Comparative studies of the effects of agricultural practices on some arid zone soils in the Middle East

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COMPARATIVE STUDIES OF THE EFFECTS OF

AGRICULTURAL PRACTICES ON SOME ARID ZONE SOILS IN THE MIDDLE EAST

John H. Stevens

Summary

The effects of different agricultural practices on arid zone soils have been studied for four selected areas in the Middle East - traditional date garden cultivation and modern horticulture in Ras-al-Khaimah and the Al Ain (Buraimi) oasis, cotton plantations in the lower Awash valley, Ethiopia, and afforestation (for sand stabilisation) at Al Hasa oasis, Saudi Arabia.

Initial preparation of the land for agriculture results in a decline in the levels of organic matter present in the soil, but only a few years of cultivation are required to raise levels above those in the natural soils. This improvement in soil organic matter content is accompanied by a lowering of pH, improvements in structural stability and a greater availability of nutrients. Some redistribution of fine material within the soil solum may also take place. In addition to these general modifications to the soil, other changes that occur may be specific to a local set of conditions e.g. changes in salinity status, decalcification of date garden soils in Ras-al-Khaimah, and the formation of silt crusts in the Tendaho plantations.

To test the thesis that cultivation causes soils to become increasingly similar, at least in their cultivated horizons,

selected analytical data from 62 profiles were subjected to cluster analysis. Numerical linkage, for these soils of major groups characterised by poor morphological definition, showed that, while there was a relatively high degree of similarity between the cultivated profiles, their separation into dicrete sub-groups was meaningful and primarily reflected geographical area, management practices and soil texture.

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by

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PREFACE

Arid zone soils have, until recently, been relatively neglected as regards their scientific agricultural use. Suitable water supplies have, of course, been the main limiting factors to their development but, with advances in technology, not only is water being extracted from greater depths than formerly, but also sources are now being used that were previously considered unsuitable for agriculture on account of their quality. This allows a general reappraisal to be made of the potential of arid zone soils for cultivation. However, amongst indigenous agriculturalists and some expatriate 'experts', there has prevailed the view that the more water applied to a crop, the better will be the response. There is far more involved in arid zone cultivation than just irrigation, and until comparatively recently there has been a lack of awareness that change might be taking place within the soils as a result of cultivation, or even of the mechanisms responsible for such changes. Concern has only been voiced when areas have gone out of cultivation through salinization or alkalization as, for instance, the 50% decrease in cultivated area at Al Hasa, Saudi Arabia, during the last twenty five years. At the recent Symposium on New Developments in the Field of Salt-Affected Soils, held in Cairo, December 4-9, 1972, the first recommendation stated that 'The Symposium recognising the importance of salt-affected soils in that their area is increasing both as a result of existing cultivation and as these soils are reclaimed to provide more land for agriculture, Recommends an intensification of research work with an emphasis on new techniques. In particular, areas of research should include fertility studies on improved salt-affected soils .....the monitoring of changes occurring in the soils of existing land reclamation schemes' (present author's emphasis.)

The author has, over a number of years been concerned with assessing the suitability of arid lands for irrigated agriculture. In such assessments, the ability of the land to sustain irrigated agriculture is related to the presence or absence of any limiting factors actually present in the soil, or other attributes of the physical environment. Little attention is paid to changes that have taken place in the soil as a result of existing cultivation, unless land has actually gone out of cultivation through soil deterioration. The usual explanation given is that the new agricultural development will use different techniques and consequently, the changes, if any, in the soil will also be different.

This thesis is an attempt to assess the changes that occur in some arid zone soils in the Middle East as a result of different agricultural techniques. Four distinct areas were chosen - Ras-al-Khaimah in the Federation of Arab Emirates, Al Ain oases, also now included in the Federation of Arab Emirates, Al Hasa oasis in Saudi Arabia, and Tendaho Plantations in the Lower Awash valley, Ethiopia. These areas are all arid with extremely high summer temperatures ($>50^{o}$C is not uncommon) and very variable rainfall amounts. Fieldwork was spread over four distinct periods - two in 1967 (in January and May/June) in July/August 1969, and August/

September 1971. In the course of these studies, 245 soil profiles were examined in the field by the author who also carried out laboratory analyses on 395 soil samples derived from 105 of these pits. Field and laboratory data have been used to assess the changes occurring in the soils of each of the study areas as a result of cultivation.

Such an approach only takes cognisance of the local factors involved in pedogenesis and, in order to ascertain the similarity, or dissimilarities, between the cultivated soils of the four areas, 62 soil profiles were subjected to statistical analysis using a clustering technique. A similarity index was calculated for each of these profiles, based on 19 soil characteristics selected by the author, using the method devised by Hole and Hironaka (1960). Taxonomic dendrograms were then prepared from the similarity indices and these link together soils that have similar properties. This approach has, in the past, mainly been utilised to question the validity of the major soil groups and has not, to the author's knowledge, been extended to include comparative studies of the effects of soil processes, in particular those of an anthropogenic nature. The possible wider use of this technique in development studies is postulated. Cluster analysis has been comparatively little used in soil studies in this country and there were unforeseen delays in the computer unit during the preparation of the dendrograms. The analytical data used to determine the similarity indices of the 62 profiles is given in Appendix II,

while the full data for these pits and others not quoted in the text of the thesis are available from the author at the Department of Geography, University of Durham.

While some of the samples were collected during development surveys, none of the material has been previously subjected to a study of this type. The author is indebted to Sir W. Halcrow and Partners for permission to use material collected during a reconnaissance survey of the Trucial States (now the Federation of Arab Emirates), and to Mitchell Cotts Services Ltd., for the material collected in Ethiopia whilst carrying out consultancy work on the Tendaho Plantations. Work at Al Ain was carried out whilst in receipt of a travel grant from the Middle East Centre, University of Durham.

Acknowledgement is made to all those who provided help during this research, and in particular to:-

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PART ONE

INTRODUCTION

CHAPTER 1

The Importance of Arid Region Soils

1.1 Introduction

Definitions of arid lands have generally been based on climatic criteria such as low precipitation, season of rainfall, maximum temperature of the hottest month and minimum temperature of the coldest month (e.g. Meigs, 1953). It is perhaps more valid to define arid lands in terms of their utility and thus Jewitt (1966) stated that arid lands were those that were 'sufficiently arid to make both rain-fed cropping and grazing potentially impossible or marginal'. Such a definition has enhanced validity in an area like the Middle East where agriculture is the dominant economic activity, with about 60% of the working population thus engaged (Fisher, 1971).

The ecosystems of arid lands are possibly the most imperfectly understood of all ecosystems, in terms of the functional interrelationships of their component parts. While traditional forms of agriculture have always been very much controlled by environmental factors, modern agricultural practices that are relatively sophisticated are being introduced. Some of the environmental controls that formerly limited agriculture have been overcome, but many of the practices have been derived from agricultural systems employed in temperate humid lands. When introduced into an ecosystem for which they are not originally designed, severe environmental problems may result unless great care is taken in their operation.

The actual area under cultivation in the Middle East is small when compared with the total land area (table 1.1). The traditional methods of cultivation are still employed in most of the agricultural areas, but new techniques and a rapid growth of markets are beginning to have important effects on agricultural patterns (Stevens, 1972b). Large development schemes are being initiated, partly as a result of the new agricultural techniques and a changing economic climate, but also on account of the discovery of new sources of irrigation water particularly from deep aquifers. Examples include Haradh, 4,000 hectares, and extensions to Al Hasa oasis, 12,000 hectares, in Saudi Arabia. However, extraction of irrigation water from these deep aquifers is greater than the recharge provided by precipitation on the mountains of western Saudi Arabia and care must be taken in their utilisation, so that depletion is not too rapid. In addition, advances are being made in the use of water that previously were considered unsuitable for irrigation purposes (Stevens, 1972a, Atkinson, 1972).

Little is known about the behaviour of arid zone soils under different agricultural practices in the Middle East except for salinity and alkalinity changes. Baumer (1964) describing the status of soil science in Saudi Arabia maintains that 'the few studies that have been made are mostly agronomic. They consist of fertility analyses or research on different salts, and as the methods carrying them out have varied fairly considerably, the results are not easy to compare'. This view is still true, not only for the Arabian Peninsula but also for the whole of the arid zone of the Middle East and North Africa.

Table 1.1

Cultivated areas and estimates for future arable development of selected Middle Eastern countries

(From FAO/UN Production Yearbook 1968)

Country	1000 hectares			
	Total Area	Arable area	Irrigated area	Estimated Potential Arable area
Egypt (U.A.R.)	100,145	2,801	2,801	561
Ethiopia	122,190	12,525	30[1]	31,799[3]
Sudan	250,581	7,100	790[2]	38,016[3]
Iran	164,800	11,593	4,651	4,127
Iraq	43,492	7,496	3,675	2,000
Israel	2,070	411	156	736
Jordan	9,774	1,140	60	302
Saudi Arabia	214,969	373	162	2,880
Southern Yemen	28,768	252		1,554

1. Eritrea only

2. 1960 figure. Extensions to the Gezira will have considerably inflated this figure

3. Includes dryland agriculture and improved grazing

An essential pre-requisite of any agricultural development is the initiation of a land capability assessment. In such a survey, the physical attributes of land, including soil, water, terrain and climate, are assessed with a view to sustained agricultural production. Socio-economic factors, such as organisation of society, land development costs and marketing surveys are also incorporated wherever feasible, and particular cognisance is taken of the current land use as being the consolidated experience of the indigenous inhabitants. Such land capability surveys have been carried out in a number of areas in the Middle East e.g. the lower Awash Valley, Ethiopia (SOGREAH, 1965), Wadi Jizan, Saudi Arabia (Italconsult, 1965) or the Trucial States (Bowen-Jones et al. 1967, Bowen-Jones and Stevens, 1967).

Land classification has the definite 'objective of segregating lands according to their productive value for supporting a farm family and paying water charges' (U.S. Bureau of Reclamation, 1953) and in order to attain this objective a considerable amount of basic environmental data is required. However, the data is only used to highlight the hazards of cultivation on a particular soil or tract of land - all too often the long-term effects of cultivation on soil characteristics are not considered unless in terms of major environmental change e.g. build-up of soil salinity and alkalinity to such an extent that agriculture is no longer practicable as in the case of parts of the Tigris-Euphrates valley, Iraq. Knowledge of how the soils will react to proposed cultivation practices is usually unknown, thus making prediction virtually impossible.

The introduction of modern agricultural techniques will have a profound effect on the characteristics of weakly-developed soils of arid regions. Even in England and Wales, the detrimental effects of continuous agricultural practice and, in particular, modern techniques are causing some concern. One particular cause for concern, emphasised by the Agricultural Advisory Council on Soil Structure and Fertility (1970), is the level of organic matter in the soil. 'On unstable soils, the influence of organic matter is all important ...... Some soils are now suffering from dangerously low levels and cannot be expected to sustain the farming systems that have been imposed on them. A whole range of soils is suffering too from the effects of the passage of heavy machinery over them in unsuitable conditions'. This is of even greater concern in arid areas, the soils of which are naturally deficient in organic matter content. The purpose of the current research is to investigate some of the changes brought about by different agricultural practices, not only those that are taking, or have taken, place in the topsoil, but also those occurring in the subsoil. As the Agricultural Advisory Council Report continues, 'the absence of such knowledge can lead to surprises and mistakes which are often quite unnecessary and, more serious, to the taking of risks which cannot be justified.'

1.2 Classification of Arid Zone Soils

In humid areas, it is comparatively easy to appreciate the concept of soil as an organised natural body (Simonson, 1968) but in arid areas the effect of contemporary pedogenesis is to produce only minimal organisation. Lack of profile development has led to problems in classification, especially with schemes that are entirely dependent upon pedogenesis as their main criteria for differentiation. It was this lack of the effects of pedogenesis, that led Western (1972) to suggest a geomorphological, or depositional, approach to the classification of arid region soils.

FAO/UNESCO (1968) prepared a soil legend for their Soil Map of the World Project in which the soil units are based on the 'present knowledge of genesis, characteristics and distribution of the major soils covering the earth's surface and their significance as resources for production'. Each unit is characterised by observable and measurable properties which not only reflect the genesis of the soil but also have significance in soil management.

In this soil legend, orders and units found in arid regions may include:

1. Fluvisols. These are soils of recent alluvial deposits which show virtually no profile development. They may be subject to periodic flooding and thus show some depositional stratification. Carbonatic fluvisols are those fluvisols containing more than 5% lime in the top 100 cms, whilst eutric fluvisols have a pH (in KCl) of more than 4.2.

2. Regosols have developed on unconsolidated material, exclusive of recent alluvial deposits. Again, eutric and carbonatic regosols are differentiated.

3. The Vertisols are those soils of heavy texture with clay minerals having expanding lattices dominating the clay fraction. As a result, gilgai microrelief is often present and slickensides occur in the profile. The dry soil is characterised by cracks at least 1 cm wide and 50 cms in depth. Vertisols may be saline.

4. Yermosols are the true desert soils characterised by weak pedogenic horizons. The pallid A horizon is low in organic matter. Cambic (altered), argilluvic (clay enrichment by illuviation), calxic (secondary carbonate enrichment), gypsic (secondary calcium sulphate enrichment) and weak natric (5-15% exchangeable sodium) B horizons are diagnostic of haplic, luvic, calxic, gypsic and solonetzic yermosols respectively. In addition, these soils may be saline having conductivities of up to 16 mmhos/cm at 25°C.

5. Xerosols. In contrast to yermosols, xerosols are found on desert edges where there is greater effective rainfall. Vegetation covers a greater proportion of the soil surface and the soils contain a higher percentage of organic matter. The pallid A horizon is well developed while stronger pedogenesis is reflected in better definition of the diagnostic horizons. Haplic, luvic, calxic, gypsic and solonetzic soils are recognised and, again, xerosols may be saline.

6. Halosols can be divided into two major units - the solonchak and the solonetz. The former is characterised by the presence of a salic horizon (one that contains a secondary enrichment of salts more soluble than gypsum) and/or has a conductivity in excess of 16 mmhos/cm at 25°C within the top 125cms. Solonetz soils are characterised by the presence of a natric horizon.

This legend is flexible for use in arid lands, but it does suffer from major drawbacks. Firstly, it is difficult to classify intergrades i.e. soils that may possess the properties of two or more distinct soil types. This problem is accentuated in depositional enviroments where it is difficult to determine what is a soil property and what is the product of geomorphological process. Secondly, no account is taken of the rapidity of change that occurs in soil properties as a result of anthropogenic influences. In certain restricted areas, man is the dominant factor in soil formation - not only may he have caused widespread erosion thus destroying the soil characteristics but, on the other hand, additions to the soil may result in a change in soil properties thus necessitating a change in classification. At Al Ain oases, yermosols have been changed into xerosols through increases in organic matter caused by cultivation over a period of certainly hundreds of years (Stevens, 1970a). The changes in soil properties caused by different agricultural methods will be analysed in succeeding chapters.

1.3 The agricultural potential of arid lands

Table 1.1 gives an indication of the potential for agricultural development in some Middle Eastern countries. In several countries, the amount of potentially cultivable land is considerably greater than that currently under cultivation, but even if this was taken into cultivation only a small proportion of the area is feasible for agriculture. Much of the arid region of the Middle East is physically unsuited for agricultural development - rocky mountains with skeletal soils, moving sand and large areas of bare rock desert. Even in the areas where suitable soils occur, development has been hampered by a lack of technical expertise both in the exploration for, and exploitation of, water resources, as well as in agricultural management and techniques. Furthermore, until comparatively recently, there have been a lack of social and economic stimuli, including poor transport networks.

As a result of income derived from oil revenues, there has been a radical change in the agricultural sector of the economy of many Middle Eastern countries. Development of modern transport networks has meant that areas suitable for agricultural development, which were formerly too inaccessible, are now being linked with major markets. For example, Al Ain is now linked with Abu Dhabi by a dual carriageway tarmac road. Here, not only does the traditional form of agriculture, the date garden, flourish, but also there has been the development of smallholdings and, in particular, larger commercial holdings of up to 100 hectares in size. Exploration for oil and the initiation of water resource surveys have led to a reappraisal of water supplies for irrigation and these, together with advanced agricultural and irrigation technology, are bringing extensive areas under cultivation. Areas of dry farming are increasing at a faster rate than with irrigation, but it is in the latter that there is the greatest potential. Productivity from irrigated cultivation is much greater than from other forms of agriculture - Jewitt (1966) estimates that 25% of the world's food supply is produced from the irrigated 13% of the total arable lands. Furthermore, more intensive use of the grazing lands in arid regions is also going to be dependent upon an extension of irrigated arable lands in order to provide supplementary fodder crops such as lucerne or lubia (Dolichos lablab).

1.4 Methods of Investigation

1.4(i) Location of Study areas and field studies by the author.

Four distinct study areas have been chosen to reflect the variety of cultivation practices now found in the arid areas of Middle Eastern countries. Their locations are shown on Fig.1.

(a) Ras-al-Khaimah. In this part of the Oman Peninsula there are a number of long-established settlements, each associated with date gardens, but since the middle 1950s there has been the rapid establishment of commercial smallholdings, mainly concentrating on the cultivation of vegetables. While the water resources of the area were sufficient for the traditional date cultivation, the new agricultural development, in addition to a rapidly increasing urban population (in 1968, the total population of Ras-al-Khaimah was over 24,000) has caused considerable problems in water exploitation. Many of the pumps irrigating the new holdings are located too close together thus resulting in a local lowering of the water table. This has had unfortunate repercussions in that, because of the close proximity of the area to the sea, saline water has contaminated the irrigation water through a reversal of the hydraulic gradient. Furthermore, because of the natural salinity of many of the soils, recirculation of irrigation water has also caused it to become more saline.

