Survey

Fig. 3 SELECTED SOIL SURVEYS FOR SOIL SERIES SYSTEM IN YEMEN



12. Soil Classification and Correlation in the Montane Plains and wadi Rima'. YAR Montane Plains and Wadi Rima Project : A land and water resource survey. 1982

13. Soil survey of Yemen Arab Republic. Final report. 1983

14. Feasibility study of Wadi Bana and Abyan Delta development project. Vol. IV. Annex C. Soils. 1984

15. Regional development study of Al-Mahweit Province Vol. 1. Annex I. Natural Resources. 1984

16. Wadi Hajr Agricultural rehabilitation project. Vol. 1. Text. Annex III. Soil survey. 1984

17. Hydrological survey of Wadi Markh region. Final report Vol. 3. Water and soil resources. Appendix VII. Soil Survey. 1989

18. Soil survey and land evaluation for irrigated agriculture (Marib Dam project for irrigation). 1989

1.3 METHODS AND PROCEDURES

A considerable number of soil series has already been identified in Yemen based on different taxonomic concepts and ideas. Since the main concern of this exercise is to provide a basis for a unified soil series system in Yemen, it was felt necessary, as a first step, to arrange and group these soil series on a conceptual basis. This would facilitate comparing soil series identified in different reports, selecting those that could form part of the list of national soil series, and introducing modifications or improvements to other series so as to make them suitable for inclusion in the national soil series system as well. The procedures followed for this activity is as follows:

1. Collection and arrangement of all available soil survey reports produced by different organizations for both southern and northern Governorates in Yemen.

2. Studying and sorting out soil survey reports which contain information on soil classification and/or soil series.

3. Reviewing all soil series and group then according to different soil classification systems being used in Yemen.

4. Selection and tabulation of all named and unnamed soil series which are supported by well described soil profiles and reliable analytical data.

5. Creation of a separate file in the computerized soil data base to accommodate the soil series information.

1.4 SOIL SERIES CONCEPT

Soil series were devised as a class of soils that can be recognized at a level where they can be useful for providing management advice to farmers. Consequently they form one of the lowest categories in the classification of soils. Soil series, or associations of soil series, can be used to map soils at semi-detailed scale, i.e. scales of 1:20,000 to 1:50,000. At detailed level, i.e. scales larger than 1:20,000 (often 1:10,000) phases of soil series are suited to characterize soils.

According to the Soil Survey Manual (Soil Survey Staff, 1951) soil series are defined as follows: "The soil series is a group of soils having soil horizons similar in differentiating characteristics and arrangement in the soil profile, except of the texture of the surface soil, and developed from a particular type of parent material. The soils within a series are essentially homogeneous in all soil profile characteristics except texture, principally of the A or surface horizon, and in such features as slope, stoniness, degree of erosion, topographic position, and depth to bedrock where these features do not modify greatly the kind and arrangement of soil horizons".

Criteria to distinguish soil series therefore include texture of the subsoil (the textural classes recognized at family level are used for this), structure, colour (if this of any significance), pedogenetic horizons and their thickness and arrangement, humus, carbonate and salt content, soil reaction and soil mineralogy. As no two soils are exactly the same, it is a certain range in one of these criteria that should be significantly different from a certain range in another group of soils before a separation in soil series can be made. However, in most cases a number of these properties (or their range) will be different between two or more soil series, as several of them are genetically related. For instance, one is unlikely to encounter two similar soil series differing in soil reaction only. Differences in pH are usually linked to variations in carbonate and salt content, and if the pH difference is large the soil colour may be affected as well.

The above criteria are known as differentiating criteria, i.e. they are used to recognize different soil series. Distinguishing criteria are used to characterize soil series. These include landscape position, slope, parent material and drainage features. Obviously, a large variation in one of these criteria cannot be accommodated in one soil series, but such variation will be expressed in one or more of the differentiating criteria. For instance, the morphology of otherwise similar immature alluvial soils will be different if they occur in a well-drained or a poorly drained position.

The texture of the topsoil can be highly variable even within short distances. As many perennial plants have most of their roots in the topsoil, and as the topsoil is important as a seedbed for plants, small differences in topsoil texture can be of great agronomic importance. Hence the topsoil texture is not considered as a differentiating characteristic between soil series, but rather within one soil series. A soil series is therefore not complete if its topsoil is not characterized. Where no clear topsoil can be distinguished, the average texture of the upper 15 cm is taken. So is it possible to subdivide the Abyan soil series into an Abyan sandy loam, an Abyan silty clay loam etc.

Agriculturally important soils in Yemen are often of recent alluvial or colluvial origin. The textural composition of such young soils can be highly variable, as they may be made

up of a number of sedimentary layers. It is not possible to base a soil series on each combination of sedimentary layers, and the general approach is to estimate or calculate the average textural composition of the subsoil and separate soil series according to this, if there are no other differentiating factors of importance (e.g layers rich in carbonates). However, sharply contrasting textures may occur in one of the layers, which can have a direct or indirect effect on crop growth. In such a case it will be necessary to distinguish one or more phases.

The phase is a further subdivision of a soil series. A phase is used where there is some variation in one or more characteristics of a soil series that potentially may be of agronomic significance, but that is not large enough to establish a new soil series. Phases of series commonly relate to soil depth, slope class, stoniness or rockiness, erosion, thickness of the topsoil, contrasting textural layers or irrigated silt overwash. It should be stressed that large variations in any of these soil properties will automatically lead to the recognition of another soil series, as the whole morphology of the soil is likely to change when there is a big change in one of the properties. Thus, a shallow or very shallow phase of an otherwise deep soil series is not possible, as the soil horizons and their thickness will be different in the shallow soil. A moderately deep phase is, on the other hand, very common. It has to be separated as a phase as deep rooting crops such as fruit trees may do less well in the moderately deep phase than in the deep version of the soil series.

A variant of a soil series is a kind of temporary soil series. It is close to an existing soil series, but differs in at least one differentiating characteristic. Little is known about its extent to warrant the establishment of a new series. In time, when more information has been collected with regard to its occurrence and range of characteristics, it may be recognised as a new soil series. If the Abyan soil series is a fine loamy soil, a coarse loamy variant could be recognised for somewhat more coarser textured soils. If it was later found that this variant is of minor extent, it could remain a variant. But if it would be widely encountered in other parts of Abyan delta, or elsewhere, a new soil series could be defined to accommodate this variant.

Soil series are commonly named after locations where the series was first recognized. Their name may also reflect the landscape in which they occur, but only if they are found over a large geographical area. A Wadi series in Yemen is only useful if it would have a large extent in Yemen's wadis. If it was restricted to e.g. wadi Zabid, then the name Zabid series would be more appropriate.

Since the publication of the Soil Taxonomy the place of the soil series in a soil classification system has been elucidated. Soil series can, by definition, only belong to one unique unit of the immediate overlying taxonomic category. In the Soil Taxonomy this is the soil family, which is characterised by texture, mineralogy, and soil temperature class, properties important for plant growth. Several soil series can thus belong to one soil family, but only one soil family can accommodate a particular soil series, even though the same combination of texture, mineralogy and soil temperature may be associated with a family that occurs in another subgroup. Figure 4 shows the relationship between the different categories in the Soil Taxonomy.

Figure 4 Hierarchy of soil categories in Soil Taxonomy and FAO-Unesco World Soil Map Legend

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SOIL TAXONOMY (1994)

ORDER	Inceptisol
SUBORDER	Ochrept
GREAT GROUP	Ustochrept
SUBGROUP	Typic Ustochrept
FAMILY	Typic Ustochrept, fine loamy, mixed, calcareous, isohyperthermic
SERIES	Jahran silt loam
PHASE	Jahran silt loam, gently sloping

FAO/UNESCO REVISED SOIL MAP OF THE WORLD LEGEND (1988)

SOIL GROUP	Cambisol
SOIL UNIT	Calcaric Cambisol
SOIL SUBUNIT	Verti-Calcaric Cambisol
PHASE	Verti-Calcaric Cambisol, phreatic phase

Chapter 2 Grouping of Existing Soil Series

The different soil series which appear in the aforementioned reports have been grouped according to one of the following criteria:

- Soil series differentiated on the basis of soil texture and degree of depositional stratification

- Soil series correlated with one of the international soil classification systems.

2.1 SOIL CLASSIFICATION SYSTEMS APPLIED IN YEMEN

Although the reasons for applying a certain classification system have not always been made clear in the different soil survey reports, it is highly likely that the background knowledge of the scientist conducting the field work greatly affected their choice of classification system. The classification systems that up till now have been used in different parts of Yemen are :

A. USDA Soil Taxonomy (1995)
B. FAO/UNESCO legend (1974-78)
C. French Soil Classification (1967)
D. Russian system

2.1.1 Soil Taxonomy

By far the most detailed and comprehensive international system is the Soil Taxonomy prepared by the Soil Conservation Service of the Department of Agriculture (Soil Survey Staff), and published in 1975 after a number of approximations. It's purpose is made clear in its subtitle "A basic system for making and interpreting soil surveys". Above the level of soil series it makes a complete break with previous systems in design and nomenclature, and introduces carefully defined diagnostic criteria for class differentiation. It is regarded by many as an international reference system (Ragg and Clayden, 1973), and has strongly influenced other national schemes and that developed by FAO/Unesco for the Legend of the Soil Map of the World.

The categories of the system are order, suborder, great group, subgroup, family and series (see figure 4). This hierarchical system is based on class distinction through precisely defined diagnostic horizons, soil moisture regimes and soil temperature regimes. Diagnostic surface horizons known as epipedons are defined in such a way that their main properties remain unchanged by cultivation over short periods. Diagnostic subsurface horizons are more numerous, and like epipedons vary a great deal in the taxonomic significance assigned to them. Classes of soil moisture regime generally determine placement at the second categoric level of suborder. Soil temperature regime classes are used for defining soil classes at various categoric levels.

Nomenclature is an important part of any classification system because of the need for unambiguous communication. In a hierarchical system the nomenclature should also demonstrate the relationship between classes at each categoric level. Soil Taxonomy uses a complete set of new names for categories above the series level. At first sight the nomenclature seems unpalatable but, with application, its merit becomes evident. Thus the names are connotative and relatively short. A formative element for each of the higher categories is successively carried down to and included in the name at family level. Soil series, however, stick to their geographic names (see also figure 4).

2.1.2 FAO/Unesco Legend for the Soil Map of the World

Although USDA Soil Taxonomy is regarded as a valuable international soil reference system, the best picture of the global distribution of soils can be obtained from the FAO/Unesco Soil Map of the World (scale 1:5,000,000),published between 1974 and 1978. An international advisory panel of eminent soil scientists was convened to develop a "legend" for the map (FAO, 1974). One of the panel's stated objectives was to "promote the establishment of a generally accepted soil classification and nomenclature". Thus the map's legend became a soil classification system in its own right. The legend uses diagnostic horizons that are largely modelled after the diagnostic horizons in the Soil Taxonomy. A fundamental difference between the two systems is, however, the absence in the Legend of soil moisture and soil temperature regimes. The co-existence of two major international soil classification systems means that for soil correlation the classification according to both systems is usually given.

The legend provides for two levels of classification, of which the highest level contains 28 units. This level is roughly equivalent to the Soil Taxonomy's suborder level. The sub-units can be compared to great groups. In the revised legend (FAO, 1988) guidelines are given for the definition of third level units, which are similar to sub-groups in the Soil Taxonomy. Names for the units are partly traditional, such as Chernozem and Podzol, are partly adopted from North America like Gleysol, Histosol and Vertisol, while some have been newly coined like Luvisol and Acrisol (see also figure 4).

2.1.3 French Soil Classification

The French have been most influential in developing ideas on classification in western Europe on the "genetic model" and these have been ably disseminated by the prolific writing of Duchaufour (1960-76). The latest official French system was published by the Commission de Pedologie et de Cartographie des Sols (CPCS, 1967) and was developed from that of Aubert and Duchaufour (1956). The system is not restricted to the soils of France but has also been applied by the Office de la Recherche Scientific Technique Outre - Mer (ORSTOM) to the soils in overseas countries where France has closed historical ties. It has not, however, gained the same international acceptance as the USDA and FAO/Unesco systems. At the highest categoric level twelve classes are distinguished by (i) degree of profile development; (ii) nature of alteration product; (iii) type of humus from and distribution of organic matter; (iv) features due to gleying or salinity (Aubert, 1965). Subclasses are separated mainly on climatic basis. At the third categoric level, groups are defined by morphological features resulting from pedogenetic processes. Thus, within the subclass of Sols brunifies, soils with

or without an argillic horizon are distinguished as Sols lessives (Udalfs) and Sols bruns (Ochrepts). This is a in marked contrast with the US system where the presence of an argillic horizon distinguished soils at highest categoric level.

2.1.4 Russian system

No information is available to describe the Russian system, which has been used for surveys in the former People's Democratic Republic of Yemen (see table 1). No soil series or comparable units were identified in these surveys.

2.2 GROUPING OF SOIL SERIES

Since this study is aimed towards correlating and updating existing soil series so as to prepare a framework for future efforts in this field, it was felt adequate to group soil series according to their classification system and the categorical level being reached within each system. The soil series of the first group are exceptional in this regard, since they were distinguished according to a locally developed classification concept based on mode of deposition, stratification and texture. The soils of the second group were differentiated according to USDA Soil Taxonomy groups and subgroups and mostly correlated with the FAO/Unesco Legend. The third group does not refer to soil series, but since it is based on a survey covering the whole of the former Yemen Arab Republic, in which the soils were classified up to the family level of the Soil Taxonomy, it has been included in this study. Soil series in the fourth group were basically differentiated according to the FAO/Unesco Legend only. The fifth group contains soil series that were correlated with the French soil classification system (CPSC, 1967). Only the soil of wadi Hadramout were classified according this system (Sogreah, 1981).

2.3 SOIL SERIES DIFFERENTIATED ON BASES OF SOIL TEXTURE AND DEGREE OF DEPOSITIONAL STRATIFICATION

2.3.1 Soil survey reports

A brief description of soil survey reports included in the first group is given below:

i. *Report on Soil Survey and Land Classification of Nuqub (Beihan Area)*

This area was surveyed at semi-detailed level (scale 1:20,000) and covers 8,070 ha. Nuqub area is situated along the north-eastern extremity of Wadi Beihan in Shabwa Governorate, nearly 200 miles north-east of Aden on the inland side of the Southern Slopes. The purpose of the survey was to delineate areas that are most suited for irrigation by the traditional single-flood system, as improved by modern masonry weirs and a controlled distribution canal network. The soil survey was conducted by Hunting Technical Services Ltd. and the report was published in 1967.

ii. *Report on Soil Survey and Land Classification of Ahwar Area*

This area was surveyed at semi-detailed level (scale 1:20,000) and covers 10,700 ha. The Ahwar area occupies the delta of wadi Ahwar and it is about 150 miles east of Aden along the Gulf of Aden. The purpose of the survey was similar to that of the above-mentioned Nuqub survey, and the work was carried out by the same company (Hunting Technical Services Ltd.) while the report was also published in 1967.

iii. *Abyan Delta Project Vol. 2: Water and Land Resources*

A semi-detailed soil survey (scale 1:25,000) was conducted in Abyan Delta covering 53,000 ha. Abyan Delta is an almost triangular area formed by three wadis (Bara, Hassan and Subayiah) with its base on the Gulf of Aden to the south-east and its apex at the foot of the mountains in the north. The area lies about 50 km from Aden along the coastal road to Mukalla. The aim of this soil investigation was to differentiate land on the basis of its suitability for single-flood irrigation. The soil survey was conducted by Dar Al-Handasah Engineers & Architects and the report was published in 1972.

iv. *Marib Dam and Irrigation Project*

Although initially a reconnaissance survey of 20,000 ha was to be carried out, from which 10,000 ha would be selected for semi-detailed survey, the final report only covers 6,500 ha of semi-detailed survey. The objective of this study was to evaluate the soils of the Marib plain for their suitability for irrigated agricultural development.

The Marib Dam and Irrigation project follows the same concept with respect to soil series characterisation as the previous three reports, but it also correlates the depositional soil series with the family level of the Soil Taxonomy, although it uses only texture as a family criteria. Parent materials can be subdivided into recent alluvium, aeolian and anthropic deposits, which are without genetic horizons. These soils belong to the Torric great group of the suborders of Psamments, Fluvents and Orthents (USDA, 1975). Older parent materials, possibly laid down during a wetter period, contain cambic, calcic and petrocalcic horizons (Camborthids, Calciorthids and Paleorthids). In the profile description the families are identified by alphabetical symbol only.

This soil survey was carried out by Electrowatt Engineering Services of Switzerland, in cooperation with Hunting Technical Services of England, and the report was published in 1978.

2.3.2 Main Concepts in Establishment of Depositional Soil Series

The soil series included in the above four soil survey reports were differentiated on the basis of soil texture and degree of depositional stratification. This was based on the finding that the soils of the areas surveyed exhibit virtually no features of pedogenesis, and

that they can thus be considered as immature alluvial soils. They are likely to remain so for the foreseeable future if present environmental conditions continue to prevail. It was mentioned that the hot, arid climate and sparse vegetation preclude the accumulation of organic matter and that therefore soil colours are unmodified. It was also stated that soil colour, free carbonates, salinity, gypsum content, structure, permeability and soil moisture characteristics all closely reflect the texture of the soil, and that this is to be expected in a profile which has undergone very little pedogenesis.