In 1965, the Trucial States Development Council commissioned a survey of the water resources and this was carried out by Sir W. Halcrow and Partners. Associated with this was a survey of the agricultural potential of the soils, undertaken by the Geography Department of Durham University. This latter survey was primarily concerned with virgin soils and their suitability for development, but it did allow the author to investigate profiles under different types of cultivation. The author investigated about 140 soil profiles in the field and collected samples from 31 profiles for

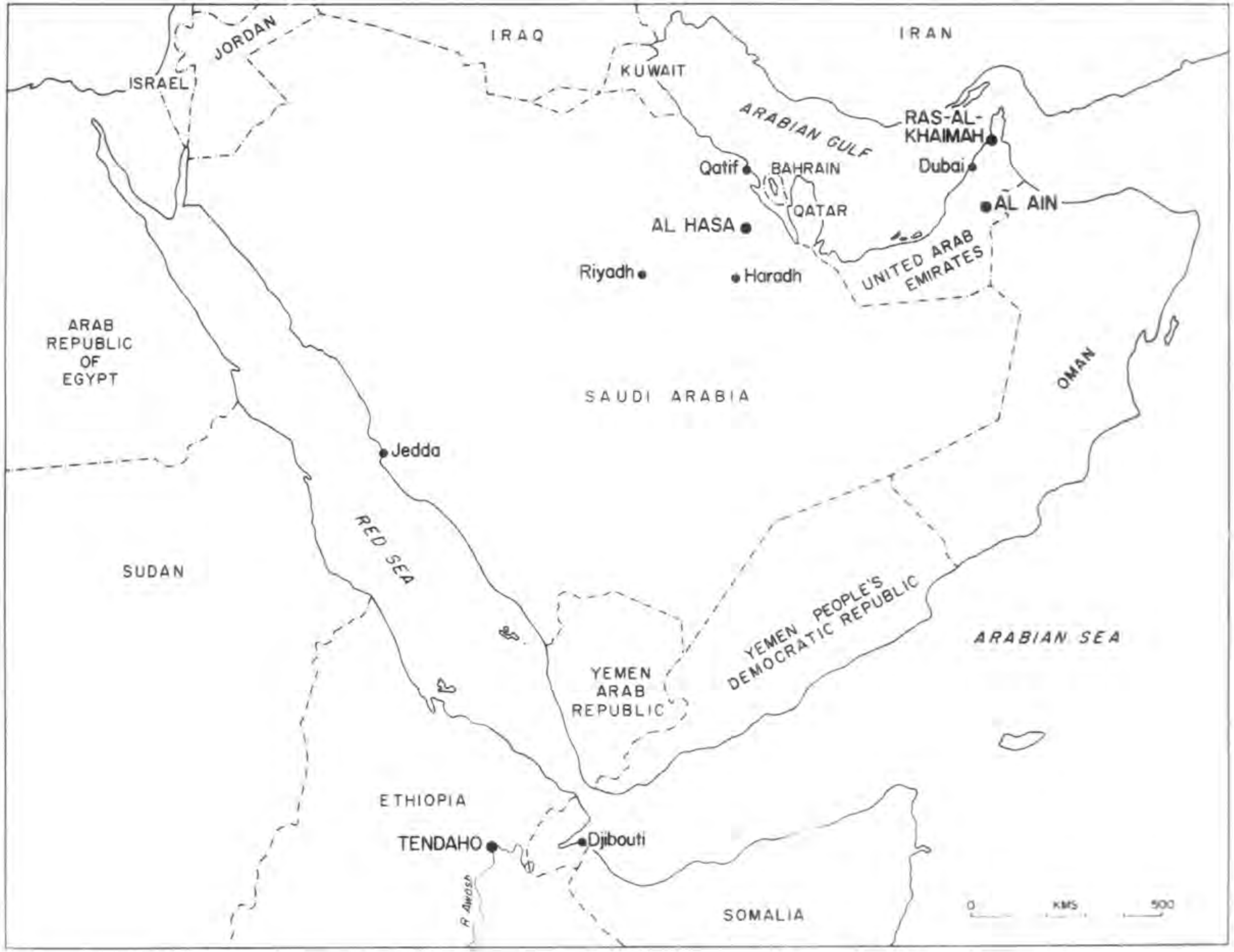

Fig.1
Location of study areas

analysis in the laboratory. Of these 31 profiles, 10 were either under cultivation or had recently been cultivated.

(b) Al Ain oases, Federation of Arab Emirates. These oases are long-established being sited on a major trading route across the Oman Peninsula. While the changes that have occurred in the type of agriculture practiced are similar to those at Ras-al-Khaimah, there has been a greater emphasis on the scientific approach, particularly in the use of fertilisers. The irrigation water is far less saline than at Ras-al-Khaimah and there is a relative absence of saline soils. 30 profiles were examined and samples were collected from 14 (11 cultivated) for analysis in the laboratory by the author.

(c) Tendaho Plantations, lower Awash Valley, Ethiopia. In contrast to the two preceding areas, which are examples of oasis agriculture, this is an area of virtual monoculture of cotton, organised and directed by European expertise. The first commercial cotton plantations were established around Dubti in the early 1960s, and soil samples were collected from fields having varied cropping histories. Some had grown cotton almost continuously since the establishment of the plantations while others had fallows and/or alternative crops (rice or maize) incorporated into their cropping pattern. 67 profiles were investigated in the field, 52 (48 cultivated) of which were sampled for laboratory analysis by the author.

(d) Al Hasa Oasis, Saudi Arabia. While this oasis is perhaps one of the oldest centres of agriculture in eastern Arabia, this study is concerned with the sand stabilisation scheme initiated in 1963. The agricultural part of the oasis has been going out of cultivation due to increasing salinity and also as a result of sand dunes, encroaching at a rate of 12-15 metres each year, overwhelming part of the cultivated area. In order to prevent this encroachment, a belt of woodland, mainly of Tamarindus species, is being planted and soil samples were collected from 8 sites in order to determine the rate at which raw, unstable, mineral particles attained some of the properties of a soil. This is a unique area in which to study soil formation, in particular because of the organic horizon that occurs under some of the longer established woodland plots. Such a horizon is usually absent in arid zone soils but it has important implications in that it could completely alter the pedogenic processes. Woodland is increasingly being used for shelter belts in agricultural areas and the effects of tree growth would certainly modify soil properties in the vicinity of thick shelter belts.

At each profile location, the soil was carefully described according to standard soil survey procedures. Some difficulties were encountered, especially in the definition of soil horizons, for depositional horizons often obscured those that were the result of pedogenic processes. As far as possible, pedogenic horizons were described but, in the subsoil, textural horizons resulting from deposition were also described. In some cases, pH and conductivity determinations were made in the field.

1.4(ii) Laboratory studies undertaken by the author.

395 soil samples and 3 organic samples were subjected to laboratory analyses. Soil analyses were carried out on samples that had been air dried, crushed gently and had passed through a 2mm sieve. Routine analyses consisting of mechanical analysis, total carbonate content, pH and conductivity determinations, cation exchange data, organic matter content and total nitrogen, were carried out on all the soil samples while supplementary analyses including total and available phosphates and potash, iron, gypsum, soluble anions, silica-sesquioxide determinations and X-ray diffraction studies were made on selected samples.

The methods of analysis employed were as follows:-

Particle size analysis. After treatment with hydrogen peroxide, to remove any organic matter, and dilute hydrochloric acid, to dissolve carbonates, the soil was shaken overnight and the separates were determined by measuring the density of the suspension with a Bouyoucos hydrometer. In cases of soils that had exceptionally high carbonate contents or were very alkaline, some anomalous results were recorded.

Total carbonates. The soil was treated with an excess of hydrochloric acid and this excess titrated with sodium hydroxide using brom-thymol blue as an indicator.

pH. Determination, by a direct reading pH meter, on a saturated paste.

Conductivity. Determination, by a conductivity bridge, on a saturated paste. This measurement gives an indication of the total soluble salt content present in the soil solution, there being approximately 10 meq/litre soluble anions for each mmho/cm at 25°C.

Soluble salts. The methods employed were those recommended by the U.S. Salinity Laboratory (1953) and the determinations were made on saturation extracts. Carbonates and bicarbonates were determined by titration with sulphuric acid, chlorides by titration with silver nitrate and sulphates by precipitation as barium sulphate.

Gypsum. The quantitative method by precipitation with acetone was employed.

Cation Exchange data. The soils of the Tendaho plantations and Al Hasa oasis were relatively low in carbonate content and ammonium acetate was used for the extraction of exchangeable cations from samples from these two areas. However, this method of extraction was not suitable for highly calcareous samples for the ammonium acetate takes into solution some of the calcium carbonate present, thus enhancing the 'exchangeable' calcium values. Instead a barium chloride-triethanolamine solution was used for extraction of cations of highly calcareous soils. Exchangeable sodium and potassium were determined on a flame photometer while exchangeable calcium and magnesium determinations were carried out on an atomic absorption spectrophotometer.

Organic carbon. The Walkley-Black method of wet oxidation of organic matter using a standard potassium dichromate solution was employed. The excess dichromate was titrated against standard ferrous ammonium sulphate using diphenylamine as an indicator. A recovery factor of 77% was assumed.

Total nitrogen. The soil was digested for at least 3 hours with concentrated sulphuric acid. The digest, after dilution, was distilled into a boric acid and mixed indicator solution and this was then titrated against hydrochloric acid.

Total phosphate and potash. Extraction was by sulphuric acid and the amounts present determined colorimetrically on a flow-through spectra.

Available phosphate and potash. These were determined colorimetrically on a flow-through spectra after extraction of 10g soil by 100ml weak acetic acid (2.5%).

Iron. Deb's method of extraction was used in which the soil is treated with sodium hydrosulphite and 0.05N hydrochloric acid. The amount present was determined colorimetrically on the flow-through spectra using thioglycolic acid to develop the colour. The sodium hydrosulphite transforms the free iron oxides into sulphides which are readily soluble in hydrochloric acid.

Silica-sesquioxide determinations. These determinations are used to give an indication of the degree of weathering that has taken place in the soil and are carried out on the clay fraction. Sodium carbonate fusion followed by treatment with concentrated hydrochloric acid produces a complete decomposition of clay particles. Silica was determined by obtaining the loss of weight on digestion with hydrofluoric and sulphuric acids in a platinum crucible, with iron and aluminium determinations being carried out on the insoluble residues. The residues were dissolved by fusion with $KHSO_4$ and the addition of dilute H_2SO_4, iron being developed using sodium salicylate and iron using thioglycollic acid and aluminon.

X-ray diffraction studies. These were used to supplement the silica-sesquioxide determinations to give an indication of the minerals forming in the clay fraction due to weathering processes. Acetone smears of clay samples, obtained by end over end shaking of untreated soil for 16hrs, standing for 4hrs and decantation and evaporation of suspension, were made and Cu Ka radiation used. Where appropriate, auxiliary tests, such as treatment with glycerol, were employed to establish the presence of expanding lattice minerals.

In addition to the analyses carried out on the mineral samples, the organic matter collected from the Tamarix woodland at Al Hasa has been subjected to laboratory tests. The first was to determine the changes in pH values occurring during the early stages of decomposition. Distilled water was added to the organic material at intervals of five days, to simulate irrigation conditions and the pH noted. A second technique employed was to separate the organic material into its components, humin, fulvic acid and humic acid. The latter two are of particular importance as they are responsible for much of the mineral translocation that takes place in the soil. The organic matter was treated with 5% NaOH and the soluble material is the fulvic and humic acid. The soluble material was then treated with 5% HCl, the precipitate being the humic acids and the acid-soluble material being the fulvic acids.

CHAPTER 2

Arid Zone Pedogenesis

2.1 Palaeosols

Contemporary climatic conditions to not favour biological activity to any great degree and as a consequence pedogenic processes are weak and severely restricted. Indeed, under conditions of extreme aridity, biological activity, can be virtually absent and the surface material may be regarded as 'pre-soil' (d'Hoore, 1964). However, this has not always been the case, especially during the Pleistocene, when, in pluvial periods, the amount of effective moisture was considerably greater than it is today. As Butzer (1963) states 'it is argued that a zonal lowering of temperature by $4-5^{o}C$ during various glacial phases would automatically reduce evaporation sufficiently so as to permit higher lake levels or greater stream discharge'. During the pluvial periods, which were ~~demonstrably~~ exactly not contemporaneous with the glacial phases in Europe, though evidence still remains partial and scattered, biological and chemical activity would have been considerably greater than at present and, consequently, pedogenic processes more intense or entirely different from those operative today.

In some instances relic soils, or palaeosols, that formed under these different past environmental conditions, have survived relatively intact, especially in areas that have remained unaffected by subsequent erosion and/or deposition. Such an area is found near Al Ain oases, Federation of Arab Emirates, on the western flanks of Jebel Hafit. Here, a red limestone soil (profile 21)[1], having some similarities with a chromic luvisol (terra rossa), has developed on a conglomeratic limestone of Miocene age. The profile shows 3 cms of aeolian loamy fine sand overlying 12 cms of 5YR4/4 (reddish brown)[2] sandy clay loam, which in turn, rests on weathered limestone. It is the reddish brown horizon which is probably a remnant of a palaesol. Table 2.1 gives some analytical data for this soil as well as comparable data for chromic luvisols in northern Jordan, described by Fisher et.al. (1966, 1968), and a typical uncultivated xerosol found in the Al Ain oases (profile 12). While the palaeosol is obviously very different from the xerosol, the distinguishing features of a chromic luvisol are not fully developed. The palaeosol has a higher pH and a higher carbonate content than the chromic luvisols whilst the acid-extractable iron oxide content is lower. Given a longer period of time under conditions more favourable to pedogenesis (in particular, a greater amount of effective moisture), it is possible that a chromic luvisol might have evolved.

However, many 'normal' arid zone soils exhibit features in their profile morphology which represent distinct environmental conditions during their formation. The polygenetic origin of many of the soils of the Gravel Plains, Federation of Arab Emirates

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1. full analytical data for profiles mentioned in the text are given in Appendix 1.

2. all Munsell colour notations are given for moist soils

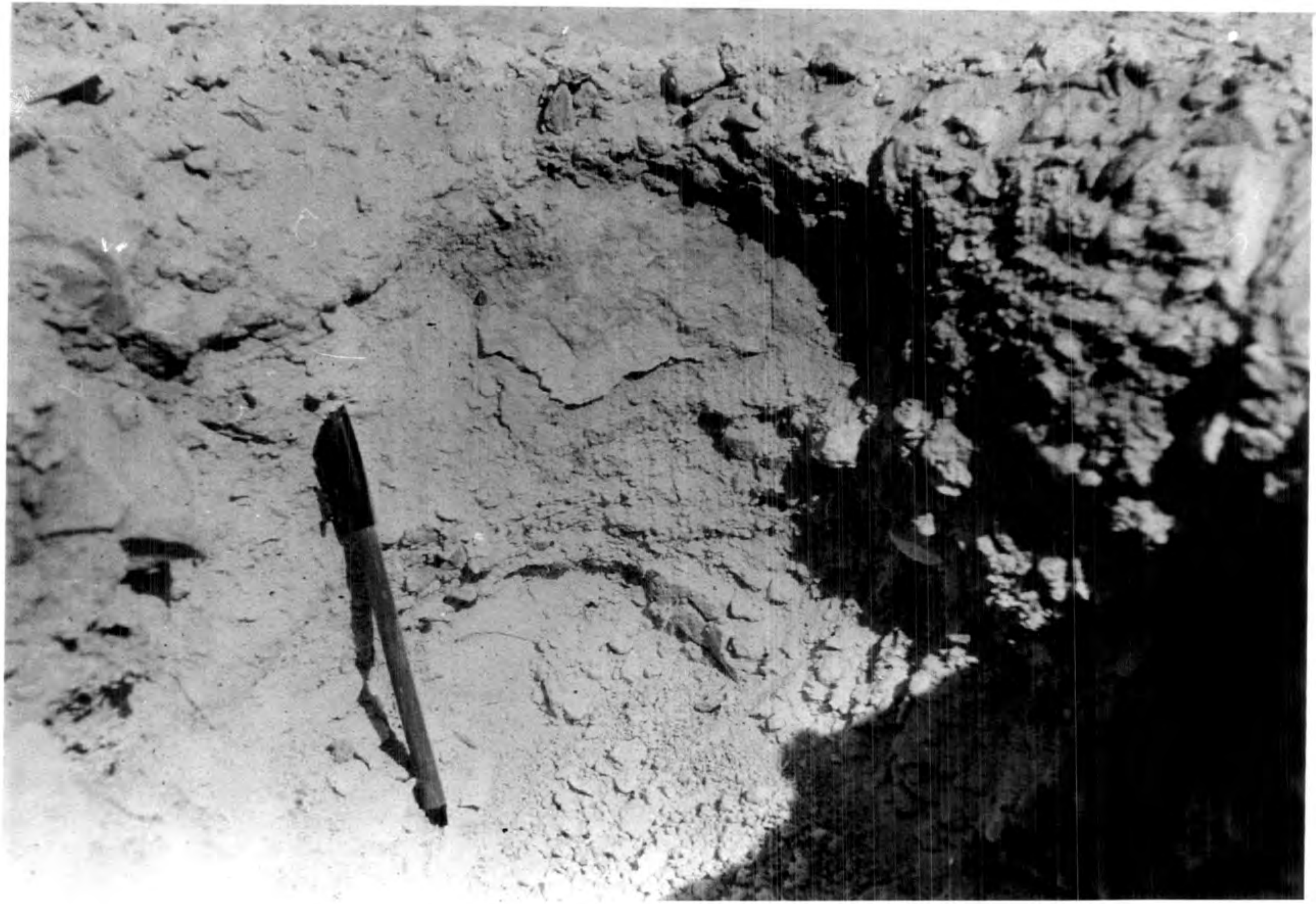

Plate 1

Palaeosol on the slopes of Jebel Hafit, Al Ain oasis. The biro is resting on hard siliceous limestone and the horizon above is of 5YR4/4 (reddish brown) sandy clay loam (profile 21).

Table 2.1

Analytical data for representative chromic luvisols (Jordan) a palaeosol (Al Ain, Abu Dhabi) and a xerosol (Al Jimi, Abu Dhabi)

PROFILE	Sample Depth	Texture International Limits			pH	Carbonates	Total C.E.C.	Free Fe_2O_3	Conductivity
	cms	Sand %	Silt %	Clay %		%	mgs/100g	%	mmhos/cm
CHROMIC LUVISOLS									
Ajlun, Jordan	0-10	40	34	26	7.8	2	37.0	6.1	0.9
	10-32	31	25	44	7.7	4	32.6	8.3	0.4
Wadi Ziqlab Jordan	0-15	12	33	55	7.4	1	46.8	7.3	0.7
	15-48	3	34	63	7.4	1	44.8	9.1	0.5
PALAEOSOL									
Al Ain, Abu Dhabi	0-3	72	11	17	7.6	35	12.3	0.8	0.5
	3-15	36	22	42	8.3	6	28.2	3.9	0.3
XEROSOL									
Al Jimi, near Al Ain, Abu Dhabi	10-15	89	3	9	8.4	38	10.8	0.4	0.1
	50-55	89	4	7	8.7	29	11.9	0.2	0.1
	95-100	85	5	10	8.7	29	11.7	0.6	0.2

is reflected in the occurrence of several gypsic and/or calxic horizons in a number of profiles (Stevens, 1969a). Profile morphology of most arid zone soils thus provides some evidence for stages in pedogenesis rather than the cumulative influence of climatic, biotic and topographic factors acting on a single parent material since its deposition.

2.2 Factors affecting contemporary pedogenesis

In terms of movement of material, the geomorphic landscape may be divided up into zones of departure, of transference and of accumulation (d'Hoore, 1964). In any one of these zones, pedogenesis is perhaps most closely affected by the intensity and frequency of precipitation. The area directly affected by a rainstorm in arid zones is relatively small - SOGREAH (1965) estimate that in the lower Awash valley, Ethiopia, the area affected by a shower of rain is no more than 15-20 sq.kms in extent. Very little of this rainfall is effective in terms of pedogenesis for the thin crust on the soil surface reduces infiltration and accentuates run-off. The latter can be considerable and the effects of a rainstorm may be felt many kilometres away in the form of flooding and sediment deposition. Soil profiles in highland areas (the zones of departure), where they occur, tend to be heavily eroded and truncated while deposition in the zones of accumulation is often far more rapid than pedogenic modifications to the parent material.

Under environmental conditions of high temperatures, low humidities, scanty irregular rainfall, and low biological activity, soil evolution is a long process and arid zone soils are characterised by their weak profile morphology. Organic matter is lacking and consequently structural development limited, weathering of minerals is severely restricted while redistribution of carbonates and soluble salts are the major processes operative due to the high evapotranspiration rates exceeding precipitation in every month of the year. Any diagnostic horizons that tend to form in parent material in zones of accumulation are quickly obscured by further deposition.

Man has been the most dynamic factor affecting pedogenesis in arid zones. Over vast areas of the Middle East, overgrazing and felling of the few trees has resulted in considerable soil erosion which also reduces the importance of diagnostic horizons. In irrigated agriculture, although the areas involved are relatively small, man has caused a different type of soil to develop in contrast to those profiles which have remained relatively free of his influence. Such soils are subjected to a moisture regime characterised by alternating periods of anaerobic conditions, severe leaching and capillary upward movement. Very little is known about the effects of different cultivation practices on soil formation but as agricultural development in the arid zone assumes greater importance, the implications of the techniques must be fully appreciated. Unless this is the case, there is the likelihood of severe ecological damage being caused.

2.3 Man as a factor in arid zone pedogenesis - general considerations

In irrigated agriculture, the hydrological regime of arid zone soils is reversed. Instead of upward capillary movement of moisture leading to the accumulation of soluble salts and carbonates at, or near, the surface, strong leaching predominates for long periods. This leaching is far more intense than that experienced by soils in humid climates, primarily because of the excessive amounts of irrigation water applied, although it may be accentuated by the excessive porosity of light textured soils, and it results in the washing down of soluble salts and carbonates. If drainage within the soil is at all restricted not only do the soluble salts tend to accumulate affecting the growth of plants, but also hydromorphism may result with adverse air/moisture ratios. A classic example of this existed at Qatif oasis, Saudi Arabia, prior to the initiation of a comprehensive drainage and development programme in 1963. The detrimental effects of hydromorphism accompanied by excessive salinity are clearly visible by constrictions in the trunks of the date palms, which are about the most resistant of all commercial crops to high salinity in the soil. In contrast, excessive irrigation applications can be beneficial in that harmful salts can be washed out of the rooting zone of plants, provided there is good drainage, and this has been a factor in the success of the Tendaho Plantations in Ethiopia (as will be seen subsequently).

Cultivation, whether of traditional date gardens or of modern commercial plantations, has resulted in the mixing of the topsoil, thus concealing any natural pedogenetic differences in the surface horizons. Even with the simplest agricultural implements, such as the digging stick or hoe, mixing of the topsoil produces a very characteristic horizon, though its thickness

Plate 2

Constrictions in the trunks of date palms, Qatif oasis, Saudi Arabia. These were caused by waterlogging and excessive salinity but subsequent land reclamation, including drainage has allowed normal growth.

is not nearly so great as that formed as a result of mechanical operations. Cropping, over a period of time, not only leads to an accumulation of organic matter in the topsoil, but will also be a drain on the fertility status of the soil unless manures and/or artificial fertilisers are applied. While the old date gardens have always had some manure added annually, some of the new smallholdings have been reluctant to apply either manure or fertilizers and impoverishment of the soil has quickly taken place.

With the introduction of irrigated agriculture, man also influences the microclimate and changes the vegetation. Both are important factors in soil formation and any alteration to them has an indirect influence on the soil profile. For instance, reductions in temperature and increases in humidity occur in date gardens as a result of the shade, provided by the palm trees, and irrigation (Bowen-Jones et.al., 1967). Direct insolation of the soil is substantially reduced, resulting in lower soil temperatures, and these environmental changes particularly influence the micro-biological activity within the soil. In the eastern part of the Arabian Peninsula, lucerne has become a major crop, not only on the newer smallholdings but also in the traditional date gardens, but nodulation is very rare, even with innoculated seed. Good yields are obtained but the bacteria required to stimulate nodulation do not appear to be able to survive the high intensity of direct insolation and/or the periodic waterlogging resulting from irrigation. Conditions, for nodulation, appear to be more favourable when insolation is reduced and controlled irrigation techniques practised as, for instance, on research stations and experimental farms.

Agriculture results in the substitution of plants ecologically adapted to the environment by ones for which there are commercial demands and which may be less well adapted. Each species has its own specific nutrient requirements and, with continuous cropping of a species, there is a progressive decline in the quantity of nutrients available in the soil unless fertilizers are applied or weathering within the soil solum provides an adequate replacement. This is particularly important in arid zone soils where the inherent fertility is generally very low. Rooting zones, too, vary from plant to plant. Lucerne roots to a far greater depth than either wheat or barley, while its water requirements are far greater due to its larger leaf area.

As a consequence of these factors, the soil that develops as a result of cultivation is very different from the natural soil in its physical, chemical and biological properties. Unless care is taken with the agricultural techniques, a soil may develop having properties that are entirely unfavourable for cultivation and instead of maintaining or even improving a natural resource, man is destroying it. The succeeding chapters are case studies illustrating areas and situations where man has affected arid zone soils through the medium of irrigated agriculture. In some cases his effect has been beneficial, in others, detrimental, to soil as a resource.

2.4 Previous work on man as a soil forming factor in arid zones

The current study basically includes three elements:-

(i) a study of the effects of different agricultural practices, including ones recently introduced, on soil characteristics in traditional oasis areas.

(ii) a study of the effects of monoculture, in this instance cotton, in an area of relatively new agricultural development.

(iii) an assessment of the rate at which soil can form from raw mineral particles, as a result of anthropogenic factors.
For each of these elements, the amount, and nature, of previous work has been very variable and, at times, the results have been very inconsistent. To the author's knowledge, none of these approaches have been applied to the areas under study.

2.4(i) Work on soils of traditional oases

Butters, the Assistant Director of the Commonwealth Bureau of Soils, in a personal communication, comments that 'not very much has been written on this subject.' The limited literature refers mainly to oases of two areas - North Africa and Soviet Central Asia. A considerable amount of the literature on the latter area is in Russian.

Early published work on desert soils was mainly directed towards the genesis and classification of virgin soils so that irrigated areas might be expanded. Thus, in North Africa, Schoonover and his co-workers (1957) studied saline and alkaline soils in Egypt while Elgabaly and Khadr (1962) carried out clay mineral studies to determine whether there was any genetic relationship between Kharga oasis soils and those of the Nile Delta.

Papers by Moustafa et.al. (1958) and Mohammed et.al. (1959), dealing with soils in the Kharga and Dakhla oases, respectively, gave little more than superficial descriptions of soils, accompanied by tables of analytical data, along with more comprehensive recommendations for reclamation. El Fekih and Pouget (1966) gave comprehensive descriptions of 'date palm loams' in the oases of southern Tunisia and they define three soil horizons. The surface horizon was approximately 30 cms deep and contained up to 3% organic matter, while the middle horizon was 20-150 cms in thickness, had lower organic matter contents (0.5-1%) and also showed some signs of hydromorphism. The deep horizon was affected by the water table which had caused the formation of a gley horizon with gypsum crusts.

In a comparison of old irrigated soils of the Kara-Kum and Libyan deserts, Minashina (1966) comments that 'the influence of cultivation on irrigated soils is so great that zonal factors are strongly masked and upon prolonged irrigation soils form anew from material supplied by irrigation waters and fertilizers.' The two areas discussed had much in common and despite distinct zonal differences the soils were similar in make-up and productivity. Gorbunov (in Kovda and Lobova,1965) summarises the reasons for this similarity. These are

'(i) the development of an eluvial process under the influence of additional moistening by irrigation water

(ii) formation of a new 'agro-irrigational' soil horizon by the intake of suspended particles and dissolved substances in such water

(iii) increase in biological activity and in the accumulation of biologically active elements within the soil, because of the cultivated crops and farming practises.'

More recent work on oasis soils has tended to concentrate on the biotic aspects. Almost all workers have commented on the increase in organic matter as a result of irrigation, but few detailed studies have been made. However, Rougieux (1966) isolated two effective strains of Rhizobium from lucerne growing in El Ahane oasis, Algeria. Bryssine (1967) examined the micro-organisms present in oasis soils and, while finding that all physiological types were represented, concluded that numbers were greatest under traditional forms of cultivation.

Russian work has mainly been concerned with changes taking place in organic matter content and composition caused by different tillage methods and their effect on the nutrient status of the soil (e.g. Shevlyagin, 1969). Kononova (1961) summarises Russian research work on the decomposition of humus following the cultivation of virgin serozem soils. 'These works indicate an extremely rapid decomposition of organic matter attributable to the higher intensity of biological processes in irrigated serozems.' This decomposition was greatest under cotton 'receiving repeated irrigation and periodic loosening of the soil during the growth period' where about one half of the total reserve of humus is decomposed in the first 3-5 years.

A second approach of Russian research has been to investigate changes in virgin soils caused by their cultivation. Many of the areas now cultivated in the arid region of the U.S.S.R. have required extensive amelioration before they were suitable for cultivation, often on account of the soluble salts present. Much work has therefore been carried out into the effects of different meliorative practices, not only on soil properties but also on subsequent crop yields. Yegorov and Letunov (1966) define the main tasks of meliorative soil science as being to evaluate the degree of suitability of different lands for drainage or irrigation, to justify the methods for basic improvement of soils following drainage or irrigation, and to devise scientifically sound ways of conserving and increasing the fertility of meliorated soils. To this end, studies have been made, in particular, of the causes and types of salinisation occurring in the soil. Stemming from such work is the finding of Minashina (1968), when studying soil formation and salt migration in the Murgab oasis, that salt migration could be active in the top 10-13 metres of the soil.

2.4(ii) Research work used on soils used for cotton cultivation

Because of the commercial significance of cotton, most studies have been concerned with agronomic aspects of soil characteristics, in particular the relationship of crop yields to different soil factors. In the Sudan Gezira, excessively salty areas have not been cultivated and, in 1941, Snow introduced the concept of the sodium value as being the main determinant to cotton yield. The sodium value was essentially similar to the exchangeable sodium percentage (ESP) and soluble sodium percentage. However, Finck (1959) considered that the clay content might be a more reliable indicator of yield. In conjunction with Ochtman (1961) he suggested a clay-yield formula of

$$Y = -49.3 + 2.57X$$

Y represents the percent relative yield of cotton and X the percent clay content in the 0-40 cm layer and it was considered that the formula was valid for soils containing 40-70% clay. More recent work by Robinson (1971) has shown that ESP is an important characteristic affecting crop yield and an optimum ESP range of 6-25 is postulated. 'This level, which is higher than usually recommended for cultivation on other kinds of soil, is probably best explained by the availability of soil moisture in this ESP range in these soils.'

Other studies on soils used for the cultivation of cotton have related to the fertility status, to irrigation rates and to planting techniques, all with the aim of increasing yield. Finck (1960) found that on Gezira soils cotton yields improved with increasing organic carbon and nitrogen in the soil, while yields on the Tendaho plantations, Ethiopia, improved by about 15% as a result of the application of nitrogenous fertilizers (Hampson, 1972, private communication). Irrigation rates and evapotranspiration from cotton fields in arid areas have been studied in considerable detail in order that a scarce resource, water, might be conserved. An example of this type of work, having particular reference to the Middle East is that of Rijks (1963). Often related to water utilisation, but also to production costs, have been studies of planting techniques, Longenecker and his co-workers (1969), for instance, found that variable row spacing, consisting of alternate wide (137 cms) and narrow (66 cms) rows, with irrigation furrows only between the

66 cms rows, not only resulted in more efficient utilisation of water but also more effective weed control. Yields were maintained.

A certain amount of work has been carried out on the effect of cotton cultivation on soil characteristics at the Gezira Research Station, Sudan. It must be borne in mind that 'Gezira clay, an alkaline, almost impermeable, highly cracking montmorillonite behaves so very differently in almost every respect from the normal, well-aggregated soils of the textbook, that the orthodox approach, via field capacity, has failed entirely to provide a satisfactory understanding of what happens when water is applied to a field'. (Farbrother, 1972). On these clay soils, Greene and Peto (1934) suggested that during a normal irrigation cycle there was very little change in the distribution of soluble salts in the top 2 metres of the soil. They concluded that while there may be a small downward movement of salts, there is no upward movement. Jewitt and Middleton (1953) followed up this earlier work and interpreted their results 'as showing that soluble salts other than gypsum show a small differential movement in response to increased irrigation, while a rather larger downward movement of gypsum has taken place.' Even with two years of fallow following a cotton crop there was no evidence of an increase in soluble salts or of the zone of gypsum accumulation rising towards the surface.

Perhaps the most important work on cotton growth in the Gezira has been a symposium to mark the 50th Anniversary of the

Gezira Research Station. Published as 'Cotton Growth in the Gezira Environment' (Editors, Siddiq and Hughes, 1970) a paper by Rai discussed the long term effect of irrigated cotton on the Gezira soil. Rai assessed previous work on this subject and came to a number of conclusions:

(i) Water-soluble salts. Some doubt was cast on the validity of Jewitt and Middleton's work and it was commented that, because of an absence of original soil data 'it cannot be said safely that no change has taken place in the plots since the experiment started in 1931. A perusal of results of all the work done during the past forty years or so shows clearly that irrigation caused both accumulation in and removal of salts from the soil. It should be remembered that the studies were done on different sites.'

(ii) Exchangeable plus soluble sodium. Again evidence was conflicting. In some circumstances there had been an increase in the exchangeable plus soluble sodium content, whilst in others there had been a decrease.

(iii) pH. Different rotations had had no effect on pH values.

(iv) Calcium carbonate content. Some increase in the calcium carbonate content of the larger than 1 mm size fraction was recorded as a result of irrigation due to the irrigation water containing appreciable amounts of calcium carbonate (about 49 ppm according to Joseph, 1925).

(v) Organic carbon and nitrogen. Amounts of organic carbon and nitrogen in the topsoil samples from continuous cotton plots were less than in plots with fallow periods incorporated into the rotation. The opposite trend was apparent in subsoil samples. Thus few clear trends were apparent in the soil as a result of cotton cultivation, but this may be explained, in part, by an absence of reliable soil data prior to the start of experimentation, and to the fact that the experiments have, in large part, been carried out on a variety of sites which precludes comparison of data.

2.4(iii) Studies on the evolution of a soil from raw mineral particles in a desert environment.

To the author's knowledge, no previous work has been carried out on the effects of anthropogenic processes causing the transformation of raw mineral particles, or 'pre-soil', into a soil having biological properties. The sand stabilisation project at Al Hasa provides a unique opportunity to undertake such a study under a given set of environmental and anthropogenic conditions.

PART TWO

CASE STUDIES

CHAPTER 3

The effects of horticultural practises and traditional date cultivation on soil characteristics, Ras-al-Khaimah

3.1 The Physical Environment

The lowland area of Ras-al-Khaimah is mainly composed of sedimentary deposits derived from erosion of the Ruus-al-Jibal/Hajar highlands to the east (fig.2). The latter rise to a height of over 2000 metres and are mainly composed of limestones, dolomites and marls of Permian to Upper Cretaceous age. Erosion of this upland area has taken place in several stages and this has resulted in a complex sequence of outwash deposits. The effects of Quaternary events on soil development have been summarised by Stevens (1969a).

In the area under study, there are two types of outwash - the outwash fans that have coallesced and been modified to form the Jiri Plain, and the smaller, well-defined fans that occur along the mountain edge, north of Habhab. The erosion of the uplands, and the subsequent transportation of the eroded material, was most marked during pluvial periods. This according to Butzer (1963), corresponded to the Wurm Early Glacial period in Europe. After the pluvial period, as the climate became progressively drier and/or hotter, evaporation of a high water table resulted in the formation of gypsum crusts, relics of which can still be found further south on the Gharif and Madam Plains. At the same time, occasional heavy rainfalls resulted in the erosion of the outwash fans causing them to become deeply trenched while the fine sediments (silts and clays) were

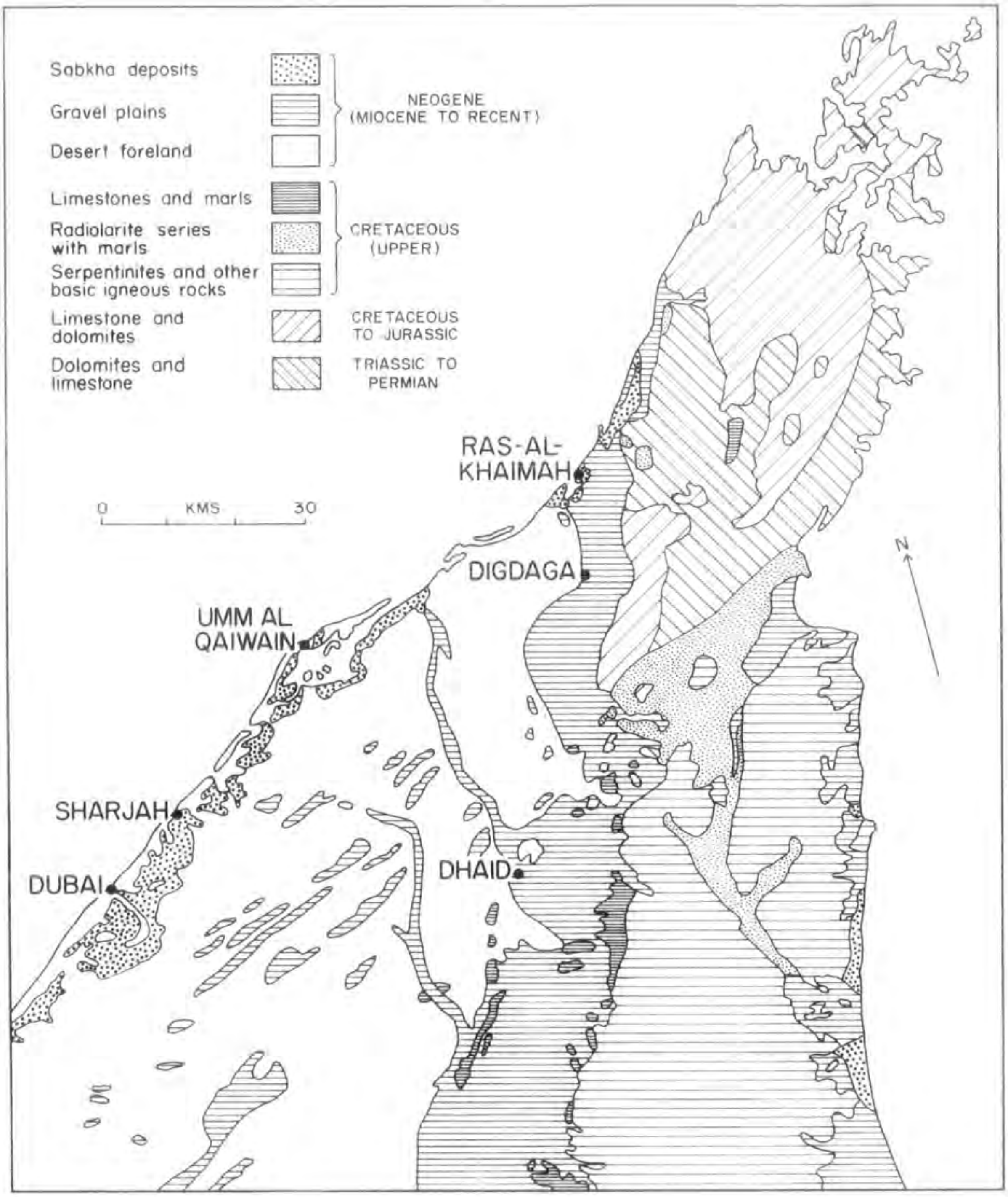

Fig.2
The Geology of Ras-al-Khaimah (based on Sir W.Halcrow and Partners, 1969)

deposited further west. A period of aeolian activity then followed which resulted in the partial infilling of the erosion gullies while sand dunes, encroaching from the west, partially covered the fine deposits. The main infilling of the erosion gullies, however, took place during a sub-pluvial period, occurring probably in Neolithic times (Butzer, 1961), when there was a partial return to conditions when rainfall was more effective. The material that infilled the gullies was washed off the surface of the outwash fans. This sub-pluvial period was also probably responsible for the well-defined outwash fans that occur north of Habhab. The fans show no evidence of erosion and slopes of these outwash fans (8-10^{o}) are appreciably greater than those occurring over the Jiri Plain (less than 3^{o}). The surface of the Jiri Plain has become further smoothed by aeolian activity that has prevailed since the sub-pluvial period, accompanied by limited sheet-flow. The sand dunes have further encroached with the result that the finest outwash deposits are now entirely covered by sand dunes. The Jiri Plain thus consists almost entirely of the coarse and medium textured outwash deposits and the restricted areas of heavy textured material found along the western edge of the plain reflects contemporary deposition by limited sheet flow across the plain.