It was concluded that since "soil series" are traditionally restricted to soils in which profiles are differentiated by a sequence of morphological features resulting from pedogenetic processes, the term should be modified for pedogenetically inactive soils. Hence the term "depositional series" was coined since the mode of deposition is the major factor through which such alluvial soils can be differentiated. According to this concept all soil series were related to the following three modes of deposition :

A. "Anthropic deposits"
These are fine alluvial deposits resulting from irrigation systems constructed and operated by man for several centuries.

B. "Fluvial deposits"
They are coarser alluvial deposits occurring along old wadi courses.

C. "Aeolian deposits"
These are sandy deposits transported by wind.

Table 2 shows all the series that have been identified in the three reports, and indicates to which mode of deposition they can be related.

The Nuqub and Ahwar soil surveys (1967) were the first attempt to classify soils in Yemen, during a period when there were no generally acceptable international soil classification systems. The Abyan Delta Project soil survey (1972) just followed the classification system used in the first two surveys. Since the development of comprehensive soil classification systems it has become possible to better characterize the immature soils of the arid regions, including the alluvial soils of the arid parts of Yemen. The Soil Taxonomy (USDA, 1975) provides a good basis for such an effort. Immature soils developed in young alluvium and aeolian material, as well as material deposited through the action of man, in the different climatic zones of Yemen can be accommodated in the Fluvent, Psamment and Arent suborders of the Soil Taxonomy, as no well developed pedogenetic features or signs of translocation of material inside the profile are required for such soils. The great groups of Torrifluvents and Tropofluvents, which represent the fine alluvial soils of the arid and semi-arid regions, can accommodate the soil series developed in fluvial deposits. Aeolian deposits series can be included in either Torripsamments, Quartzipsamments, or Tropopsamments, which are characteristic for the sandy deposits.

In depositional soil series differences between soil series are most outspoken if based on texture, but difficult to justify when related to degree of stratification, the nature of the stratified material and its thickness. Differentiation of soil series according to stratification characteristics might defeat the pragmatic concept of soil series (see also section 1.4). In the third soil survey report of this group (Dar Al-Handasah, 1972) soil salinity was not considered

adequately at the series level, which led to a request for another soil survey to take into consideration this important aspect (W.S. Atkins & Partners, 1984).

Table 2 List of identified depositional soil series

No.	Soil series name	Survey area	Mode of deposition
1	Ahwar	Ahwar	Fluvial deposits
2	Hanad	,,	Anthropic deposits
3	Busti	,,	" "
4	Misani	,,	Fluvial deposits
5	Bersahan	,,	Anthropic deposits
6	Wadi	,,	Fluvial deposits
7	Jol	,,	" "
8	Nuqub	Nuqub	Fluvial deposits
9	Hima	,,	" "
10	Saminah	,,	" "
11	Wadi	,,	" "
12	Goz	,,	Aeolian deposits
13	Saban	,,	" "
14	Timna	,,	" "
15	Giar	Abyan delta	Anthropic deposits
16	Zinjibar	,,	Fluvial deposits
17	Al Husn	,,	Anthropic deposits
18	Batais	,,	Mixed deposits
19	Wadi	,,	Fluvial deposits
20	Hcz	Marib Dam	Anthropic deposits
21	Bs	,,	Fluvial deposits
22	Hcl	,,	Anthropic deposits
23	Csk	,,	Fluvial deposits
24	Ccl	,,	Mixed deposits
25	Hfz	,,	Anthropic deposits

2.4 SOIL SERIES DIFFERENTIATED WITHIN THE SOIL TAXONOMY FRAMEWORK AND CORRELATED WITH THE FAO-UNESCO SYSTEM

2.4.1 Soil survey reports

A brief description of the soil survey reports which include soil series characterized within the framework of the Soil Taxonomy is given below.

i. *The soil survey of El-Kod farm*

The survey area covers 500 feddan (208 ha) of the Al-Kod Agricultural Research Centre, located in the south-western part of Abyan Delta. The soil survey of this farm was carried for the following reasons :

1. show the distribution of low yielding plots within the farm and correlate soil properties with crop growth and yield.

2. characterize the soils of new land (145 ha) recently included in the farm and show their distribution and suitability for irrigated agriculture.

3. recommend appropriate management practices most suited to the soils of the research farm and neighbouring farmlands.

With regard to the main idea behind the establishment of soil series it is stated that a soil series is a group of soils that have soil horizons similar in differentiating characteristics and arrangement in soil profile. Variations in soil texture are only allowed in the A horizon. It was also mentioned that from a pedogenetic point of view old layers may be considered as argillic or calcic horizons. However, an argillic was ruled out on account of the presence of stratification. Seven unnamed local soil series were recognised which belong to two Soil Taxonomy orders (Entisols & Aridisols).

The soil survey was carried out by M.A. Abdel Salam and others and published in 1975 (UNDP/FAO Project PDY/71/516).

ii. *Detailed soil survey of three Demonstration and Research Farms*

The survey area of the experimental farm of El-Kod encompasses 175 ha and lies within the 208 ha of the previous report. Two other farms, Al-Araise in the Tihama, and Suweri near Seiyun, cover 200 and 300 ha respectively. The main objectives of these surveys are :

1. To identify and classify the soils and their phases occurring in the farm.

2. To prepare a soil and irrigation land use map.

3. To evaluate soil properties in terms of potentiality for improved agricultural use.

The definition of the soil series is almost similar to what was mentioned in the previous El-Kod soil survey report. The report also states that although soil series are differentiated on the properties of the control section (25-100 cm), a few may be recognised on the basis of topsoil properties. Phases of soil series account for differences in depth, slope, erosion and salinity or sodicity which influence the use of soils. Differences between soil phases were often of greater agricultural significance than differences between soil series.

These soil surveys were carried out by H.R. Rahman and published in 1978 (UNDP/FAO Improvement of Crop Production project PDY/75/019).

iii. *Soil survey and irrigation suitability classification of Wadi Rima'*

The survey area covers an area of 64,000 ha along both banks of Wadi Rima', extending from the coast of the Red Sea to the interfluve in the Dhamar plain. This soil survey aimed at assessing the irrigation suitability of different soil types along Wadi Rima'.

In the study it is concluded that the soils of Wadi Rima' do not show any well developed morphological features resulting from pedogenetic processes. Soil series differentiation is therefore based mainly on differences in soil texture and profile stratification, features that are related to the depositional history of the soil. It was also intended that the soil classification criteria should reflect differences in soil-water characteristics in order to be able to assess their suitability for irrigation. From the considerable differences among the soils in field capacity and wilting point values it became clear that texture is of primary importance.

The soil survey was carried out by I.P. Anderson of the Land Resource Development Centre in the UK, and published in 1979.

iv. *Soil classification and correlation in the Montane plains. Montane plains and Wadi Rima' Project*

The survey area covers 280,000 ha of the highland plain which lies astride the main road from Sana'a to Taiz between Yizlah and Sumarah passes, a distance of approximately 90 km. The area is about 40 km wide and bounded on the west by the indented scarp of the Red Sea rift valley and on the east by watersheds that mark the descent of the highlands towards Al-Rub Al-Khali.

The report, written primarily for soil specialists, is concerned with the classification and correlation with international systems of the soil profiles described during the soil survey of the area. A local soil classification was designed to enable users to recognize and distinguish between different soils. The three main characteristics which have been taken into consideration are: suitability for arable cultivation, soil properties and soil horizons. It is stated that there is a very sharp distinction in the Montane plains between cultivated and uncultivated land. Thus the landscape is divided into areas with soils suitable and unsuitable for arable cultivation. In lieu of precise information on moisture-holding capacity

and moisture availability throughout the year, great significance has been attached to soil texture, depth, stoniness and site characteristics, all of which can be assessed in the field. Three distinctive horizons are used in the local classification of soils, and are recognised mainly by colour.

The study, based upon an earlier report describing the soil survey, was undertaken by B.D. Acres of the Land Resource Development Centre in the UK, and published in 1982.

v. *Hydrological survey of Wadi Markhah Region (Wadi Markhah & Wadi Khawrah)*

The Wadi Markhah soil survey covers about 21,700 ha and is situated in Nissab district of Shabwa Governorate. As mentioned in the report, the objective of the study was a quality and quantity estimation of the soil resources in the area of interest, including their description and characterization, position and topographical representation on maps at scales of 1:100 000 and 1:20 000 which also show vertical ground relief and wadi bed courses.