North of Digdaga and Fahlain, the area between the outwash fans, formed during the sub-pluvial period, and the sand dunes is ill-drained and made up of heavy textured sediments, silts and clays. These deposits are both saline and alkaline, and reflect a former inland extension of the Ras-al-Khaimah lagoon which is now only a fraction of its former size.

This part of the Arabian Peninsula has a hot arid desert climate with high summer temperatures and warm winters with some rainfall. There are, however, no long term meteorological records for Ras-al-Khaimah - a rain gauge was only installed at Digdaga Agricultural Station in 1959 with additional equipment being added in the mid-1960s. However, at Sharjah, some 75 kms from Ras-al-Khaimah but also on the Arabian Gulf Coast, a full range of meteorological observations have been kept since 1950, while rainfall records date back to 1934.

The coldest months at Sharjah are December and January with mean minimum temperatures of about $7^{o}C$, while July and August are the hottest months with mean maximum temperatures of about $43^{o}C$. Temperatures below $0^{o}C$ have not been recorded at Sharjah but the station at Digdaga, about 12 kms inland from Ras-al-Khaimah, recorded a temperature of $-0.6^{o}C$ in February 1967. With increasing distance from the sea the frequency of occurrence of such temperatures will undoubtedly increase. A consequence of the high summer temperatures is that the Arabian Gulf is noted for its high humidities, though it has been suggested (Sir W. Halcrow and Partners, 1969) that the highest relative humidities occur during the winter months. Nonetheless, high summer humidities can make summer working conditions very difficult especially during the months May to October inclusive. There is also a high rate of evaporation during the summer months and a U.S. Weather Bureau Class A pan was installed at Digdaga in 1966.

Table 3.1

Rainfall Characteristics, Sharjah and Digdaga (Ras-al-Khaimah) 1968-1969.

		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Sharjah	Rainfall	-	-	25.3	109.1	0.2	-	5.2	-	Tr	-	Tr	Tr	139.8
	Rainy Days	-	-	1	7	1	-	3	-	-	-	-	-	12
Digdaga	Rainfall	-	-	50.3	65.8	-	-	2.5	-	-	-	-	-	118.6
	Rainy Days	-	-	3	8	-	-	1	-	-	-	-	-	12

Rainfall figures in mms.

Source: Hydrologic Year Book 1968/69. Trucial States Council, 1970.

The average daily evaporation rates (in mms) over the period October 1966 - September 1969 have been as follows:-

	O	N	D	J	F	M	A	M	J	J	A	S
Evaporation (mms)	8.0	6.1	4.2	4.0	4.3	7.2	8.2	10.5	11.9	13.1	12.0	10.0

In no month did rainfall exceed the evaporation as recorded by the pan.

The average annual rainfall at Sharjah amounts to about 103 mms falling mainly in the months November to May. There are great annual variations which have ranged from 0.3 mms in 1961/62 to over 258 mms in 1956/57. Much of this rain falls as localised showers and a rainy day at Sharjah does not necessarily mean that rain will fall at Digdaga (table 3.1). Furthermore, because of the localised nature of the rainfall, there are considerable disparities in annual rainfall totals between the two stations (table 3.2).

Sandstorms can also have an important effect on agriculture and these mainly occur between January - March and August - October. Hutton (1964) considered that a windspeed of 17-18 knots was sufficient to move loose sand, while once the windspeed exceeded 20 knots then a true sandstorm developed. Such winds are most common in March when the predominant wind direction is W or WNW and consequently the agricultural areas of Ras-al-Khaimah tend to be affected by blown sand derived from the desert to the west.

The cultivated area of Ras-al-Khaimah is shown in fig.3. The oldest forms of cultivation are the date gardens which are located around the villages of Ḥabhab, Khatt and Fahlain, and also

Table 3.2

Annual rainfall, Sharjah and Digdaga

Year	Annual rainfall - mms	
	Sharjah	Digdaga
1959/60	47.6	138.0
1960/61	89.3	149.7
1961/62	0.3	51.7
1962/63	227.9	158.7
1963/64	127.6	195.5
1964/65	122.9	153.2
1965/66	60.8	61.0
1966/67	11.5	17.5
1967/68	81.8	66.6
1968/69	139.8	118.6

Sources: Trucial States Council data

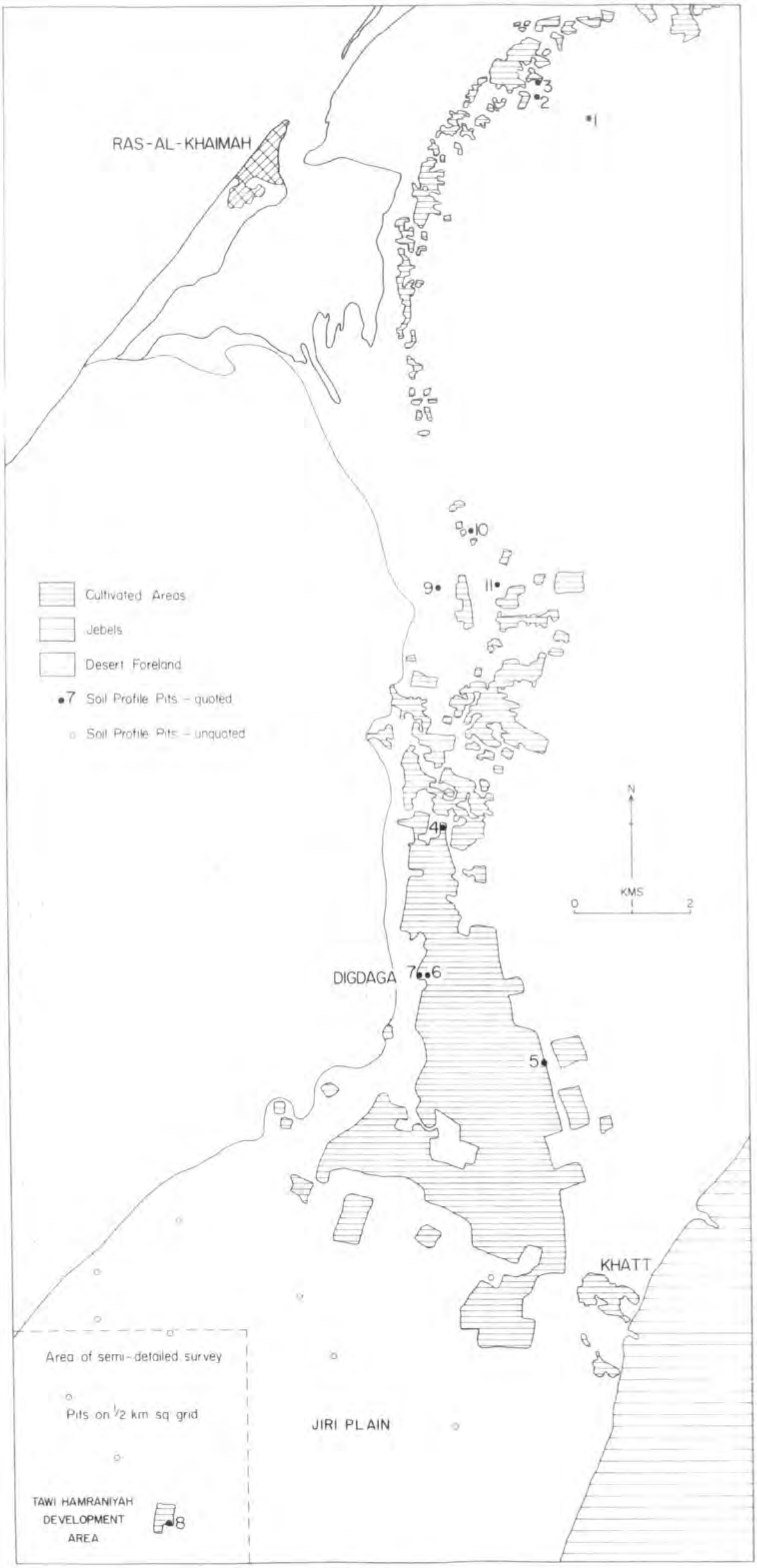

Fig.3

Cultivated area of Ras-al-Khaimah (1967) showing location of soil profile pits in a crescentic arc on the edge of an outwash fan adjacent to the extension of the lagoon. Some of these gardens have probably been cultivated for many hundreds of years for Ras-al-Khaimah is an old settlement and port-excavations there have revealed the presence of potsherds dating back to at least the 13th century A.D. Irrigation water for the date gardens was mainly derived from sub-surface flow, through the gravel fans. This reflected run-off from the mountains and consequently tended to be unreliable. Furthermore, it had to be at shallow depth so that it could be exploited by primitive lifting devices. However, between Khatt and Habhab, a falaj (Falaj Usayli) was constructed, while the date gardens of these two villages were additionally irrigated by spring water. The spring water is hot, about 39°C compared with temperatures of about 30°C for groundwater beneath the outwash plains, and issues from limestone of Jurassic-Cretaceous age. Whilst no significant diurnal or seasonal variations in water temperature have been observed, the salinity fluctuates between 2.3 and 2.9 mmhos/cm (Sir W. Halcrow and Partners, 1966).

The shallow groundwater and the springs only provided irrigation water sufficient for the traditional forms of agriculture. With the recent rapid development of agriculture, the traditional sources of water were no longer adequate and new sources of supply were essential. These have been discovered by Sir W. Halcrow and Partners in the sediments of the Jiri Plain which are composed of thick deposits of gravel alternating with silty and sandy horizons. Groundwater is generally found

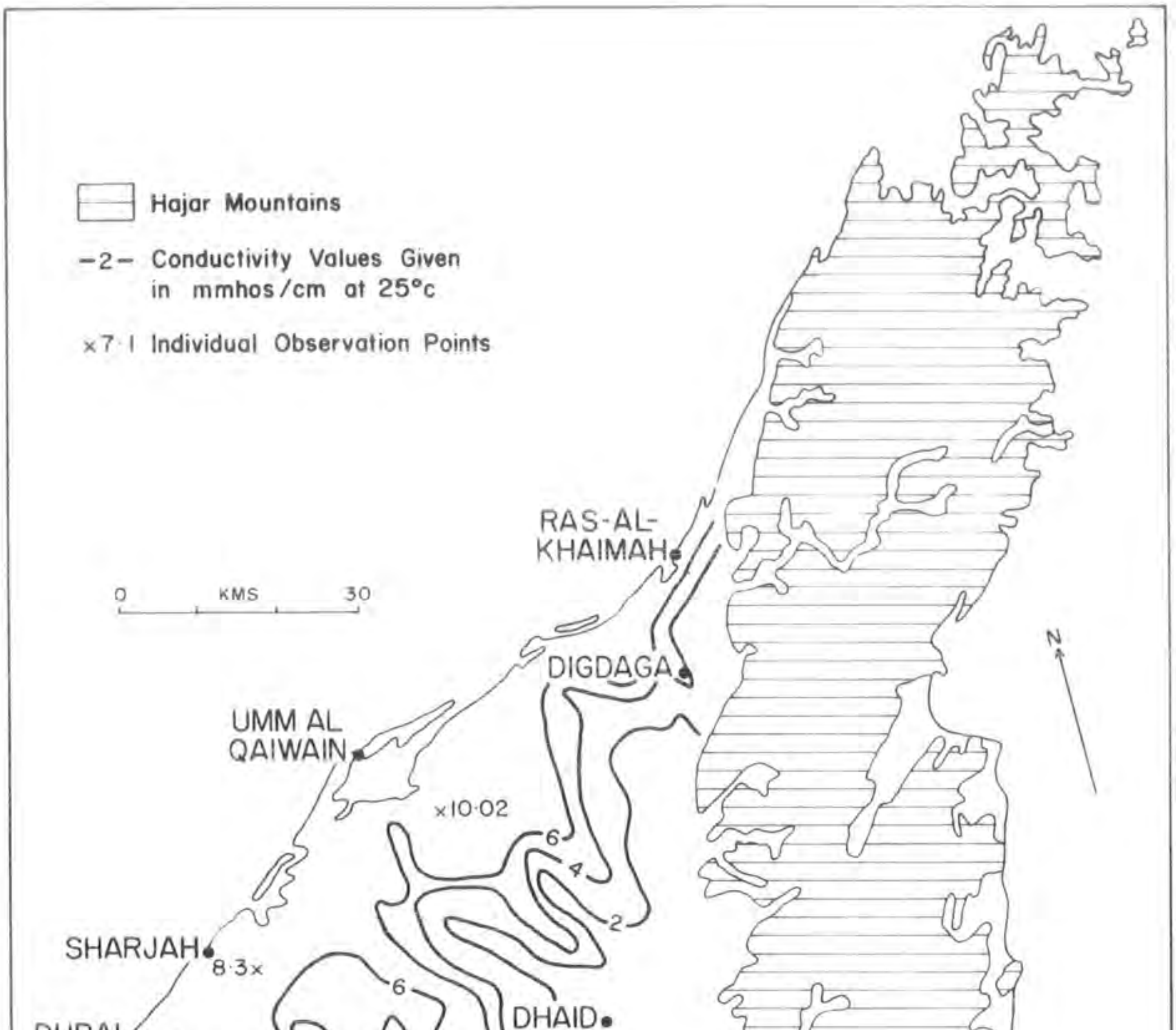

Fig.4
Groundwater salinity, Ras-al-Khaimah

at depths of less than 50 metres above an aquiclude formed by calcium carbonate cementation. This groundwater is recharged by runoff from the mountains - it is disgorged by the mountain wadis onto the outwash plains where it quickly sinks below the surface to replenish the aquifers. In periods of exceptionally heavy rainfall, the runoff may flow right across the Jiri Plain to be ponded up against the sand dunes. It slowly evaporates or infiltrates into the soil leaving behind silt deposits.

As the subsurface flow approaches the coast, not only does the gradient of flow decrease but also the water becomes more saline (fig.4). This increase in salinity is the result of a number of factors. The groundwater not only takes up soluble salts present in the outwash deposits, but also the rapid development of agriculture has emphasised the salinization process. Recirculation of irrigation water, especially in the Digdaga - Fahlain area has caused an increase in salinity (though short term monitoring by Sir W. Halcrow and Partners, 1969, gives conflicting evidence) while in certain situations there has been a local lowering of the water table. This could be potentially very dangerous for there could be a reversal of the hydraulic gradient - at the Agricultural Trials Station the groundwater table is only about 3 metres above mean sea level.

3.2 Agriculture

The cultivated area of Ras-al-Khaimah has expanded enormously since the mid-1950s, some indication of the rate of this expansion

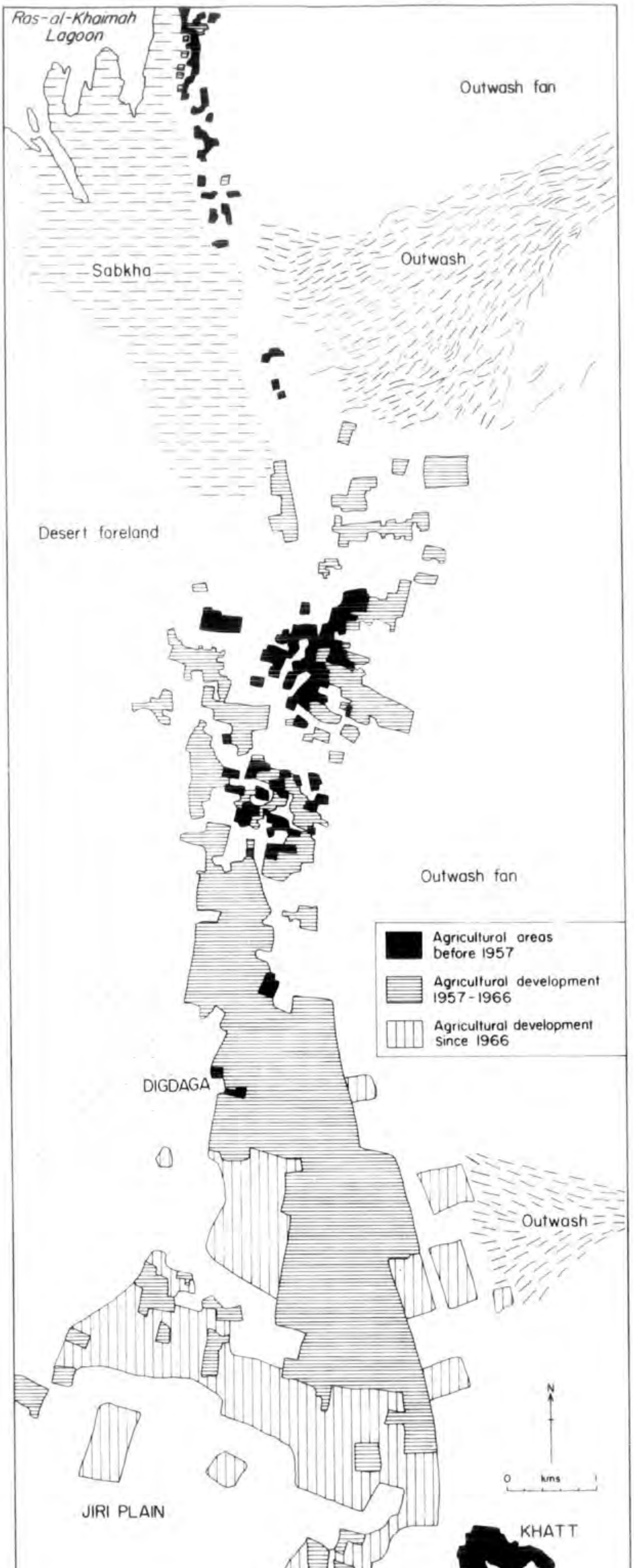

Fig.5
Agricultural expansion, Ras-al-Khaimah

being evident in fig.5. When the Agricultural Trials Station was established at Digdaga in 1954, the only agriculture practised on any scale was the cultivation of date gardens. Agricultural practices have changed little in these traditional gardens over the centuries - dates are the dominant crop grown though a few citrus and banana trees may also be cultivated for subsistence and limited exchange functions. Only very small areas are given over to vegetables, again for subsistence, while some fodder grasses are grown under the date palms for livestock. Livestock (cattle, sheep and goats) are usually kept under the shade of the date palms, especially during the hot summer months, and it would be during this period of the year that the date gardens would receive most of their organic manure. Some of the more enterprising owners have applied dried fish, of the sardine variety, to individual palm trees, while others buy in animal manure from the hill tribes. Irrigation water is applied at monthly intervals during the winter, but in summer the rate of application is somewhat greater, about once every 7-10 days.

Commercial smallholdings have become established since the early 1950s and they now make up the majority of the cultivation units. Their development has been stimulated by the growth of urban markets in the Gulf area, notably at Abu Dhabi, Dubai and Sharjah, though now some fresh produce is air freighted further afield. These commercial units have concentrated on the cultivation of vegetables with only limited dependance on tree crops. One or two of the more progressive smallholders are now devoting a major proportion of their holdings to tree crops including citrus, bananas, dates, pomegranates, apples, almonds and vines. For the successful economic cultivation of these crops, rather more sophisticated expertise is required, including attention to irrigation rates and correct fertiliser and manurial programmes.

However, most of the 'new' smallholders devote most of their holdings to the cultivation of vegetables and other ground crops. The size of an individual holding is generally less than 10 hectares, though an owner may operate more than one holding. Irrigation water is supplied by pump and distribution within the holding is usually by unlined channels. The maximum range of crops is grown in winter, including tomatoes, aubergines, cabbages, cauliflowers, lettuces, onions, potatoes, carrots, marrows, herbs and peppers. In winter, it is very rare for less than 35% of a holding to be cropped and as much as 65% of the area of a holding may be under vegetables. The situation is very different in summer when usually no more than 40% of the holding is given over to crops, mainly cucurbits and melons. In some cases the proportion of cropped land may be as low as 10%. The main reason for this low proportion of summer cropping is that, because of the high evapotranspiration rates and the general high porosity of the soils, the pumps cannot supply more than a small proportion of the holding with sufficient irrigation water. However, it would seem that a greater proportion of the holding could be cultivated, both in summer and winter, if there was a willingness on the part of the smallholder to use new ideas and techniques. It is the commercial smallholders who have benefited most from the proximity of Digdaga Agricultural Trials Station - the latter has been important in introducing new crops, in seed selection and in carrying out fertiliser trials. As a result, most of the smallholders now apply ammonium sulphate to 'leafy' vegetables such as cabbages, in order to alleviate the low nitrogen status of the soil. Organic manures are also applied, being mainly obtained from local Bedu or hill tribes, while one or two cultivators also use humus imported from the Lebanon. A very recent feature has been an increasing use of urea by the more progressive farmers.

3.3 The effects of cultivation practices on soil characteristics

3.3(i) Uncultivated soils

In a reconnaissance survey of the soils of the Trucial States (Bowen-Jones et.al. 1967), the soils of Ras-al-Khaimah were classified in three major groups - sierozems, non-saline alkali and saline-alkali soils. These groups were subdivided into lower categories on the basis of their texture and carbonate content. This was an artificial classification scheme but it was suitable for the type of reconnaissance survey undertaken, in that the categories were descriptive of the soils and highlighted their salient features in terms of their effect on potential cultivation. Most of the 140 soil profiles examined in the field by the author were of uncultivated soils and little consideration was given as to how the soils might change as a result of cropping, except such major criteria as salinity or alkalinity. Furthermore, the classification scheme was devised for local use within the

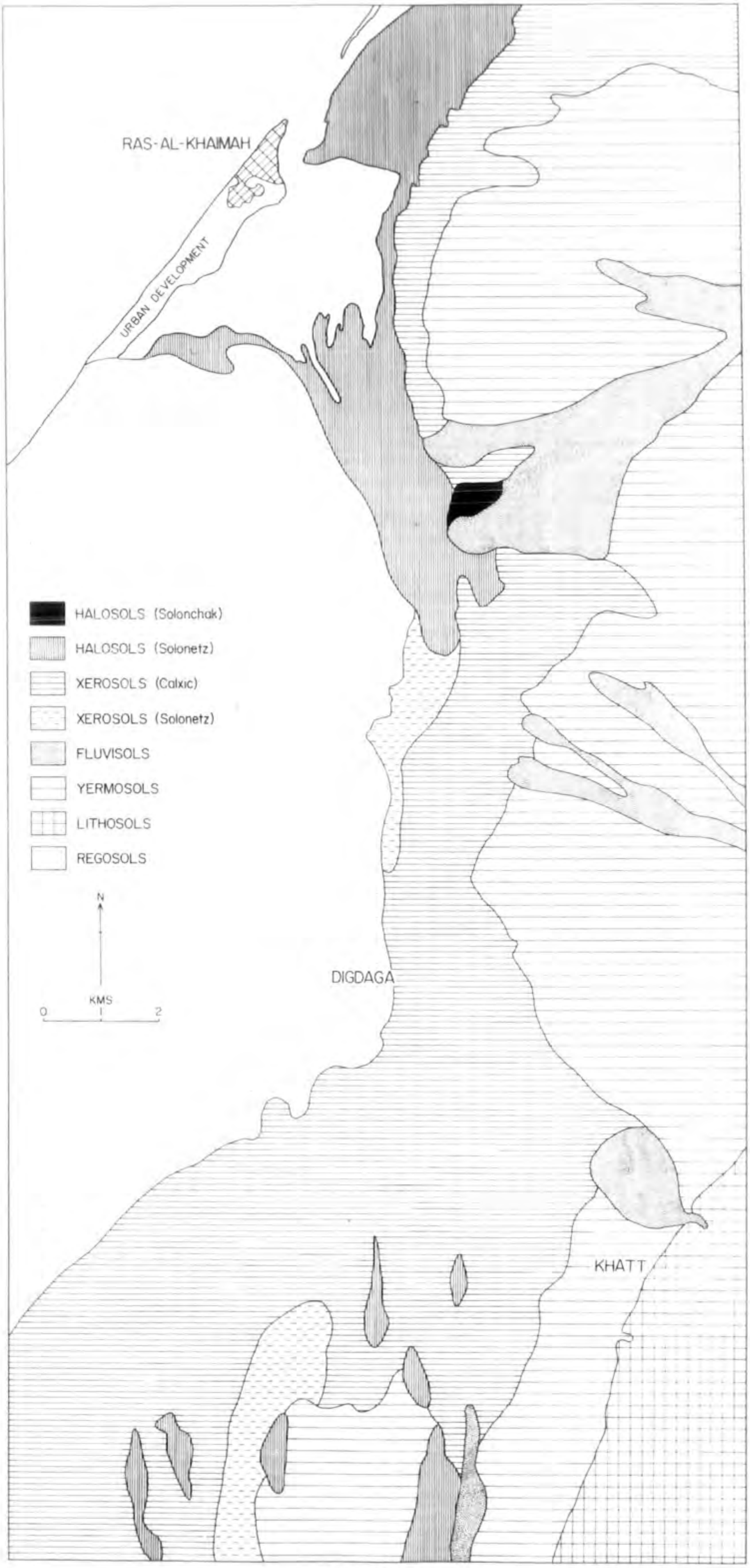

Fig.6
Major soil groups, Ras-al-Khaimah

Trucial States and, as such, is not suitable for comparison with other areas.

In order to overcome this latter objection, the soils have been reclassified according to the FAO/UNESCO scheme and the distribution of soil orders and units is shown in figure 6. This reclassification was not possible in the original survey as the analytical data from most of the 31 profiles sampled for this study were not available. The soils of the Jiri Plain are basically xerosols having organic matter contents in excess of 0.5%, reflecting the sparse cover of Haloxylon salicornicum. The soils are generally of light texture and have a weak angular blocky structure in close proximity to the surface which consists, where undisturbed, of a thin platey crust. Gravel horizons often occur within 50 cms of the surface. The xerosols are characterised by moist colours of 10YR4/3 - 4/4 (dark brown), pH values of below 9.0 and conductivities less than 1 mmhô/cm at 25°C. The cation exchange capacity is dominated by the calcium cation, though in some profiles there is an increase in exchangeable magnesium at depth. A typical example is profile pit 5. A belt of heavier textured xerosols is found along the western edge of the plain and these support stands of Prosopis spicigera trees, as for instance, around Tawi Hamraniyah. These stands are able to survive because the heavier texture of the soils allows moisture to be retained for much longer periods of the year. In both types of xerosols, pedogenic horizons are weakly developed.

Halosols occur in two distinct situations. The main area represents the former extension inland of the Ras-al-Khaimah lagoon.

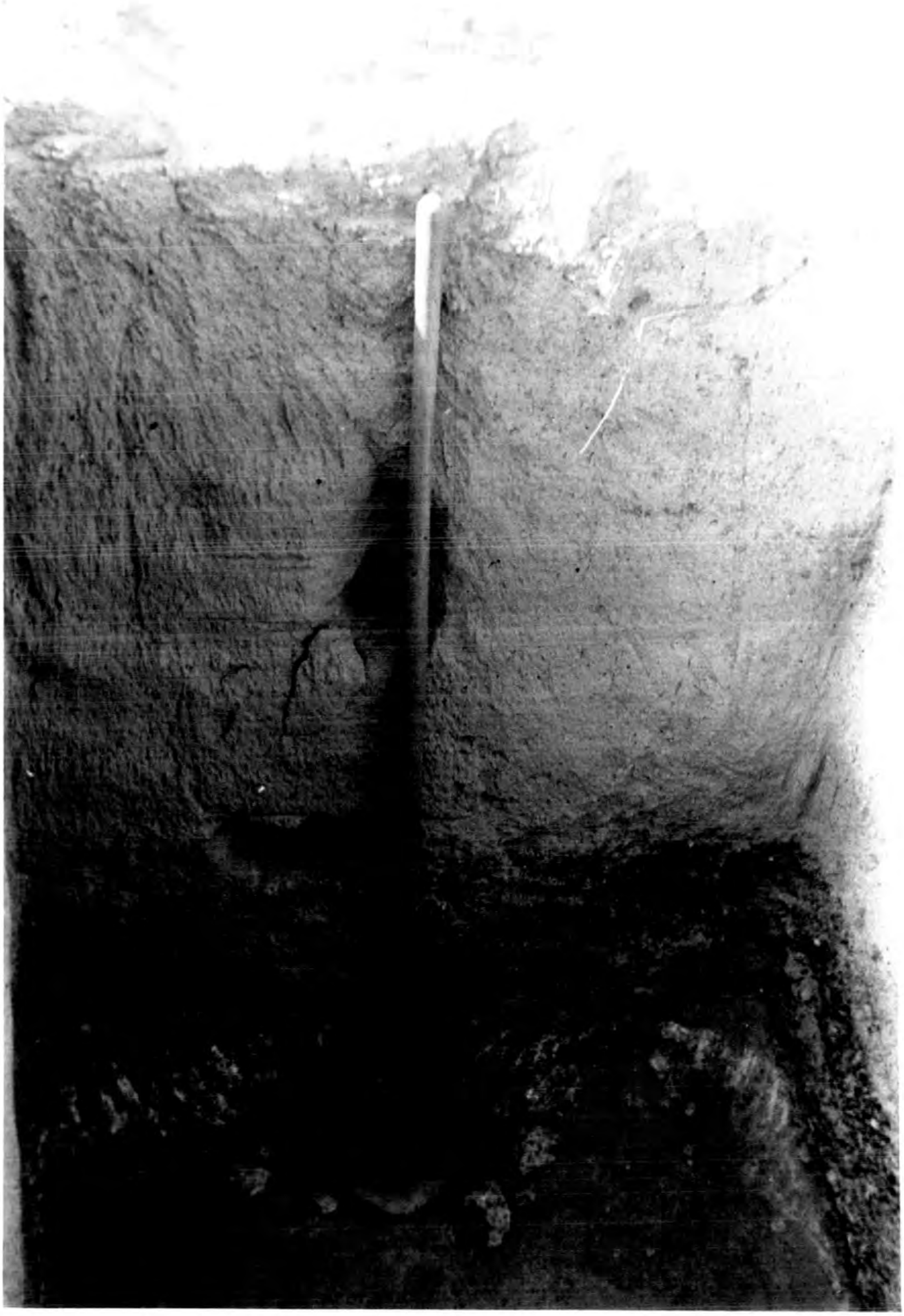

Plate 3

Typical Calxic Xerosol, Jiri Plain, Ras-al-Khaimah. Characteristics include weak structural development, coarse texture and low organic matter contents in the surface horizons. Note the calxic horizon at depth, which is overlain by depositional horizons of fine gravel.

Solonetz (saline-alkaline) soils predominate and in addition to conductivities often in excess of 10 mmhos/cm at 25°C, the exchangeable sodium percentage (ESP) frequently exceeds 25. These soils are of heavy texture (e.g. profile pit 9), have a low permeability and are consequently moist for the entire year. They occupy the lowest parts of the landscape but coarser textured halosols are associated with the slightly higher ground on the edges of the outwash fans. Halosols are also found on the Jiri Plain. On air photographs they appear as dark patches, devoid of vegetation, in discontinuous strips which probably represent eroded remnants of old outwash fans partially covered by more recent deposits. These halosols tend to be of coarse texture and are of the solonchak (saline) type and further south on the Gharif Plain may contain gypsic horizons.

Yermosols and regosols are also present in Ras-al-Khaimah. The former are found on the outwash fans adjacent to the Ruus-al-Jibal highlands. These outwash fans are mainly composed of coarse rudaceous deposits with carbonate contents well in excess of 50%, reflecting the origin of the outwash in the limestone uplands. Pedogenic horizons are even more weakly developed than with the xerosols, moisture retention is very low, but organic matter contents of the soil are usually in excess of 0.25% due to the scattered Acacia bushes and grass species. The former have extensive root systems and are able to tap the deeper moisture while the grass species are associated with the seasonal wadis. In contrast, the regosols are associated with the sand dunes of the Desert Foreland. Vegetation is very sparse

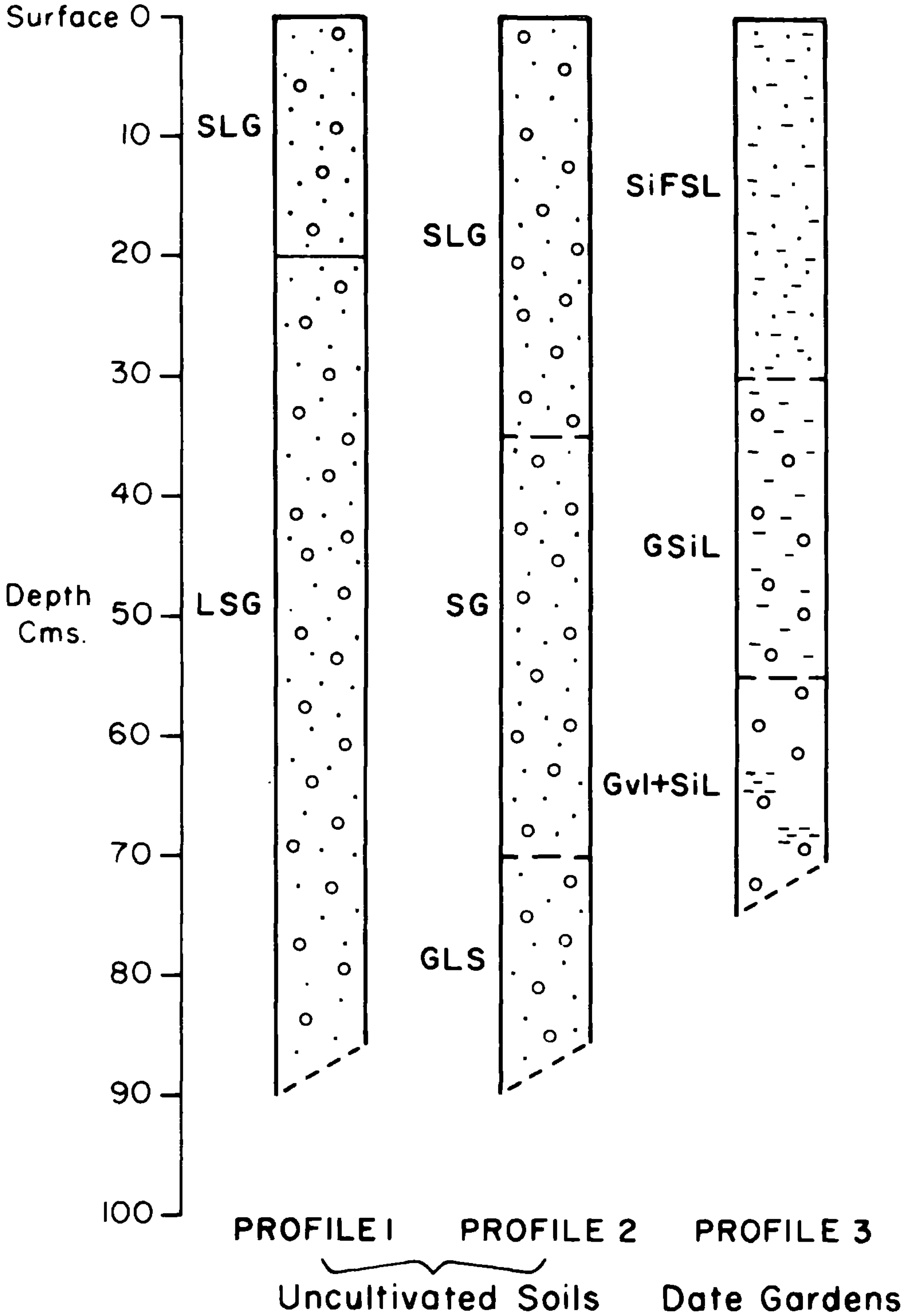

Fig.7
Soil profiles in a depositional sequence, Shimal, Ras-al-Khaimah

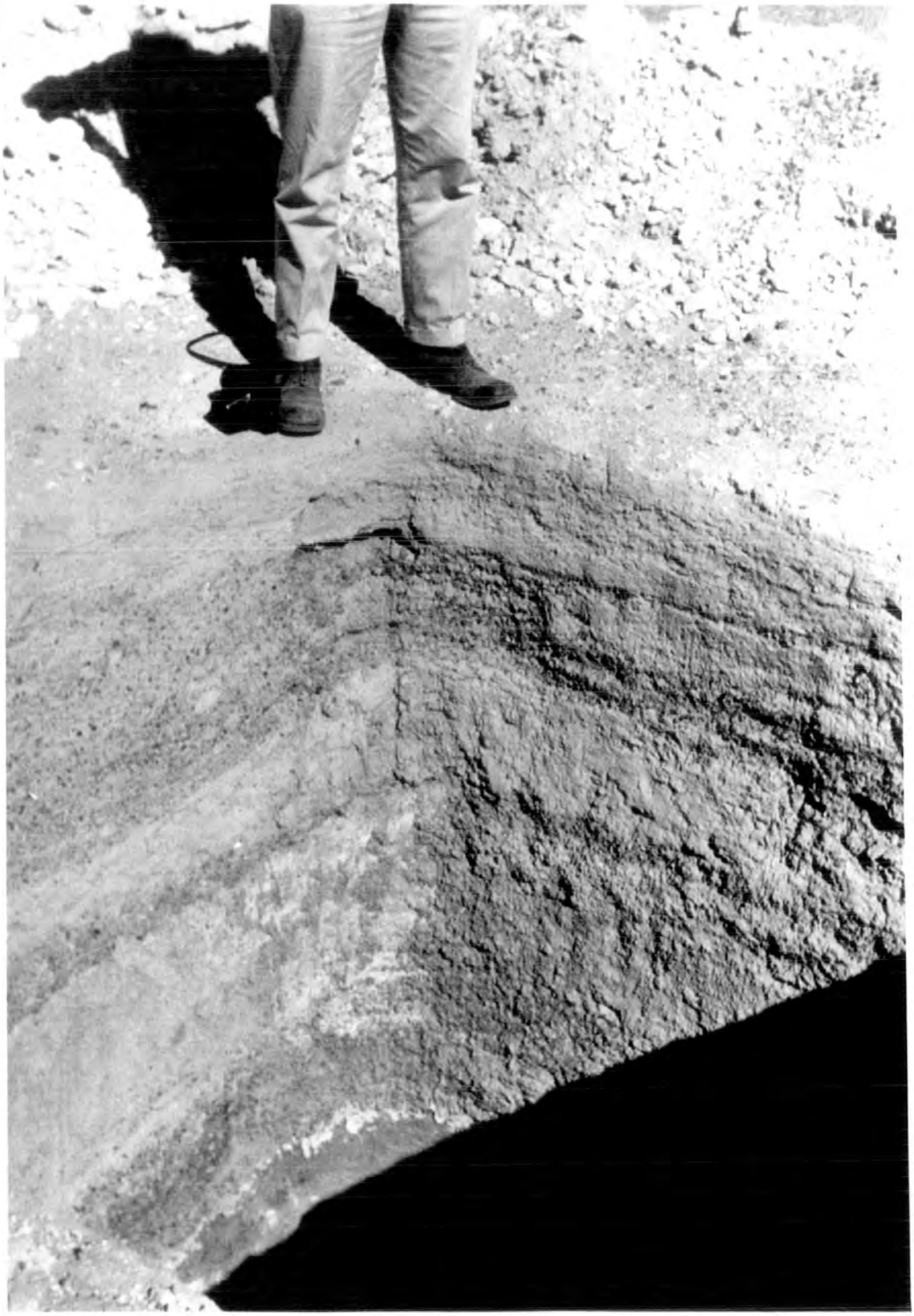

Plate 4

Typical Fluvisol on edge of Jiri Plain, near Khatt, Ras-al-Khaimah. While of limited distribution, the depositional characteristics of the horizons are clearly evident. The salt accumulations immediately above the shadow at the bottom of the photograph are from well water and not the soil.

and organic matter contents are less than 25%. Single grain structure predominates, profile morphology is lacking and the 'soils' are subject to windblow.