The soil series distinguished are basically developed in two types of parent material: alluvial plain material and loess formations. The main factors considered for differentiating the 12 soil series in both parent materials are morphogenetical, i.e. texture, stratification, topsoil etc. It is stated that in this way lower-order soil units (soil series) with characteristic soil and agronomic properties have been distinguished. The common characteristics of the alluvial plain soils are: slightly distinct recent profile development (A-C), sandy texture, often stratified, and with overlaps (recent sedimentary deposits), frequent gravelly and stony phases, the presence of carbonates in the whole profile, fluvial, fluvioeolian to eolian parent material, and a slightly dissected relief. The soils formed in loess are agronomically better with a higher permeability and water holding capacity. This is due to a mostly medium texture, better soil structure and more suitable stratification. These soils are situated predominantly in the upper and middle parts of mountain wadis. The study was prepared in 1984 by Strojexport.

vi. *Proposals for follow-on measures for Al-Boun feasibility study. Appendix 1: Soil and land-use suitability for rainfed cultivation and irrigation in the Amran high valley*

The nucleus of the project area (Qa Al-Boun) stretches from Amran to Raydah, and encompasses an area 50,000 ha, of which 25,784 are covered by this survey. The main objectives of the survey ware:

- Increase agricultural production,

- Improvement of farmers' income, and consequently reduced migration from agricultural areas,

- Satisfaction of basic needs and preservation of natural resources.

Under the semi-arid conditions of the area, physical soil weathering processes dominate, chemical processes only prevail during comparatively short periods when the soils are moist. Soil forming processes are mainly erosion and deposition. The influence of parent material and topography is relatively large on soil formation. The Amran formation, a yellowish-grey limestone formation rich in fossils and intercalated with clay slate, produces a weakly alkaline soil with a high content of Ca ions in the exchange complex. Most of the soils have not formed in-situ, but developed in reworked eroded material from surrounding mountain ranges, mixed with volcanic ash. According to the Soil Taxonomy classification of the soils, Torriorthents and Torripsamments are predominant, while Calciorthids, Paleorthids and Cambiorthids occur on marginal sites in the valley.

The study was carried out by D. Rethwilm and W. Brandes of GTZ in 1979. It does not contain any profile description or analytical data.

vii. *Hydrological survey of Nissab region*

Nissab region lies in the central part of Shabwah Governorate. The main objective of the hydrological survey was to provide qualitative and quantitative information on water and soil resources in the region. This information would serve as a foundation for agricultural development planning of Nissab region. The area covered by the survey is 30,820 ha.

The soil survey was executed following the guidelines from the Soil Survey Manual (Soil Survey Staff, 1951). The soils were classified according to the Soil Taxonomy up to subgroup level, and further distinguished into gravelly, stony, sodic, salic and topsoil texture phases. Due to the intricate nature of the soil pattern, some mapping units consist of soil complexes. The soils identified belong to the Entisol and Aridisol orders (Torripsamments, Torrifluvents, Torriorthents and Calciorthids). Anthropic soils, having no diagnostic horizons were classified as Arents. These, together with Torriorthents and Calciorthids developed in medium textured loess deposits, were considered as the most suitable agricultural soils along the middle and upper reaches of wadis Dura and Abadan. Alluvial soils (Torrifluvents) are considered, on account of their low water-holding capacity, as suitable for agriculture only if irrigated. Outwashed and redistributed loess deposits, which are widely cultivated along all wadis, are an exception to this due to their more favourable texture. However, these soils have sometimes strongly been affected by wind erosion.

The survey was conducted by Strojexport of Prague, Czechoslovakia, and the report was published in 1982.

viii *Regional development study for Al-Mahweit province. Vol. 1, Annex 1: Natural resources*

Al-Mahweit province lies north-west of Sana'a. The total area of the province is approximately 2,330 km^2. The area consists of a narrow belt of lowlands,

surrounded by steep and intensively dissected mountain regions and a small part of the central highlands in the very western part of the province around Shibam.

With regard to the pedogenetic processes prevailing in the province it was stated that in view of the arid and semi-arid climatic conditions physical weathering dominates over chemical weathering. Chemical weathering depends on wet periods, and therefore is effective only during short periods, in which the solution of easily soluble minerals, such as carbonates, and their precipitation in deeper horizons is the main process. Accumulation of humus and the displacement of clay particles and other soil forming processes are of minor importance. It was also mentioned that other processes are still more important than those which are typical of arid or semi-arid regions. Due to relief conditions and above all, due to human influence over hundreds of years, soil displacement (through erosion or even by caterpillars, as observed on the highland plateau near Bayt Mufarriah) plays a very important role in soil "development".

Most of the cultivated soils of the province are accumulations rather than "in situ" developed soils. The discussion was concluded by pointing out that most soils of the province do not have a strongly expressed profile development. Nevertheless, some genetic features can be observed and they are mostly related to the dislocation of calcium carbonate. Other pedogenetic processes, common in arid and semi-arid regions, do not occur. No pronounced natric, salic or gypsic horizons do occur, but slight accumulations of salt were observed in deeper layers in some wadi soils.

Calcium carbonate accumulations in the soil may form calcic horizon. Soils with a calcic horizon can be found on gently sloping concave footslopes, usually under desert pavement. Indurated calcic horizons (so called petrocalcic horizons) are very rare. Their formation is related to areas where the accumulation of calcium carbonate by dislocation is augmented by an additional supply of calcium carbonate through groundwater flow. It was also mentioned that due to the predominantly physical weathering, most soils of the province display a clear relationship to their parent rock from which they have been derived. Humus accumulation (mollic epipedon) can be observed in some soil profiles of the upper highland zone. They do not, however, occur in terraced land. Apart from climatic influences their development seems to depend on peculiar bedrock and vegetation conditions. Limestone as parent rock and a dense grass cover obviously are favourable and even render the formation of mollic epipedons possible.

In this report the soils were classified into two main types considering the pedogenetic processes:

a. Soils without strongly expressed profile development.

These soils have been classified as Fluvents and include most of the cultivated soils of the province. The soil material of the man-made terraces is obviously accumulated by water transport from adjacent non-cultivated slopes - at least soil material of the upper layers. A comparison between the soil profile of very

recently renewed terraces, which earlier had been destroyed by stream flows, and the soil profile of terraces of unknown age did not show significant differences. The more clayey soil material often found at depth is not the result of soil forming processes such as clay illuviation, but has been ascribed to accumulation of soil material deposited under more humid climatic conditions of former times. Soils which show very slight indications of alteration in any horizon deeper than 1 meter are classified as Ustifluvents or Torrifluvents. Transitional forms (Ustic Torrifluvents) occur as well.

Depending on the parent rock and conditions of sedimentation, the Fluvents show great variation as far as physical (texture, stoniness, etc.) and chemical properties are concerned. Soils which due to truncation and erosion do not show pronounced horizons or soils over recent colluvial material are classified as Orthents. Truncated soils are very common in the province and cover most of the steep uncultivated slopes. As the moisture characteristics of these is always torric due to the accelerated runoff from steep slopes and the reduced infiltration, these soils were classified as Torriorthents. Fluvents and Orthents are the most widespread soil types of the province. Torripsamments can be found near sandstone or granite outcrops and in wadi channels.

Table 3 Correlation of Soil Taxonomy with FAO/Unesco classification in Al-Mahweit study

F A O	U S D A (SOIL TAXONOMY)
Fluvisol	Fluvent (mainly Xerofluvent and Ustifluvent, also Torrifluvent)
Eutric or calcaric Fluvisol	Torripsamment or Torrifluvent
Lithosol	Lithic Torriorthent (and lithic subgroups of other orders)
Regosol	Entisol (e.g. Psamment)
Yermosol	Argid and Orthid (among them Camborthid and Calciorthid)
Yermosol and some Xerosol	Argid and Orthid (among them Paleargid and Paleorthid)
Xerosol and poorly developed Kastanozem	Argid and Orthid, also poorly developed Ustoll or Xeroll
Kastanozem	Ustoll and some Xeroll and Udoll
Haplic Phaeozem, Haplic Kastanozem and Haplic Chernozem	Haplustoll, Calciustoll and others

b. Soils with genetic profile development

Mollisols and Aridisols are the two soil orders accommodating the soils with a strongly expressed profile development identified in the province, but of minor extent. Mollisols occur in the more humid regions of the upper highland zone. They are generally decarbonated, rather humic and well structured. They are always shallow and therefore not cultivated. More common than Mollisols are Aridisols, the typical soils of arid to semi-arid climatic zones. Commonly the Aridisols of the province are not well developed. Shallow, lithic and stony phases dominate. Only the loess-like Camborthids of the basins and depressions of the lowlands and the uplands, which are strongly influenced by aeolian deposition, are cultivated.
The study was conducted by IP Institute for Project Planning for the German Agency for Technical Co-operation (GTZ), and the report was published in 1984. Table 3 shows a correlation between the FAO/Unesco and USDA classifications as given in this study.

2.4.2 Main concepts in establishing Soil Taxonomy based series

The soil series in this section were differentiated on soil properties within the control section (mostly 25-100 cm). Morphological, physio-chemical and related pedogenetic properties were used as diagnostic criteria to differentiate soil series. This procedure of separating soil series goes well with the principles of great groups and subgroups of Soil Taxonomy which were applied in this group of soil series. Although the depositional concept was mentioned in some explanations the soils were correctly categorized in the Torrifluvent, Torripsamment and Arent groups and subgroups. All of the series have been correlated with the FAO/Unesco Legend, with the exception of the series of the Nissab and Wadi Markah surveys.

Table 4 lists all the soil series identified in this section, together with the Soil Taxonomy and FAO/Unesco correlations. From this list it is clear that some soil series cover a number of soils that are classified differently at higher Soil Taxonomy level (e.g Kiba, Nimijah, Tinnan, Jalab series). Only one series (Numarah) is classified consistently under the Soil Taxonomy appears with two FAO/Unesco classifications (Calcaric Fluvisols and Albic Arenosol). This anomaly is because, even though both Soil Taxonomy and the FAO/Unesco Legend have separate categories for young sandy and alluvial soils, the sandy soils are keyed out first in the Soil Taxonomy (irrespective of whether or not they are of alluvial origin), while in the FAO/Unesco Legend the alluvial soils (sandy and non-sandy) are separated first, followed later by non-alluvial sandy soils. As for those soil series having one name and different USDA Taxonomy classifications, a thorough revision is needed to correct these anomalies. In some cases the soil classification itself needs correction. For instance, in the case of Samah Ulya series, a soil with windblown material (>90% sand) was classified as an Aridic Ustochrept

Table 4 List of identified soil series defined within framework of Soil Taxonomy

Soil Series		Soil classification		Survey Area
No	Name	USDA	FAO/Unesco	
1	Al-Khadad	Typic Torriorthent	Calcaric Fluvisol	Al-Kod
2	Al-Araise	" "	" "	"
3	Al-Shaqa	" "	" "	"
4	Al-Anad	" "	" "	"
5	Al-Zyeda	" "	" "	"
6	Al-Qoz	Typic Torripsamment	Calcaric Fluvisol	Al-Suweri farm
7	Qasam	" "	" "	" "
8	Guraf	" "	" "	" "
9	Suweri	Orthic Camborthid	Haplic Yermosol	" "
10	Tarim	" "	" "	" "
11	Ba-Allal	" "	Haplic Xerosol	" "
12	Djaima	" "	" "	" "
13	Al-Kod	Typic Torriorthent	Calcaric Fluvisol	Al-Kod farm
14	Al-Husn	" "	" "	" "
15	Al-Summah	" "	" "	" "
16	Al-Nash	" "	" "	" "
17	Al-Intifadah	" "	" "	" "
18	Al-Kadama	" "	" "	" "
19	Al-Kurnah	Typic Torripsamment	Calcaric Fluvisol	" "
20	Madan	Fluventic Camborthid	Haplic Yermosol	Wadi Rima'
21	Habaq	" "	" "	" "
22	Isabah	" "	" "	" "
23	Husayniyah	" "	" "	" "
24	Badwah	" "	" "	" "
25	Mahatt	Typic Torrifluvent	Calcaric Fluvisol	" "
26	Murrah	" "	" "	" "
27	Mujaylis	Typic Salorthid	Gleyic Solonchak	" "
28	Rakhamah	Entic/Udorthentic Chromustert	Chromic Vertisol	Montane plains
29	Maris	Udic Ustochrept	Calcic Cambisol	" "
30	Atalaba	" "	" "	" "
31	Shirah	" "	" "	" "
32	Makhdarah	" "	" "	" "
33	Bani Falah	" "	" "	" "
34	Afiq	" "	" "	" "

Table 4 List of identified soil series defined within framework of Soil Taxonomy

Soil Series		Soil classification		Survey Area
No	Name	USDA	FAO/Unesco	
35	Jalab	" "	" "	" "
36	Tinnan	Udic Ustochrept	Calcic Cambisol	Montane plains
37	Yizlah	" "	" "	" "
38	Samah Ulya	Aridic Ustochrept	" "	" "
39	Sumaydah	" "	" "	" "
40	Wasitah	Typic Aridic Ustochrept	" "	" "
41	Mahanashah	Typic Ustochrept	" "	" "
42	Balasan	" "	" "	" "
43	Kiba	" "	" "	" "
44	Jalab	" "	" "	" "
45	Kathaf	" "	" "	" "
46	Numarah	Typic Ustipsamment	Calcaric Fluvisols	" "
47	Numarah	" "	Albic Arenosols	" "
48	Jahran	Typic/Fluventic Ustochrept	Calcic Cambisol	" "
49	Tinnan	Vertic Ustochrept	Vertic Cambisol	" "
50	Yafa	Lithic Ustochrept	Calcic Cambisol	" "
51	Qumah	" "	" "	" "
52	Kiba	Lithic Ustochrept	" "	" "
53	Darb	" "	" "	" "
54	Abisiyah	Typic Salorthid	Mollic Gleysol	" "
55	Nimijah	Histic Halaquoll	" "	" "
56	Nimijah	Typic Calciaquoll	" "	" "
57	"	Typic Halaquept	Gleyic Cambisol	" "
58	"	Udertic/Vertic Haplustoll	Calcic Chernozem	" "
59	Sawad	Typic Halaquept	Gleyic Solonchak	" "
60	"	Typic/Lithic Ustorthent	Calcaric Regosol	" "
61	"	Typic Calciaquoll	Mollic Gleysol	" "
62	"	Cumulic Haplustoll	Lithosol	" "
63	Lithosol (Rock)	Lithic Ustorthent	Lithosol	" "
64	Gravel Ridge	Typic /Aridic Ustorthent	Calcaric Regosol	" "
65	Gravel Ridge	Aridic Ustochrept	Orthic Solonchak	" "
66	Soil series no. 1	Typic Torrifluvent	Calcaric Fluvisol **	Wadi Markhah
67	" " 2	" "	" "	" "
68	" " 3	" "	" "	" "

Table 4 List of identified soil series defined within framework of Soil Taxonomy

Soil Series		Soil classification		Survey Area
No	Name	USDA	FAO/Unesco	
69	" " 4	" "	" "	" "
70	" " 5	" "	" "	" "
71	Soil series no. 6	Typic Torripsamment	Haplic Arenosol * *	Wadi Markah
72	" " 7	Arent	Cumulic Anthrosol * *	" "
73	" " 8	Typic Torriorthent	Calcaric Regosol * *	" "
74	" " 9	Typic Calciorthid	Haplic Calcisol * *	" "
75	" " 10	Typic Torriorthent	Calcaric Regosol * *	" "
76	" " 11	" "	" "	" "
77	" " 12	Typic Torriorthent Typic Calciorthid	" " Haplic Calcisol * *	" "
78	Soil series no. 1	Typic Torrifluvent	Calcaric Fluvisol * *	Nissab region
79	" " 2	Typic Torrifluvent Typic Torripsamment	" " Haplic Arenosol * *	" "
80	" " 3	Typic Torrifluvent	Calcaric Fluvisol * *	" "
81	" " 4	" "	" "	" "
82	" " 5	" "	" "	" "
83	" " 6	Typic Torripsamment	Haplic Arenosol * *	" "
84	" " 7	Arent	Cumulic Anthrosol * *	" "
85	" " 8	Typic Torrifluvent Typic Calciorthid	Calcaric Fuvisol * * Haplic Calcisol * *	" "
86	" " 9	Typic Torriorthent Typic Calciorthid	Calcaric Regosol * * Haplic Calcisol * *	" "
87	" " 10	Typic Torriorthent	Calcaric Regosol * *	" "
88	" " 11	Typic Torriorthent	" "	" "
89	" " 12	Typic Torriorthent Typic Calciorthid	" " Haplic Calcisol * *	" "

* Name not clear in photocopied text

* * FAO/Unesco classification added by first author according to FAO (1988)

(instead of an Ustipsamment). Soil temperature and moisture regions need to be updated due to availability of more information in this respect. Finally, although the soil series in this group have been classified according to the overall framework of the Soil Taxonomy and, in some cases, the FAO/Unesco Legend of the Soil Map of the World, the criteria employed in differentiating soil series, such as depositional characteristics and texture, are mostly similar as in the first group.

2.5 SOIL UNITS DIFFERENTIATED AT SOIL TAXONOMY FAMILY LEVEL

2.5.1 Soil survey reports included in this group are only two :

i. *Soil survey of the Yemen Arab Republic*

This soil survey covers the 208,512 km^2 of the former Yemen Arab Republic (the Western and Northern part of the present Republic of Yemen). The soil survey aimed at producing a generalized soil map at a scale 1:500,000, and based on field observations. It was mentioned that only limited information was available on the soils of Yemen and that the few soil surveys that had been conducted previously were not sufficient or adequately correlated to national or international systems to serve development needs. It was also stated that previous soil surveys varied in degree of detail and needed complementary studies to respond to the increasingly demand for soil information. This reduced their usefulness and restricted the transfer of technical knowledge from other areas with similar ecological conditions.