3.3(ii) The effects of date cultivation on yermosol/xerosols.

The effects of different cultivation techniques on soil characteristics discussed in this section and the following one (3.3iii) are based on the laboratory analyses and field data derived from 31 soil profiles (10 cultivated) that were sampled in the field by the author. The author carried out routine soil analyses on 114 samples while, in addition, there was field evidence from a further 109 profiles. This included routine profile descriptions and in most cases determinations of pH and electrical conductivity. The material derived from these sources has not been interpreted previously, for a study of this nature.

In contrast to other parts of the Arabian Peninsula, the date gardens of Ras-al-Khaimah, particularly those between Hail and Shimal, are well tended. There is little evidence of disease while few of the trees are old. The palms are spaced at sufficient intervals to allow full development of the palm to take place. The date gardens are located on the edges of the outwash fans where the coarse rudaceous outwash has some finer material deposited on top, the soils being classified as either yermosols or xerosols. Representative profiles showing the nature of these deposits are shown in figure 7, the location of pits being shown on figure 3.

The date gardens were originally located to take advantage of the finer deposits on the edges of the outwash fans. However, laboratory analyses by the author would suggest that subsequent irrigation over long periods has led to a redistribution of this fine material within the profile for there has always been a tendency to over-irrigate. This redistribution of fine material is marked in most cultivated profiles (e.g. profile 3) where, although silt and clay are present throughout the profile, the large cobbles in the gravelly silty loam horizon, at a depth in excess of 75 cms, have accumulations of silt on their upper surfaces. In addition to the redistribution of fine material, the irrigation water also adds a small quantity of insoluble residues to the topsoil and, though there is eventual downward translocation, there is a tendency for there to be an increase in the fine fractions of topsoil samples. This is shown in table 3.3.

A major affect of cultivation has been to increase the organic matter content of the soil (table 3.3). At any one time the amount of organic matter present in the soil represents a balance between the addition of undecomposed organic material and the processes of decomposition, and consequently there will be seasonal variations. As decomposition proceeds, losses first fall on the carbonaceous parts of the organic material and, when the organic material is well humified, as in the uncultivated profiles, the C:N ratios appear to be of the order of 10-13 in topsoil samples. Under cultivation, the C:N ratios of the surface horizons are wider (18-20) because there is the periodic addition

Table 3.3

Analytical Data: Shimal and Digdaga Date Gardens located on yermosol/xerosol soils

	Cultivated Date Gardens						Uncultivated		
Pit	Pit 4 (Fahlain)			Pit 3 (Shimal)			Pit 2 (Shimal)		
Sample Depth (cms)	15-21	42-48	100-106	15-21	39-45	70-75	10-16	39-45	84-90
+Silt %	18.2	11.0	7.6	22.4	24.4	9.0	10.0	1.0	5.0
+Clay %	19.2	14.8	9.8	17.2	22.8	22.8	7.8	1.8	1.8
Carbonates %	54.0	57.5	60.0	58.0	57.0	61.5	73.0	76.0	77.5
pH	8.60	8.60	8.65	8.60	8.55	8.60	8.80	8.60	8.80
Conductivity (mmhos/cm)	0.85	0.38	0.38	1.13	1.29	0.81	0.17	0.17	0.19
E.S.P.	11.5	10.2	20.5	17.1	11.6	13.3	11.4	11.8	9.9
Organic Matter %	1.27		0.21	2.02		0.38	0.93		0.18

+ Silt and Clay are expressed as percentages of the fine earth sample (International limits).

of organic matter from the date palms, ground crops, weeds and livestock. Biological activity is also very different in the cultivated soils due to the profound change in soil climate. For instance, in each of the two profiles sampled in the date gardens, the author observed the presence of a species of small worm - such activity is totally absent in the hot, dry uncultivated profiles. By such activity, through the decomposition of old root systems in situ in the soil, and also as a result of the downward percolation of irrigation water, organic matter is not restricted to the top few centimetres of the soil profile but can occur at considerable depths. In profile pit 4 (Fahlain), channels of grey mineral matter having an organic matter content of 1.2% (in contrast to values of 0.21% for the surrounding soil) were observed down to depths of at least 1 metre.

The increase in organic matter also influences two other soil characteristics:

(i) The structure of these long cultivated soils is noticeably different from that of the surrounding uncultivated soils. The structure of the latter consists of weak angular blocks which break down to unaggregated material. In contrast, as a result of the organic matter, the structure of the topsoil of cultivated soils tends to consist of moderate medium angular blocks which break to small angular blocks and granules. Even under irrigation, there is a noticeable stability of structure in these cultivated soils.

(ii) Decomposition of organic matter releases acids and these appear to have caused a certain amount of decalcification to have taken place. The outwash, on which the soils have developed, is predominantly derived from the limestone uplands and, in the area around Shimal, uncultivated yermosol profiles have carbonate contents of about 70% (table 3.3). However, cultivated profiles have carbonate contents of less than 60% in, at least, their top 50 cms, though there is some increase in their carbonate content at depth. Brammer (1968) commented on the decalcification of Gangetic alluvium in East Pakistan and he ascribes this process to the reducing conditions that prevail during seasonal flooding. $CaCO_3$ is transformed into $Ca(HCO_3)_2$ in the presence of organic matter and remains in solution due to the flood conditions. Different rates of decalcification are due to the variable levels of organic matter, the length of flooding and to biotic mixing of the soil. A similar process could contribute to decalcification of the soils of the date gardens for, despite their characteristic of free drainage, the irrigation regimes practised by the owners mean that the soils are flooded at regular intervals and during these periods reducing conditions will prevail. While a slight reduction in pH values is also noticeable in these cultivated soils, values still remain above 8.5.

Sir W. Halcrow and Partners (1969) in their water resources survey of the Trucial States classified water from wells and pumps between Hail and Shimal as being of either C_4S_4 or C_4S_3 categories, i.e. having a very high salinity hazard and a high or very high alkalinity (sodium) hazard. Such irrigation water is not suitable for irrigation under normal conditions and even on these very freely draining outwash deposits there has been some increase in soluble salt content, as measured by conductivity and ESP (table 3.3). Neither has, however, increased to such an extent that the growth and productivity of the date palms have been affected, even though cultivation is of undoubted antiquity, since the groundwater table is at sufficient depth not to interfere with the root growth of the palms.

3.3(iii) Commercial smallholdings and their effects on the characteristics of xerosol and halosol soils.

The main area where the commercial smallholdings are situated lies between the southern extremity of the Ras-al-Khaimah lagoon and the village of Khatt, though much of the recent expansion of agriculture over the last five years has been on the Jiri Plain. This agricultural development has mainly taken place on the xerosols and some solonchak halosols, the latter in the vicinity of the Ras-al-Khaimah lagoon. As has been seen previously, this development is of very recent nature and it would not be expected that radical changes should have taken place in the soil. What changes have occurred relate to organic matter contents, the salinity and the alkalinity of the soils.

With cultivation, the initial disturbance of the soil destroys the surface crust and the weak structure of the topsoil allowing the rapid oxidation of any organic matter present. This is reflected in the topsoil sample (10-16cms depth) from profile pit 6 where the organic matter content was only 0.28% about a week

Table 3.4

Comparative data for uncultivated and cultivated xerosols, Digdaga Agricultural Trials Station (sampled 1967)

Depth cms	Profile 6 - uncultivated			Profile 7 - cultivated		
	Silt & Clay[1] %	Conductivity mmhos/cm	E.S.P. %	Silt & Clay[1] %	Conductivity mmhos/cm	E.S.P. %
10-16	20.6	0.21	5.1			
15-21				23.8	1.16	14.3
39-45	24.1	0.29	4.7			
45-51				26.9	2.40	16.7
75-81				21.8	2.11	28.4
78-84	19.5	0.21	4.8			
94.100				20.0	1.50	15.0
105-111	19.8	0.20	5.3			
120-126	21.2	0.21	9.4			
134-140				21.4	1.53	8.5

[1] Silt and clay - International limits (0.02 mms) - excludes carbonate content

after it had first been cultivated. Over a period of time, the net effect of cultivation is to increase the level of organic matter present in the soil, though the amount of this increase will be related to the type of crop grown. Profile pit 8 was located on a smallholding in the middle of the Jiri Plain in a plot that had grown vegetables for 6 years prior to sampling and the topsoil sample (8-14 cms) had an organic matter content of 1.33%. This figure compares to an average value for the topsoil samples of 11 uncultivated xerosol soils on the Jiri Plain of 0.99%.

The most rapid changes in soil characteristics can occur when irrigation water of poor quality is used and both the soluble salt content and the alkalinity can rapidly increase. These effects are accentuated when internal soil drainage is poor, due to the presence of heavy textured horizons within the profile, or if the soil occupies a low position in the landscape. Comparative data for two xerosol profiles (pits 6 and 7) located on Digdaga Agricultural Trials Station show these effects quite clearly (table 3.4). The high ESP value of 9.4 (relative to the higher horizons) recorded for the uncultivated profile at a depth of 120-125 cms probably reflects the location of the profile pit in a topographic depression quite close to the Ras-al-Khaimah lagoon and sea water may have moved inland by subsurface flow as a result of a local drawdown of the fresh water table. Also recirculation of the irrigation water may have caused an increase in salinity in the groundwater table. At the time of sampling (January 1967), the irrigation water had a conductivity of 3.4 mmhos/cm at 25°C and its salinity had apparently been increasing for

Table 3.5

Characteristics of cultivated and uncultivated halosols. Profile 11 was located in a plot going out of cultivation

	Profile 9			Profile 10				Profile 11			
	Uncultivated			Profile formerly cultivated				New cultivation			
Sample Depth (cms)	5-13	30-38	112-120	7-15	37-45	77-85	100-108	7-15	35-43	92-100	125-133
% Silt and clay[1]	44.9	77.4	89.9	24.6	31.5	27.6	64.3	16.7	36.6	40.4	13.6
% $CaCO_3$	55.0	46.0	46.0	75.0	57.5	39.5	37.5	59.5	55.0	53.0	50.0
Exchangeable Na[2]	4.1	8.4	8.2	1.3	4.2	6.8	9.7	1.1	2.8	2.3	1.2
E.S.P.	28.9	26.6	26.2	12.2	30.0	34.4	34.8	10.2	21.9	16.0	24.5
Conductivity[3]	9.98	9.35	11.10	0.29	1.26	1.74	8.29	2.96	4.09	5.23	2.68

1 International limits

2 meq/100grms

3 mmhos/cm at 25°C.

a number of years. Two factors allegedly were responsible for this - recirculation of irrigation water caused by the increasing number of smallholdings in the vicinity and/or local drawdown of the water table, again caused by the expansion of agriculture, so that more saline water was being tapped. However the quality of the irrigation water has not further deteriorated and the trend may even have been reversed (Sir W. Halcrow and Partners, 1969). The area in which pit 7 was located was capable of growing squashes and melons in 1967, but by 1969 soil salinity in the topsoil had increased to such an extent that the plot had been given over to the cultivation of tree species, notably Tamarix spp, for windbreaks and amenity areas. A single topsoil sample (4-10 cms) taken by the author in 1969 from this plot had a conductivity of 7.4 mmhos/cm at 25°C.

The halosols which occupy the area of the former extension of the Ras-al-Khaimah lagoon have not been used extensively for cultivation. These soils are poorly draining, with standing water frequently being observed on the surface, and their permeability is not only affected by the silty nature of their texture but also by the high levels of exchangeable sodium (e.g. profile 9, table 3.5). Profiles usually have conductivities in excess of 10 mmhos/cm at 25°C while the levels of exchangeable sodium remain relatively constant throughout the profile, with ESP's above 25. Their carbonate contents of 45-60% are similar to those of the deposits forming the Jiri Plain. However along the eastern edge of the lagoon, more recent outwash of highly calcareous, but non-saline character have been deposited over lagoonal sediments as in the case of profile 10 (table 3.5).

Some of these soils have been taken into cultivation as the surface deposits are relatively freely draining, have low ESP's and low conductivities. There is, however, impedance caused by the underlying horizons being of heavier texture and after a number of years these soils have gone out of cultivation. While the amounts of soluble salts in the surface horizons may have been leached into the lower horizons of the soil solum, there has been a build up in the level of exchangeable sodium to a greater extent than prior to cultivation through the use of irrigation waters having a high alkalinity hazard. In some instances, ESP levels of 30-35% have been recorded and these are intolerable for crop cultivation.

In addition, as agriculture expands, some farmers have attempted to cultivate some of the poorer drained halosols. This situation is exemplified by profile 11 (table 3.5) which was on the point of being taken out of cultivation in 1967. In such soils the levels of both salinity and alkalinity are beyond those generally accepted for crop cultivation and while crops such as beans, radishes and tomatoes might yield for a year or two, agriculture soon becomes impossible. Much of the disused agricultural land in Ras-al-Khaimah is of this type.

For commercial agriculture to be successful in Ras-al-Khaimah the xerosol soils of the Jiri Plain offer the best potential. Over the last five years, there has been the rapid development of agriculture on these soils, for with the groundwater table at a depth well below the rooting depth of any plants likely to be grown, there is little likelihood of salinity being a problem in the near future. Furthermore, with the low cation exchange capacities of the sandy soils having a low content of adsorbed sodium, alkalinity problems are not in evidence. The only problems that are likely to arise are through an over use of the limited supplies of water and a consequent draw down of the aquifer preventing the full area being irrigated.

CHAPTER 4

The effects of date cultivation and recent agricultural development on soil characteristics in a traditional oasis area, Al Ain oases, Federation of Arab Emirates

4.1 The Physical Environment

The Al Ain group of oases lies on the western edge of the Al-Jaww Plain, at the northern extremity of Jebel Hafit which rises to over 1160 metres (figure 8). The oases, often referred to as Buraimi oasis, are located at a height of 270-285 metres above sea level, on outwash derived from erosion of the Hajar mountains. While the latter include some Oligocene and Cretaceous limestones, the core is predominantly serpentinite and consequently the outwash is not so calcareous (less than 40% calcium carbonate content) as that occurring in Ras-al-Khaimah. However, around Jebel Hafit, composed of Tertiary limestones and marls, erosion has produced restricted areas of more calcareous material, containing over 55% calcium carbonate.

Immediately to the west of the oasis area is the Desert Foreland, much of which is characterised by high dunes, up to 70 metres, occurring in ridges with a NE-SW trend. Some of these dunes have impinged on the oasis area; for instance, the date gardens at Mutarad'h oasis lie some 8-10 metres below the crests of the surrounding sand dunes. Furthermore, a belt of low dunes separate the southern oases (Al Ain, Mutarad'h and Muweiqii) from the northern group (Al Jimi, Qattarah and Hili). A third group, of which Buraimi is one, lies in Oman territory but are not being considered in this discussion.

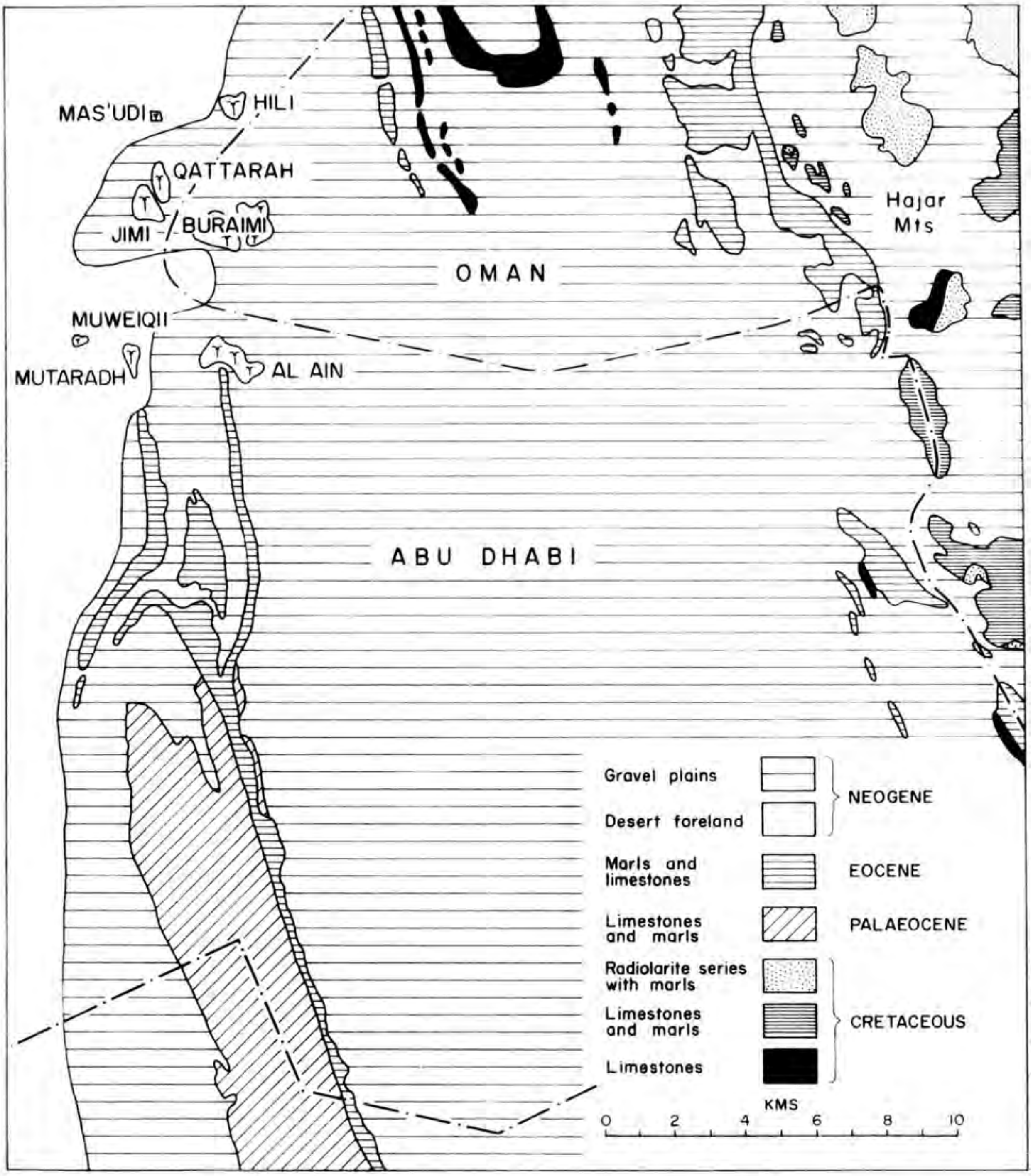

Fig.8
The Geology of the Al Ain area, Abu Dhabi. (Based on Sir A.Gibb and Partners, 1969)

There is even less meteorological data available for Al Ain than for Ras-al-Khaimah, with rainfall records having only been kept at Jahili Fort since October 1965 (table 4.1). One feature that these records show is the irregularity of the rainfall, a point emphasised by Stevens (1970b). The winter rainfall results from depressions, tracking down the Arabian Gulf from the Mediterranean, being forced to rise by the mountains of the Oman Peninsula and depositing their moisture. The infrequent summer rainfall is probably caused by the instability of maritime air over the Hajar mountains as it is drawn in over the land due to the northward daily movement of the inter-tropical convergence zone. This daily movement is also responsible for humid conditions occurring on some summer days when the wind is blowing from the south.