The soil map legend was defined on the basis of soil genesis concepts and field survey principles. The scale of 1:500,000 permitted the delineation of associations of soils at Soil Taxonomy subgroup level (Soil Survey Staff, 1975), which occur in a repetitive pattern in the landscape. The map units were recognized on the basis of climate, geology, relief, vegetation and morphology. Selected pilot areas were mapped at larger scale (1:25,000) to estimate the percentage of each soil component in the association. The predominant soil orders identified are :

1. Aridisol
2. Entisol
3. Inceptisol
4. Mollisol

Individual soil profiles were classified to the family level and appropriate phases were also designated where useful for future land use decisions. The importance of soil moisture regimes, which in Yemen range from aridic (dry) to udic (wet), is related to crop production. The predominant soil moisture regime is usually given in the subgroup name. Considerable variation in air and soil temperature, related to the mountainous nature of the country, results also in a range of soil temperature regimes. Together with other parameters (texture, depth, mineralogy, carbonate and gypsum content, etc) the soil temperature is employed to differentiate soils at family level. An example of the usefulness of families for interpreting soil suitability for crop growth is given for the following family :

Typic Torrifluvent, coarse loamy, mixed, calcareous, hyperthermic family.

- Aridic soil moisture regime (expressed by "torri-") - needs irrigation
- Hyperthermic temperature regime - may be too hot for some crops
- Calcareous - may have some micronutrient deficiencies
- Low organic matter content
- Coarse loamy texture - low water holding capacity and some possible impediments to mechanical cultivation.

The soil survey was conducted by Jack W. King II and others of Cornell University, under contract from the USAID's Near East Bureau. The final report was published in May 1983.

Table 5. Soil families in the (former) Yemen Arab Republic

No.	Subgroup name	Texture class, mineralogy and calcareousness	Soil temperature regime
1	Typic Calciorthid	Coarse loamy, mixed	Isohyperthermic
2	" "	Loamy skeletal	"
3	" "	Coarse loamy, mixed, calcareous	Hyperthermic
4	" "	Fine loamy, mixed	Isothermic
5	" "	Coarse loamy, mixed	"
6	Typic Torrifluvent	Coarse loamy, mixed, calcareous	Hyperthermic
7	" "	Coarse loamy, mixed	Isomegathermic
8	" "	Sandy, mixed, calcareous	"
9	" "	Coarse loamy, mixed, calcareous	Isohyperthermic
10	" "	Coarse loamy, mixed,	Hyperthermic
11	Typic Torriorthent	Sandy skeletal, mixed	Isohyperthermic
12	" "	Coarse loamy, mixed, calcareous	Isothermic
13	" "	Coarse loamy, mixed	"
14	" "	Loamy skeletal, mixed, calcareous	Hyperthermic
15	" "	Coarse loamy, mixed	"
16	" "	" " "	Isohyperthermic
17	" "	Fine loamy, mixed	"
18	" "	Coarse loamy, mixed, calcareous	Hyperthermic
19	Typic Gypsiorthid	Coarse loamy, mixed	Isohyperthermic
20	Lithic Torriorthent	Coarse loamy, mixed, calcareous	Hyperthermic
21	Typic Salorthid	Sandy, mixed	Isohyperthermic
22	" "	Coarse loamy, mixed,	"
23	" "	" " "	Hyperthermic
24	Typic Fluvaquent	Coarse loamy, mixed, calcareous	Isomegathermic
25	Typic Tropaquent	Coarse loamy, mixed	"
26	Typic Udifluvent	Coarse loamy, mixed, calcareous	Hyperthermic
27	Typic Torripsamment	Mixed, calcareous	Isomegathermic
28	Typic Torripsamment	mixed	Hyperthermic
29	Typic Ustifluvent	coarse loamy, mixed	Isothermic
30	" "	Fine loamy, mixed	"
31	" "	Coarse loamy, mixed	Isohyperthermic
32	" "	Fine loamy, mixed	"

Table 5. Soil families in the (former) Yemen Arab Republic			
No.	Subgroup name	Texture class, mineralogy and calcareousness	Soil temperature regime
33	" "	Coarse loamy, mixed	Hyperthermic
34	Typic Haplargid	Fine loamy, mixed	"
35	Typic Ustorthent	Sandy skeletal, mixed	Isothermic
36	" "	Coarse loamy, mixed	"
37	" "	Fine silty, mixed	"
38	" "	Coarse loamy, mixed, calcareous	Isomesic
39	" "	Fine loamy, mixed	Isothermic
40	Typic Camborthid	Loamy skeletal, mixed	"
41	Aquollic Salorthid	Fine clayey, mixed	"
42	Typic Fluvaquent	" " "	Isohyperthermic
43	Typic Ustipsamment	Mixed, calcareous	"
44	Tropofluvent	(Not mentioned)	"
45	Typic Natrustalf	Fine clayey, mixed	Isothermic
46	Entic Haplustoll	Coarse loamy, mixed	Isomesic
47	Typic Argiudoll	Sandy skeletal, mixed	"
48	Lithic Ustorthent	Sandy skeletal, mixed	"
49	Ustic Torriorthent	Fine loamy, mixed	Isothermic
50	Udic Haplustoll	Loamy skeletal, mixed	"
51	" "	Fine silty, mixed	"
52	Entic Ustropept	(Not mentioned)	(")
53	Petrocalcic Calciustoll	Fine loamy, mixed	"
54	Typic Calciustoll	Fine silty, mixed	"
55	" "	Coarse loamy, mixed	"
56	Typic Ustropepts	Fine silty, mixed	"
57	" "	Fine loamy, mixed	"
58	Ustollic Calciorthid	" " "	"
59	Vertic Haplustoll	" " "	"
60	" "	Coarse silty, mixed	"
61	" "	Fine loamy, mixed	Isomesic
62	Udic Pelustert	Fine clayey, montmorillonitic	Isothermic
63	Typic Torrert	" " "	"
64	Ustollic Camborthid	Coarse loamy, mixed	"
65	Ustic Torripsamment	" " "	"
66	Typic Halpustoll	" " "	"
67	Typic Hapludoll	" " "	"

Table 5. Soil families in the (former) Yemen Arab Republic			
No.	Subgroup name	Texture class, mineralogy and calcareousness	Soil temperature regime
68	Entic Hapludoll	" " "	"
69	Aridic Haplustoll	(not mentioned)	(Isothermic)
70	Lithic Calciorthid	Coarse loamy, mixed	(Isohyperthermic)
71	" "	" " "	Isothermic
72	Rock outcrops & Basalt flows	-	-

ii. *Soil survey and land suitability evaluation for Marib irrigation project area*

The Marib Dam project area irrigation is located 120 km east of Sana'a. No mention is made in the report about the objectives of the survey.

The soils were classified to the family level of the Soil Taxonomy. The recent alluvial deposits in the project area belong to the Entisol order. Water transported material are given priority over eolian deposits in the classification system. Thus Fluvents are the dominant soils at suborder level, and Orthents are the second important suborder. The latter are found where the water deposits fail to meet the requirement for Fluvents. Psamments occur where wind transported sands prevail, normally in locations far from water action. These three suborders are characterized by a Torric (Aridic) soil moisture regime at the great group level. It was also mentioned that as soil characteristics are close to the central concept of the great group, Typic subgroups represent the soil at the lower level. At the family level texture plays the most important role in classifying the soils of the project area, due to homogeneity in other characteristics. It was noted that since the hyperthermic soil temperature regime prevails in the whole area, the mineralogy class is expected to be mixed. A coarse loamy textural class was found to be the most common class within the project area. A sandy texture is found in all soils classified as Psamments, and hence it is not being mentioned separately.

The soil survey was conducted by Soil Science Division of The Arab Centre for The Studies of Arid Zones and Dry Lands, Damascus and the report was published in 1989 (ACSAD/SS99/1989). Table 5 shows all the families identified in the above two reports.

2.6 SOIL SERIES DIFFERENTIATED ACCORDING TO FAO/UNESCO LEGEND

2.6.1 Only two soil survey reports, described below, are included in this group.

i. *Wadi Bana & Abyan Delta Development Project*

The study area covers a gross area of just over 23,000 ha, or net irrigated area of about 13,000 ha. The area of study was confined to those lands between wadi Bana and wadi Hassan that are in the command of Wadi Bana Irrigation Canal System and lies within the survey area already done by Dar Al-Handasah in 1972.

The soil survey was carried out with the following objectives :

1. evaluation of previous work undertaken by Dar Al-Handasah
2. the identification and location of areas of saline soil
3. consideration of the feasibility of reclaiming these saline areas.

The FAO/Unesco Legend was used to classify the soils. No correlation with the Soil Taxonomy was made despite the availability of almost complete chemical and physical data. Also the main soil formations were noted and described but no soil genesis was discussed. It seems that the concept of depositional soil series which exist in previous soil survey reports was not considered since it does not reflect salinity nor alkalinity of the soils which is the main concern of this revision study. Two classes of the FAO/Unesco system (Orthic Solonetz and Orthic Solonchak) were used here to reflect clearly these properties.

The soil survey was conducted by WS Atkins and Partners in association with Binnie & Partners England and the report was published in 1984.

ii. *Wadi Hajr Agricultural Rehabilitation project*

The survey area is situated in the catchment of wadi Hayr, Hadramaut Governorate. The area covers about 9,460 km ^{2}. Agriculturally, it was mentioned that the area can be subdivided into two large units.

- The lower Hajr area, extending 2500 ha, and situated in the wadi delta on both sides of Aden-Mukalla road.

- The upper Hajr area situated around 60 km to the north of above mentioned area, along the upstream course of the wadi. This area covers 2450 ha.

This detailed soil investigation was meant for lower Hajr only, with the objective of examining the possibility of expanding agricultural production through a better understanding of soil properties.

The FAO/Unesco Legend was adopted for this study. The soils in the area studied were classified into three main units:

i. Xerosols
ii. Regosols
iii. Fluvisols

Within each unit sub-types and varieties were distinguished according to the potential uses of the soil. The factors taken into consideration include the depth of the soil, soil salinity or alkalinity, lime content, thickness of the humus layer, etc, which mostly affect crop production (see table 6).

This soil survey was carried out by Tesco - Viziterv from Budapest and the report was published in 1984.

Table 6. FAO/Unesco soil units in wadi Hajr

Soil unit (FAO/Unesco Legend)	Description	Soil types
Xerosol	These are the typical soils of areas with winter rains and dry summers. In this particular area they are situated in the highest parts of the landscape (3rd terrace). The soil is generally shallow (< 30 cm), or of medium depth (50 to 80 cm), but sporadically deep soils are also encountered. In the majoirty these soils are not saline, highly calcareous and show a mildly alkaline reaction. Physically they belong to the coarse silts.	a. Shallow calcic Xerosol b. Moderate calcic Xerosol c. Deep calcic Xerosol
Regosol	These are typical soils of arid zones, with a profile showing a sandy character down to great depths. In the area of wadi Hajr these soils are normally situated on the 2nd terrace. Their development has been influenced by the recurrent floods, wind erosion, successive shifting of the sand dunes and sedimentation of loess material migrating from the coast. The salts content revealed considerable differences in the soil profiles. Depending on the thickness of the coarse layer covering the surface two subtypes have been distinguished.	a. Deep calcic Regosol b. Very deep (> 150 cm) calcic Regosol
Fluvisol	These soils have developed in recent alluvial wadi deposits and reveal no pedogenetic horizons. Their texture and stratification result from the alluvial origin. At regular annual intervals inundation adds a fresh layer of sediment onto the surface. Such soils occur on the first terrace of the wadi. Physically they belong to the fine silts. Two subtypes could be distinguished according to their salt content.	a. Saline calcic Fluvisol b. Non-saline calcic Fluvisols

2.7 SOILS DIFFERENTIATED ACCORDING TO THE FRENCH CLASSIFICATION

2.7.1 Brief description of survey report included in this group

i. *Wadi Hadramout feasibility study. Final report. Vol. 1. Specific Study Report 2 : Soil survey and land classification*

This study covers that part of Hadramaut plain stretching from the confluence with Wadis Amd and Duan to the confluence with Wadi Khubayrth, downstream of Tarim. Wadi Hadramaut and its tributaries have eroded deep into the Palaeogene limestone plateau. The base level of the plain is now 150 to 200 m lower than the plateau. The plain is very entrenched and bordered by steep cliffs. It is covered by a 50 m thick sedimentary layer of Quaternary origin. The wadis have eroded their beds in these deposits, forming a series of terraces in places.

The main objective of the study was to identify potential areas for agricultural development and establish a more accurate soil and land classification map to a scale of 1:20,000. This work was based on a previous study done by the Soviet team and later on by Sogreah to identify irrigable lands in Hadramaut valley. About 47,600 ha, in the central valley of Wadi Hadramaut and the lower reaches of its principal tributaries were covered by the semi-detailed soil study.

In the French classification used for this study (see 2.1.3), which was correlated with the FAO/Unesco Legend and the Soil Taxonomy, characteristics of soil profile development are the mode, process and intensity of soil evolution. This classification allows for a range of criteria under which classes, subclasses, groups and subgroups are defined. The classes identified in wadi Hadramaut are mentioned below (see also table 6).

a. Soil Class defines the mode and intensity of soil evolution. The soils of Hadramaut valley come under the following classes:

1. Raw material soil not having undergone evolution
2. Slightly developed soils with little differentiation between soil horizons and sometimes with low soluble salt content
3. Calcic-Magnesic soils characterised by an exchange complex saturated to more than 70% by calcium and a more marked degree of evolution.
4. Sodic soils with high soluble sodium salt content.

b. A sub-class depend on "pedo-climate" ("Soil climate") conditions, these in turn depending on "eco-climate" factors.

1. Raw material soils and slightly developed soils are associated with hot climate (Xeric) inhibiting evolution or with recent deposition of alluvial or collu-alluvial material, which has not had time to develop in the local climate (non climatic),
2. Carbonated soils are characterized by comparatively soluble carbonate compounds,

Table 7. Soil classes in wadi Hadramaut, based on French classification

Class	Sub-class	Group	Sub-group	Facies	Soil Unit
Raw mineral soil	Non-climatic	Allu-colluvial deposit	Lithosol	Predominatly stony	1
		River deposit		Generally sandy texture, but variable	2
	Xeric	Dunes			3
Slightly developed soil	Xeric	Grey sub-desertic soil	Modal	Non saline Very slightly saline Slightly saline	4 5 6
	Non-climatic	Alluvial deposit	Modal	Non saline Very slightly saline Slightly saline	7 8 9
		Aeolian depost		Non saline Very slightly saline in deep horizons Slightly saline in deep horizons	10 11 12
Calci-magnesic	Carbonated soil	Brown calareous soil	Modal		13
Sodic soil	With undisturbed structure	Saline soil (solonchak)	Modal	Moderately saline	14
			With carbo-gypsiferous encrustment	Moderately saline (generally)	15
	With disturbed structure	Saline alkali soils (solonchak-solonetz)	Powdery structure in the surface layer	Highly saline Very highly saline	16 17

3. The soluble sodium salts in sodic soil do not affect the physical priorities of clay minerals - soil structure is not degraded.
4. Soil groups indicate characteristics of the soil evolution process. In this study, subgroups denote only the existence of salinisation phenomena. The intensity of salinity is denoted by different facies. Each type of soil is identified on the soil classification map by a mapping unit.

Although the Xeric "pedo-climate" (soil climate) of the French classification used in the subclasses of this study was correlated with Xeric soil moisture regime in the Soil Taxonomy, the existence of this moisture regime in the study area has still to be verified. It was not explained how the Xeric soil climate was defined for this study. Table 7 shows the tentative correlation between the French classification, the Soil Taxonomy and the FAO/Unesco Legend.

The soil survey was carried out by Sogreah, Consulting Engineers; Grenoble-France and the report was published in December 1981.

Table 8. Tentative correlation for wadi Hadramaut soils between French classification, Soil Taxonomy and FAO/Unesco Legend.

Class (French)	Sub-class (French)	Group (French)	Soil Taxonomy Group	FAO/Unesco subunit
Raw mineral soil	Xeric	Deposit organised	Xeropsamment	Eutric regosol
	Non-climatic	Collu-alluvial deposit	Xerorthent	Lithosol
Slightly developed soil	Xeric	River deposit	Xerofluvent	
		Grey non-desertic	Camborthid	
	Non-climatic		Salorthid	Orthic greyzem
		Alluvial deposit	Camborthid	Eutric fluvisol
		Aeolian deposit	Ustipsamment	Eutric regosol
Calci-magnesic soil	Carbonated soil	Brown calcareous soil	Xerochrept	Calcic cambisol
Sodic soil	With undisturbed structure	Saline soil	Salorthid	Orthic solonchak

CHAPTER 3 DISCUSSION AND RECOMMENDATIONS

3.1 DISCUSSION AND CONCLUSIONS

Ninety named soil series and eighty family classes from the eighteen soil survey reports listed in this study were reviewed and grouped according to their system of classification.