The summers can be very hot. Extreme maxima of up to 47°C were noted by Sir A. Gibb and Partners, (1969), while the present author experienced a shade temperature of 50°C during July 1969, and this period of high temperatures is also accompanied by frequent dust storms. These are emphasised if the wind is blowing from a NW direction or from the south. Minimum winter temperatures occur during January and February and it is possible that temperatures of less than 0°C may be more frequently recorded than is generally thought, on account of the increased continentality of the area relative to Ras-al-Khaimah. Several of the Sheikhs have commented that the Al Jaww Plain is 'white' during winter - presumably a reference to hoar frost.

Table 4.1

Rainfall at Jahili Fort, Al 'Ain oases, 1965-1969

(Figures in mms.)

	1965	1966	1967	1968	1969
January		nil	nil	5.0	33.5
February		37.5	nil	69.8	1.3
March		nil	6.4	nil	nil
April		nil	5.9	2.5	4.3
May		nil	Tr	nil	nil
June		1.0	nil	nil	nil
July		1.0	2.5	nil	6.4
August		nil	nil	nil	
September		nil	nil	nil	
October		nil	nil	nil	
November	nil	nil	nil	nil	
December	nil	nil	nil	nil	
Annual Total		39.5	14.8	77.3	

During the summer months, evapotranspiration is very high. The nearest comparable data for evaporation from a U.S. Weather Bureau Class A pan are the short term records from Tawi Mileiha, located in a similar situation, about 100 kms to the north. Consequently the data may be regarded as somewhat more 'maritime' in their characteristics than Al Ain, and over the period July 1967 - September 1969 the average daily evaporation, in mms, was:-

	O	N	D	J	F	M	A	M	J	J	A	S
Evaporation (mms)	11.3	7.2	5.0	5.2	5.2	9.5	12.0	16.2	20.8	16.5	16.1	12.4

These figures are substantially higher than those recorded at Digdaga, and it is likely that if a similar pan was installed at Al Ain, recordings would be even higher. Despite the high evaporation and very limited summer rainfall, there is considerable variety in the natural vegetation - Haloxylon salicornicum, Salsola spp, Acacia spp, Prosopis spicigera, Calotropis procera, Zizyphus spina-christi in addition to grasses and herbs. Stevens (1970b) noted the frequency of dew during July 1969 and undoubtedly dew formation is important in providing some moisture for plant growth during the summer months and thus indirectly aiding pedogenesis.

The population of the oasis area was estimated at 12,900 by the 1968 census while, in 1969, it was estimated by the water resources survey that approximately 482 hectares were under cultivation (Sir A. Gibb and Partners, 1969). There is thus a very high demand for water and this demand is increasing as both the area under cultivation and the population expand. As in Ras-al-Khaimah, the original

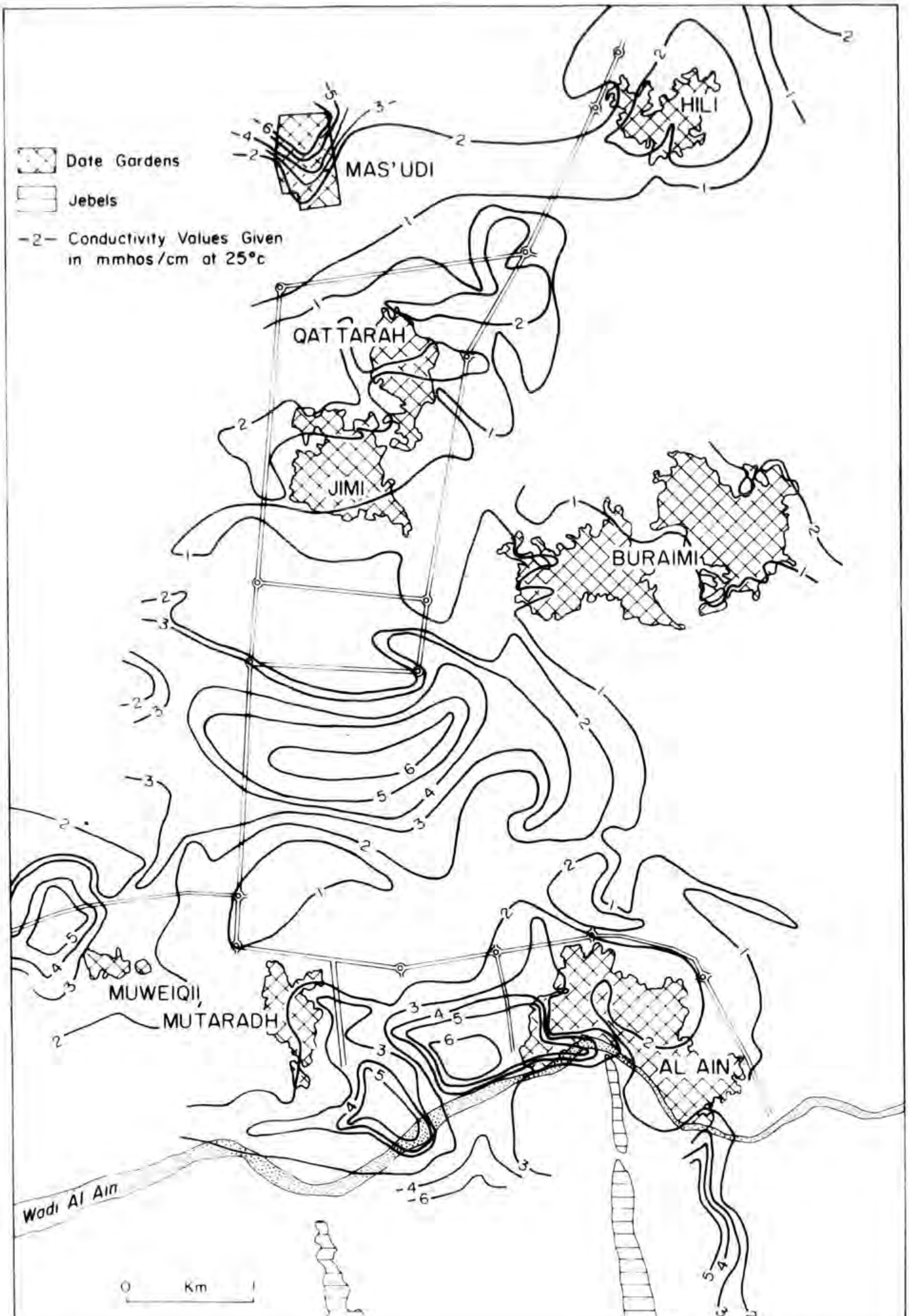

Fig.9

Water quality at Al Ain oases. (Based on Sir A.Gibb and Partners, 1969).

centres of the oases were the date gardens and their water supply is derived from the aflaj.[1] Seven aflaj now supply the oases in the territory belonging to the Federation of Arab Emirates, though in the past there were more operational. Their source of water is run off from the Hajar mountains which has rapidly infiltrated into the coarse rudaceous deposits of the eastern Al Jaww Plain. Jebel Hafit acts as a barrier to the westward subsurface flow of this water and much is deflected around the northern edge of the mountain. Consequently there tends to be an accumulation of groundwater at relatively shallow depths (about 5-30 metres) in the vicinity of Al Ain and this tends to be of C_2S_1 or C_3S_1 quality, i.e. having medium or high salinity hazard but low sodium hazard. A feature of the falaj water is that the aflaj are also used as communal washing and bathing facilities and consequently before the water is used for irrigating the date gardens it has accumulated some salts and detergents from these sources. However, the irrigation water is of better quality than that used at Ras-al-Khaimah because the distance of subsurface flow from the mountains is much shorter and the water has not had the opportunity to acquire a high content of harmful sodium or salts.

The newer agricultural holdings obtain their water from wells, usually with a pump. While the water is of reasonable quality (figure 9), a number of the pumps are not able to work to their full capacity because many of the wells have been dug too close together. This has led to local drawdown of the water table and while this may

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[1] Aflaj - plural
falaj - singular

only be a temporary phenomenon lasting for merely a few hours, in some instances it takes several days for the full restoration of the water table. As a result, some smallholdings do not obtain sufficient irrigation water and less than 20% of their area may be under cultivation. These holdings are potential wind erosion areas, for the vegetation has been cleared, any natural structure in the soil destroyed and consequently the soil has a high degree of erodibility due to its coarse texture.

4.2 Agricultural development

The Al Ain group of oases are long established agricultural centres, Zwemer (1902), for instance, stating that 'Bereimi was for many centuries the most important centre of western Oman'. This importance was emphasised by the location of the oases on two major trading routes - one north/south along the western edge of the mountains and the other westward to Abu Dhabi and the Arabian Gulf. Cox (1925) also visited the oases in the early twentieth century and, as well as noting that Mas'udi was established in about 1900, he describes the agriculture of the oases in the following terms, 'light though it is the soil is evidently most prolific, and it was calculated that the oasis supported not less than 60,000 date palms besides all the fruit and vegetables to be found in that region e.g. grapes, melons, limes, figs, pomegranates, a few mangoes, and in the way of crops, wheat, barley and jowari, and quantities of lucerne'. Because of its location on trading routes, Al Ain undoubtedly engaged in more trade than other oases in the area and this is reflected in the range of crops grown.

The pattern of agriculture remained substantially the same until the 1950s with the date gardens growing a range of ground crops, in particular lucerne, in contrast to the areas of cultivation around Hail and Shimal. Then the growth of urban markets on the Arabian Gulf, in addition to the introduction of vehicles able to traverse the Desert Foreland, caused a change in agriculture. Smallholdings, concentrating in the main on vegetables and fodder crops, were established and the process accelerated as Abu Dhabi started to exploit its oil wealth. While most of the smallholdings obtain income from the sale of both vegetables and fodder crops, there is greater specialisation than in Ras-al-Khaimah and 80% of the smallholdings derived the major part of their income, in 1969, from the sale of lucerne (Stevens, 1970a). By 1971 even exports of strawberries were finding their way to Beirut.

Agricultural and irrigation practices differ according to the type of cultivation undertaken. The date gardens receive the major part of their irrigation water from the aflaj, and there is a cooperative agreement over irrigation water from this source. This allows for a longer interval between irrigations in the summer months, when there is also increased pressure on the water supply for domestic purposes. The date gardens are irrigated every 3-4 weeks in summer and about every fortnight in the winter. To offset this water shortage during the summer months, some owners have also dug wells within their date gardens so that they can irrigate their ground crops more frequently. Both pumps and simple lifting devices are used to extract water from these wells. There is a tendency for owners who are diversifying away from dates, as well as all the new smallholders, to dig wells or boreholes and install pumps. The use of the latter allows a greater area to be irrigated while there is also more control over rates of application. Fodder crops are irrigated every 3-5 days in summer and weekly in winter, while vegetables are irrigated every 2-3 days in summer (water melons, cucumbers, squashes) and weekly during the winter months, when a much wider range of crops are grown.

The prolific nature of the soil noted by Cox (1925) was undoubtedly due to the relatively heavy manuring that the date gardens have received. Organic manure is applied at a rate of about 1.5 tons/dunum[1]/annum in the better gardens, though there is no placement around individual palm trees. The organic manure is, however, not of particularly high quality since it contains a relatively large proportion of sand and the woody tissue of such plants as Haloxylon salicornicum. The latter is used for bedding of the animals. Additional manure is obtained from the large cattle population which is kept in the date gardens during the summer months. The standard of date palm husbandry is not so high as at Ras-al-Khaimah - date palms are often planted less than 4 metres apart, there is a comparatively high incidence of diseased palms, while many are old and beyond their productive life. The problem is accentuated by the long irrigation interval in the summer when the palms do not receive sufficient water for their needs. When dead or excessively diseased palms are cut down,

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[1] 1 dunum = 0.1 hectare

they are burnt on the spot and the ash and mineral nutrients spread over the soil. Only a few of the owners applied dried fish, on account of the distance of the oases from the coast, but additional organic matter is added to the soil through the lucerne crop. This is usually allowed to remain in the ground for 5-7 years after planting and, because it is cut so close to the ground that the corn is damaged, the crop takes on a very patchy appearance after about the third year. The dead plants are allowed to remain and their subterranean portions decompose in situ.

The smallholders have followed the tradition of organic manuring but, because of the rapid increase in cultivated area, local supplies have not managed to keep pace with the demand. Some smallholders travel considerable distances into Oman in order to obtain supplies, while others are changing to humus imported from the Lebanon. There has been a tendency for the smallholders to use considerable quantities of mineral fertilisers especially superphosphate which is applied to fodder crops at a rate of 20-60 kgs/dunum/annum. It was Department of Agriculture policy, in 1969, to distribute free superphosphate to smallholders growing lucerne, each smallholder receiving amounts equivalent to an application of 25 kgs per dunum of lucerne. Sulphate of ammonia is the common fertiliser applied to vegetable crops with rates of application being variable, up to 35 kgs/dunum/annum. Fertiliser applications are essential for the cash crops remove considerable quantities of nutrients from the soil, which is not over endowed with nitrogen,phosphate and potash (see analytical results, Appendix 1.)

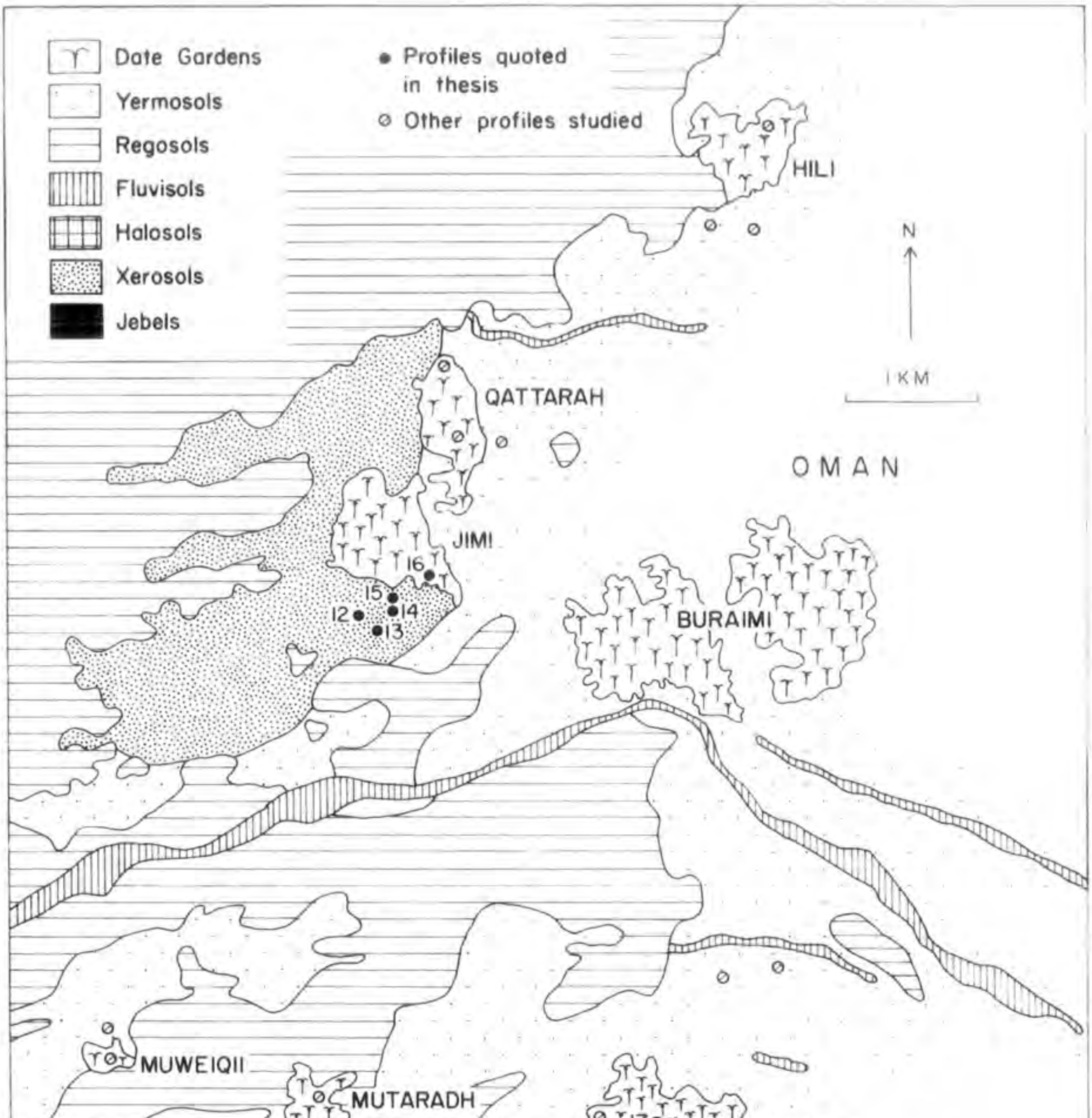

Fig.10
The soils of the Al Ain Oases, Abu Dhabi

4.3 The effect of agricultural practices on soil characteristics

Because of the increased continentality of the area, the vegetation tends to be much sparser than on the outwash plains of Ras-al-Khaimah, despite a greater variety of species present. Consequently, soil organic matter is much lower, and structure is weakly developed with single grain structure predominating in most horizons. The natural soils tend to be yermosols or xerosols, though regosols are also present (figure 10). Hunting Technical Services carried out a soil survey for Sir A. Gibb and Partners (1969) but they were only concerned with assessing the suitability of virgin soils for agricultural development, and no attempt was made to assess the changes that had occurred in cultivated soils as a result of different agricultural practices, - virtually none of their profile pits were located on cultivated land.