In the first group, which includes soil series defined on the basis on their depositional characteristics, the soils were developed in natural and/or anthropic deposits with layers of variable texture. Due to the complexity and intermixing of the parent materials, the soils have mostly been differentiated according to their physiographic position. This resulted in soil series with a wide range of characteristics. Also contrasting layers within the control section, such as sandy layers within an otherwise silty deposit, were not considered properly. Contrasting layers affect the movement of water and hence water availability to plants. In the Soil Taxonomy such soils are classified in different families depending on their layers of contrasting textures. The depositional series, due to the lack of an taxonomic framework, can only be identified and reviewed through profile descriptions and analytical data. As a first step towards the rationalization of the depositional series, they should be correlated to the Soil Taxonomy and/or the FAO/Unesco Legend. This is likely to lead to a smaller group of depositional soil series, which can be more easily linked to series defined in the other groups.

In the second group, which is the largest group of soil series discussed in this report, although soils have already been classified according to Soil Taxonomy and FAO/Unesco system, a revision is needed for following reasons :

i. update categories of soil series to accommodate all changes and modifications in Soil Taxonomy and FAO/Unesco Legend since 1978.

ii. correct some soil series which have a similar name but cover more than one Soil Taxonomy class.

iii. some soil series were identified by number only, and this has to change into a name.

iv. the soil series eventually have to be correlated with other soil series already established elsewhere in Yemen.

Although the soils in the third group were not classified as series, this group is very important because of two reasons:

i. The soils are classified to family level, which is the level of classification immediately overlying the soil series level, and

ii. It provides a complete coverage of all the soil families that occur in the Northern Governorates (the former Yemen Arab Republic).

As from the viewpoint of parent material and physiographic conditions the difference between the former Northern and Southern Yemen is not very large, the soil families identified in the North should, by and large, also occur in the South. Obviously, more families may be found in both parts of Yemen, but their number is likely to be limited. Therefore, the Cornell study on the soils of the Yemen Arab Republic (1983) could well serve as the basic framework for a system of soil series in Yemen.

None of the soils in the fourth and fifth group were classified at series level, or correlated with the Soil Taxonomy. In order to make them useful for the establishment of a soil series system in Yemen, they have to be correlated to the Soil Taxonomy and, as a matter of routine, to the FAO/Unesco Legend. Not enough data are in all cases available to be able to define the soil series to which they belong, but it should normally be possible to assign them to one of the soil families of the third group.

3.2 RECOMMENDATIONS

The third group, which is the most comprehensive group and covering a wide range of fully characterised soils, should be used to form the basic framework of a soil series system for Yemen. Since the soils in this group have been classified according to the Soil Taxonomy, this implies that the USDA system of soil classification would be the main tool to classify soils in Yemen. However, for purposes of international correlation, and soil resource inventory, classification according to the FAO/Unesco Soil Map of the World legend should be carried out in all cases as well.

The following steps are recommended to set up a National soil series system:

1. All soils for which descriptive and analytical data are available, are classified according to the latest version of the Soil Taxonomy (7th edition of the Keys to Soil Taxonomy), where possible up to family level, and correlated with the Revised Legend of the FAO/Unesco Soil Map of the World. Correlation with the World Reference Base for Soil Resources (FAO/ISRIC 1994), which is expected to succeed in due course the FAO/Unesco Legend, could be considered as well.

2. All presently identified soil series be assigned to their respective family. Where there are anomalies, such as more than one classification given for profiles belonging to one series, a screening should be undertaken to find out to which family the series in question belongs.

3. Series belonging to one family be thoroughly reviewed to determine whether the differences among them are significant enough to warrant several soil series, or whether they (or some them) can be combined into one soil series. If it is decided that more than one soil series is required than this should be for one of the following reasons:

   i. The differences between the series have implications for soil management,

ii. Although similarly classified under the Soil Taxonomy, more than one classification would be possible under the FAO/Unesco Legend. Each series should have one unique classification under both classification systems.

4. For each series a decision should be taken whether enough information is available to establish it as a Yemeni series, or whether it should be considered a variant. If there are more than one name for the series, the name that covers the largest area, based on hitherto executed surveys, should be selected.

5. A format must be designed for the description of each series. This should be accompanied by a representative profile description. The range of characteristics, based on all known profile descriptions associated with the series in question, should be indicated as well, together with phases that have been used. All series fully described must be entered into a Register of Yemeni Soil Series. Soil series should also be indicated for profiles included in the Soil Database.

Once a significant proportion of the Register has been completed, it would be advisable to make an effort to spread the knowledge on soil series to agricultural researchers, extension workers and other interested parties. This could be done through the preparation of pamphlets, lectures and the preparation of soil monoliths of the major series in each agro-ecological zone.

As a first step towards the establishment of a Register, all series identified in the studies discussed in this report were reviewed in order to find out whether enough information was available to use them for possible inclusion in the proposed Register. Those that met this criterion are listed in table 9, together with the Soil Taxonomy family class to which they belong and their corresponding FAO/Unesco classification (the Soil Taxonomy classification is basically an update of the classification given in the various reports, no attempt has been made here to reclassify soils). Due to significant differences in parent material, a number of families include more than one series. Variations in other relevant parameters have, at this stage, not been taken into account. From this table it may be seen that out of the 72 families mentioned in 2.5.1, eight already have one or more series assigned to them.

Table 9 Selected soil series and their Soil Taxonomy and FAO/Unesco correlation 1/

Soil Taxonomy (1994) family level classification (particle-size class only)	2/	FAO/Unesco Legend (1988) correlation	Soil series name
Aridic Ustochrept, sandy		Cambic Arenosol	Samah Ulya
,, coarse loamy		Calcaric Cambisol	Suwaydah
Udic Ustochrept, clayey		Calcaric Cambisol	Maris
,, fine loamy		,,	Atalaba
,, fine loamy		,,	Shirah
,, coarse loamy		,,	Bani Falah
,, coarse loamy		,,	Afiq
,, gravelly clay		,,	Makhdrah
Typic Ustochrept, fine loamy, mixed	x	Calcaric Cambisol	Mahannashah
,,	x	,,	Balasan
,,	x	,,	Wasitah

Table 9 Selected soil series and their Soil Taxonomy and FAO/Unesco correlation 1/

Soil Taxonomy (1994) family level classification (particle-size class only)	2/	FAO/Unesco Legend (1988) correlation	Soil series name
Lithic Ustochrept, fine loamy		Eutric Leptosol	Yafa
,, coarse loamy		,,	Qamah
,, coarse loamy to fine loamy		,,	Kiba
,, fine loamy		,,	Darb
Fluventic Ustochrept, fine loamy		Calcaric Cambisol	Jahran
Typic Haplaquept, fine loamy		Gleyic Solonchak	Sawad
Typic Haplocambid, coarse loamy		Calcaric Cambisol	Husayniah
,, coarse loamy		,,	Badwah
,, coarse loamy		Eutric Cambisol	Suwari
,, coarse loamy		,,	Ba-Aelal
,, fine loamy		,,	Tarim
Fluventic Haplocambid, coarse loamy		Calcaric Cambisol	Madan
,,		,,	Habaq
Lithic Ustorthent, fine loamy		Calcaric Regosol	Yizlah
Typic Torrifluvent, fine loamy		Calcaric Fluvisol	Mahat
,, fine loamy		,,	Isabah
,, coarse loamy	x	,,	Murrah
,, coarse loamy	x	,,	Ahwar
,, sandy	x	,,	Wadi
,, fine loamy		,,	Nuqub
,, coarse loamy	x	,,	Zinjibar
,, coarse loamy	x	,,	Batais
,, coarse loamy	x	,,	Giar
Typic Torriorthent, fine loamy	x	Calcaric Regosol	Al Araise
,, coarse loamy	x	,,	Al-Husn
,, coarse loamy	x	,,	Al-Anad
,, coarse loamy	x	,,	Al-Kadama
Typic Torripsamment	x	Haplic Arenosol	Al-Qoz
,,	x	Haplic ,,	Qasam
,,	x	Cambic ,,	Al-Kurnah
,,	x	Haplic ,,	Saban
,,	x	Haplic ,,	Timna
Typic Ustipsamment	x	Albic Arenosol	Numarah
Entic/Udorthentic Chromustert, clayey		Eutric Vertisol	Rakhamah
Typic Salorthid, coarse loamy	x	Haplic Solonchak	Mujaylies
,, fine loamy		,,	Abisiyah
,, clayey		,,	Jalab
,, clayey		Sodic Solonchak	Kathaf
Histic Haplaquoll, fine loamy		Mollic Gleysol	Nimijah
Cumulic Haplustoll, clayey		Calcaric Phaeozem	Tinnan

1/ The soil series in previous soil surveys were classified according the Soil Taxonomy (1975) and FAO/Unesco legend (1974). The classification of selected soil series in this table were updated using Keys to Soil Taxonomy (Soil Survey Staff, 1994) and FAO/Unesco revised legend (1988).

2/ Soil families already identified in earlier studies (see table 5) are indicated by an "x"

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