The author, in this study of the effects of cultivation on soil characteristics at Al Ain, examined 30 profiles in the field, the majority being located in cultivated holdings. Routine laboratory analyses were then undertaken on 52 samples derived from 14 profiles (10 cultivated). In addition to the routine analyses, X-ray diffraction studies were made of selected samples and the free iron oxides were also determined.

Some of the changes that have occurred through cultivation can be illustrated in a sequence of five soil pits (profiles 12-16) at Al Jimi, one of the northern oases in the group. The locations of the five soil pits are shown on figure 11 and at each of these pits a different type of agriculture was practised:

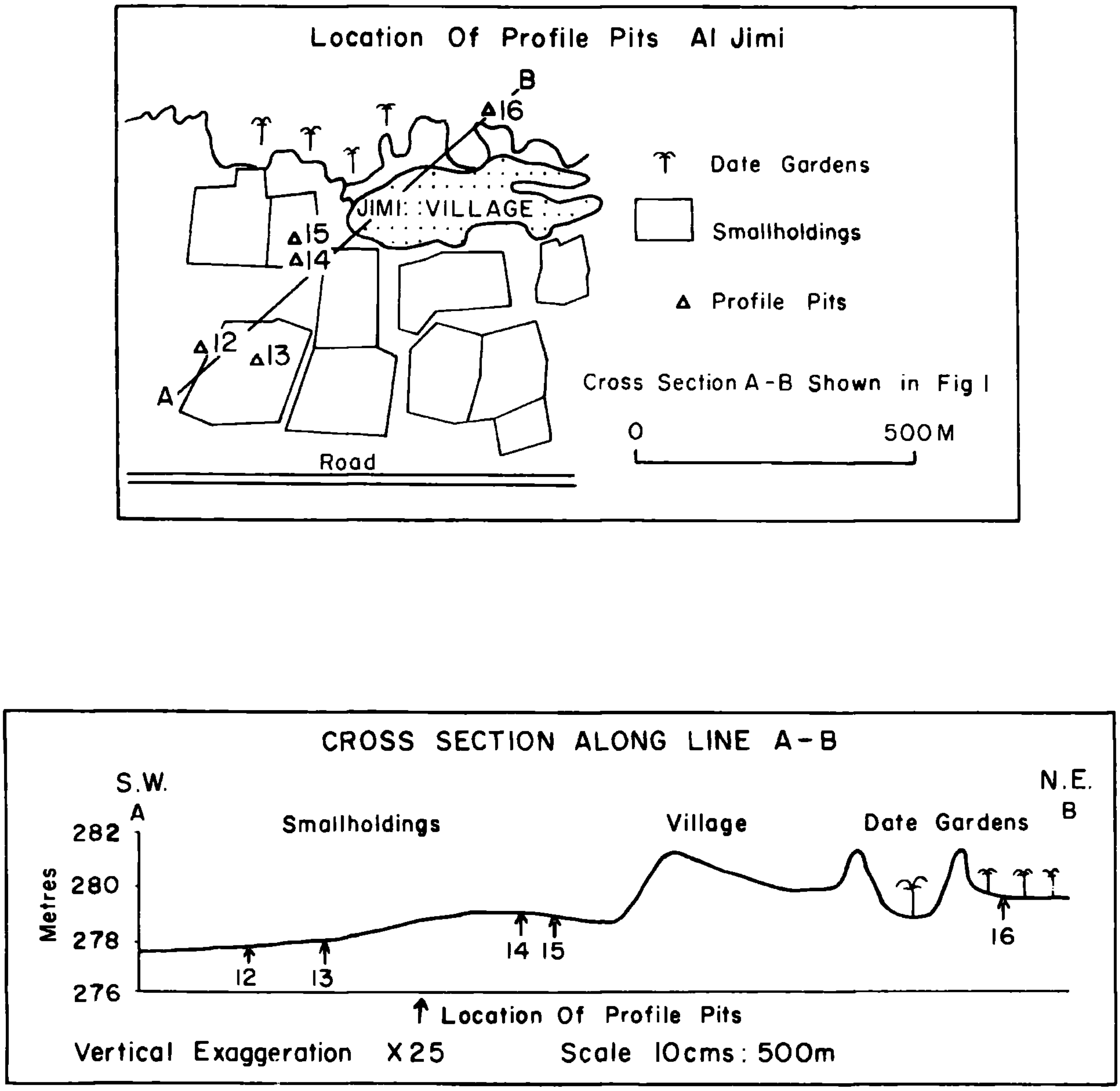

Fig.11

Location of profile pits at Al Jimi, Abu Dhabi

(i) Profile 12. This profile was located outside a smallholding on uncultivated land which had a sparse (>5%) cover of Haloxylon salicornicum that was used for grazing. Haloxylon salicornicum grows on small mounds which are the result of foliage trapping the aeolian material. Unless disturbed, such uncultivated xerosol profiles have a thin silt crust which gives the soil some protection from wind erosion. In close proximity to Al Jimi village, this crust has been disturbed and windblow of the topsoil is common with some small dunes, less than 1 metres in height, being present in the vicinity of profile pit 12. The profile is typical of the uncultivated xerosols that occur in the area.

(ii) Profile 13. The soil pit was located in a smallholding that concentrates on vegetable production and which was established in 1958. The plot in which the profile pit was sited was in summer fallow at the time of sampling (July 1969) but had grown cabbages the previous winter. Organic manure had been applied at a rate of 0.75 metric tons/dunum six days prior to the planting of the cabbage crop, while sulphate of ammonia had been applied at a rate of 33 kgs/dunum given in two applications. The first of these was given when the cabbages were about 15 cms high and the second a fortnight later. Irrigation of the cabbage crop took place once weekly using water having an electrical conductivity of 1.1 mmhos/cm at 25°C.

(iii) Profile 14. This soil pit was located in a holding which was established in 1953 in a plot which had grown lucerne for the previous six years and, as a consequence, was very patchy. Citrus trees had been planted in the plot four years previously but they had a very chlorotic appearance, possibly due to the high free calcium carbonate contents inhibiting the uptake of nutrients. However, superphosphate had been applied to the plot in 1968 at a rate of 55 kgs/dunum and it has been recorded that the application of phosphate fertilisers could mobilise copper by the conversion of mono-calcium phosphate into phosphoric acid, causing toxic levels of copper to occur around the citrus roots (Spencer, 1963). The superphosphate had had little effect on the lucerne crop due to the age of the crop when it was applied. Some organic manure had also been applied when the citrus trees were planted. Irrigation was twice weekly in summer and weekly during the winter months with water having a conductivity of 0.85 mmhos/cm at 25^{o}C.

(iv) Profile pit 15 was located in the same holding as pit 14 but was situated in the part of the garden that had been given over to dates since the establishment of the holding. Fodder crops had been grown beneath the date palms, and at the time of sampling, the remains of a lubia (Dolichos lablab) crop were in evidence. Organic manure had been applied at a rate of about 0.75 metric tons/annum each year while some superphosphate had been applied in the past. Irrigation was at weekly intervals.

Plate 5
Soil profile under 16 year old dates, Al Jimi, Abu Dhabi (profile 15).

(v) Profile pit 16 was sited in a traditional date garden. The plot was irrigated at intervals of three weeks in the summer and 12 days in winter by falaj water having a conductivity of about 0.47 mmhos/cm at 25°C. The owner had no well or pump to supplement falaj supplies. The date palms were growing on small bunds separating plots which were used for the cultivation of fodder and bedding crops such as lubia, lucerne and 'dhufra' (a vetch). No mineral fertilisers had been applied but organic matter is spread over the plots at a rate of 1.5 metric tons/dunum each year. However, irrigation washes the organic manure to the ends of the plots furthest from the source of the irrigation water, and the beneficial effects of manuring are only felt to their full in a small part of the plot. Additional organic manure was also added to the soil through the owner keeping cows, sheep and goats in the date garden during the summer months.

Comparative analytical data for the five profiles in the soil transect at Al Jimi are given in Table 4.2. Some of the trends apparent in the soils of Ras-al-Khaimah as a result of cultivation also occur in these profiles, in particular the increase in organic matter content, but there are also some anomalies. There is no apparent decalcification of the soils under traditional date cultivation, and calcium carbonates remain over 40% throughout most of the profile. Two explanations may be invoked. Firstly, the date gardens are surrounded by high mounds (figure 11) which Sir A. Gibb and Partners (1969) partially attributed to the erosion of an old land surface. However, the author considers that many of these mounds are composed of material resulting from

Table 4.2

Comparative data for a soil transect at Al Jimi
N.D. - no data

	Profile 12		Profile 13		Profile 14		Profile 15		Profile 16	
Depth (cms)	Texture (%) - International limits									
	Si	C	Si	C	Si	C	Si	C	Si	C
0-10	3.4	6.6	6.5	5.5	7.2	5.3	12.9	4.9	12.0	10.7
35-45	N.D.	N.D.	18.2	4.9	4.7	8.1	7.0	6.1	5.5	7.4
	Organic carbon and nitrogen (%)									
	O.C.	N	O.C.	N	O.C.	N	O.C.	N	O.C.	N
0-10	0.95	0.09	1.32	0.07	0.58	0.03	1.03	0.04	1.77	0.08
35-45	N.D.	N.D.	0.61	0.04	0.57	0.05	0.97	0.05	0.83	0.05
	pH and carbonates (%)									
	pH	Carb.	pH	Carb.	pH	Carb.	pH	Carb.	pH	Carb.
0-10	8.8	35.5	8.7	34.0	8.75	38.0	8.8	37.5	8.8	42.5
35-45	N.D.	N.D.	8.95	36.0	8.4	34.5	8.4	28.5	8.8	33.5
	Conductivity (mmhos) and E.S.P. (%)									
	Cond.	ESP	Cond.	ESP	Cond.	ESP	Cond.	ESP	Cond.	ESP
0-10	0.12	N.D.	0.21	17.3	0.07	13.1	0.09	9.3	0.14	8.5
35-45	N.D.	N.D.	0.15	6.4	0.12	12.5	0.11	10.3	0.26	9.6

Profile 12 - uncultivated xerosol

Profile 13 - smallholding (vegetables)

Profile 14 - 6 year old lucerne

Profile 15 Date cultivation (16 years)

Profile 16 Date cultivation (traditional) the original clearance and levelling of the old date garden area. Such clearance and levelling could have removed some of the top deposits and profile 12 shows high calcium carbonate contents (43.5%) at a depth of 127-132 cms. Furthermore, a profile pit dug by Hunting Technical Services (quoted in Sir A. Gibb and Partners, 1969) to the east of Qattarah oasis also had a carbonate content of 40% below 1metre depth. These figures are very similar to those occurring in the top sample of profile 16 located in the traditional date garden. A second explanation is that because of the lower irrigation duty, the reducing conditions prevail for much shorter periods which are insufficient to cause any marked decalcification.

The increase in the silt and clay content in the topsoil samples may not thus be wholly related to agricultural practice, though the falaj water used for irrigation might be expected to cause an increase in the amount of fine material in the topsoil. Sir W. Halcrow and Partners (1969) comment on the fact that a number of aflaj in the Al Ain area had fallen into disuse through blockage of the underground channels by silt, whilst others had their flow severely reduced. Their teams had cleared out a number of blocked aflaj to improve the flow of irrigation water to the main oases when this study was undertaken. Material carried in suspension by the irrigation water presumably would have to be deposited somewhere in the date gardens, but in fact there is little evidence for such deposition. Some deposition certainly occurs where bathing and washing are carried on but deposition in the date gardens may be modified by aeolian material trapped by the date palms. This aeolian material is certainly coarser than that transported by the falaj water and there is a high frequency of dust storms especially when the shamal (NW wind) blows.

As at Ras-al-Khaimah, there tends to be an increase in the organic matter content, as reflected in the organic carbon percentages, depending upon the length and type of cultivation. The amount of organic carbon in profile pit 12 may be considered anomalous for two Haloxylon salicornicum bushes were growing in close proximity to the pit, uncultivated profiles quoted by Hunting Technical Services and others sampled by the author have organic carbon contents of about 0.5%. The relatively high levels of organic carbon occurring in the top sample of profile 13 (1.32%) may be attributed to the remnants of the cabbage crop decomposing in the surface layers. It is considered that the regular additions of organic matter, applied before each vegetable crop is planted, have had comparatively little effect on the long term build up of organic matter content in the soil, for, not only will the frequent irrigations assist rapid decomposition but also the high level of direct insolation during the summer fallow period will also cause oxidation. This is emphasised by the relatively low level (0.55%) of organic carbon in profile pit 14 despite the cultivation of lucerne for the previous 6 years. Lucerne is a crop which usually adds organic matter to the soil in considerable quantities for it has a close root system. However, in the plot in which profile 14 was located, the crop had a very patchy appearance and little shade was afforded to the soil from either the crop or the young citrus. Consequently, the organic matter on the surface was quickly burnt up while that within the profile decomposed more rapidly as a result of the higher soil temperatures and frequent irrigations. The effect of the long established date gardens is shown by soil profile 16 and emphasised by profile pit 17, located in the date gardens at Al Ain. In this latter profile, the amount of organic carbon in the topsoil sample was over 2.1% and the colour of the surface horizon was 10YR4/2 (dark greyish brown), in contrast to the 10YR5/4-7/4 (yellowish brown) colours that usually predominate in the uncultivated profiles.

Despite the lack of increase in soil organic matter resulting from the cultivation of lucerne, the latter has been beneficial to structural stability, as is shown in Table 4.3. Soil aggregates were gently wetted to above field capacity and the numbers resistant to this treatment noted. The table gives a relative indication of the water stability of the aggregates as a result of different cropping patterns. A feature of the structure is that small (<5 mms diameter) angular blocks (almost granules) only occur in any appreciable numbers after a crop of lucerne has been grown, while it would also appear that they are more resistant to irrigation than the medium sized aggregates. Furthermore, they can also withstand a certain amount of mechanical working - the plot that had grown lucerne continuously for the past seven years had been ploughed by tractor only a fortnight before sampling. However, there is the suggestion that even these small aggregates break down fairly quickly with mechanical operations, irrigation and different crops as exemplified in the data given for the plot that had grown

Table 4.3

Water stability of structural aggregates, in the topsoil (0-20 cms), related to different crops

Cultivation	Uncultivated	Lucerne (6 yrs)	Lucerne (7 yrs)	Lucerne (7 yrs) Vegetables (2 yrs)	Vegetables (10 yrs)
Profile pit	12	14			13
Type of aggregate	Medium angular blocks	Small & medium angular blocks	Small & medium angular blocks	Small & medium angular blocks	Small & medium angular blocks
Number of aggregates treated	50	50	50	50	50
Number of small aggregates in samples	2	33	38	18	8
Number of aggregates water stable	6	39	43	25	11
% of small aggregates water stable	100	87	92	88	88

vegetables for two years following seven years of lucerne.

Cultivation practices, in particular manuring and fertilising, do not seem to have improved the nutrient status of the soil to any appreciable extent. The amounts of the major nutrients (N,P,K) present at certain depths in each of the five profiles are given in Table 4.4. Lucerne does not appear to have improved the nitrogen status of the soils and it was observed that no nodulation had taken place in the crop growing at the site of profile 14 or in any other smallholding growing lucerne. It was not known whether the seed had been innoculated prior to sowing. All of the nitrogen in sulphate of ammonia is in ammoniacal form which dissolves readily in water but it can enter into cation exchange and be held on the clay micelles. However, only very limited amounts can be retained by these coarse textured soils and consequently little long term improvement in the nitrogen status of vegetable gardens, e.g. profile 13, could be expected. The vegetable crop would quickly utilise the adsorbed ammonia cations and there would probably be very little for later conversion to nitrate nitrogen. Furthermore, sampling in midsummer probably provides the minimum quantities present as the high temperatures would cause conversion to atmospheric nitrogen. Superphosphate had been applied to lucerne crops (e.g. profile 14) but again no improvement in available phosphate was noted. However, the amount of total phosphate present in the soil, particularly the topsoil sample, was somewhat higher than in other profiles. The applied superphosphate probably quickly combined with the free caloium carbonate to form an

Table 4.4

Nutrient status of cultivated and uncultivated soils at Al Jimi

		Profile 12 Uncultivated	Profile 13 Cabbages	Profile 14 Lucerne	Profile 15 Dates & Lubia	Profile 16 Date Garden
Nitrogen %	0-10 cms	0.09	0.04	0.03	0.05	0.11
Total Phosphate mgs/100g	0-10 cms	N.D.	24.2	36.9	30.4	21.6
	30-40 cms	22.0	26.4	33.6	30.8	N.D.
	55-65 cms	32.6	23.8	28.5	N.D.	22.0
Available Phosphate mgs/100g	0-10 cms	N.D.	0.31	0.18	0.04	0.18
	30-40 cms	0.22	0.22	0.18	0.13	N.D.
	55-65 cms	0.18	0.09	0.13	N.D.	0.16
Available Potash mgs/100g	0-10 cms	N.D.	8.2	12.1	12.2	23.4
	30-40 cms	40.2	12.3	11.4	14.3	N.D.
	55-65 cms	37.1	23.1	19.3	N.D.	30.3

insoluble calcium phosphate compound that was unavailable for plant nutrition, and profile 14 contained substantially higher quantities of total phosphate in the topsoil compared to the other profiles. This reversion to an insoluble form is further emphasised by relatively high ammoniation of superphosphate (Volk, 1971). The low available potash figures recorded in the soils at Al Jimi that had grown either vegetable crops or lucerne were not reflected in other soil samples collected in the oasis area.

There has been no appreciable increase in soil salinity as a result of cultivation at Al Jimi because the irrigation water had a low salinity and the coarse-textured soils are naturally freely draining, for thick gravel deposits are usually found within 3 metres of the surface. Elsewhere in the oasis area, problems have arisen through inherent soil salinity or saline water being used for irrigation. On the Department of Agriculture Experimental Farm, the line of an old falaj is reflected in a belt of saline soils running through the farm. While the falaj was excavated in sandy or gravelly deposits, these underlay silty loam or silty clay loam deposits. As the falaj became blocked the salinity of the water undoubtedly increased (there is a general tendency for salinity to increase with increasing amounts of sediment) and water seeping into the overlying heavy textured horizons would evaporate leaving behind concentrations of soluble salts. This is shown in profile pit 18 where a conductivity of 40 mmhos/cm at 25°C was recorded in the topsoil sample and strawberry cultivation had failed.

To the south of Al Ain, on the eastern flanks of Jebel Hafit, the irrigation water is saline but the soils are relatively freely draining. Modifications to an existing garden allowed a completely unirrigated soil profile (profile 19) to be compared with one sampled beneath an irrigation channel (profile 20). The latter had been used daily for about a year and the irrigation water at the time of sampling had a conductivity of 5.1 mmhos/cm at 25^{o}C. Under these intense conditions, during which the soil did not dry out, there has been almost continuous downward translocation of soluble salts. Comparative data for the two profiles are given in Table 4.5. There has been a general reduction in conductivity in profile 20 reflecting a net loss of soluble salts out of the upper parts of the profile and, in particular, this loss of soluble salts has fallen most heavily on the chlorides which have almost been completely washed out of the soil. There have also been marked losses in the amounts of sulphate present.

Profile 20 is not representative of what would happen under traditional techniques, for the soil profile was never allowed to dry out. Traditional irrigation techniques not only allow the topsoil to partially dry out between irrigations, but also the soil dries out to at least 50 cms during the fallow period if vegetables are being grown. Using irrigation water of this salinity (5.1 mmhos/cm at 25^{o}C) the soluble salts will wash down the profile where they will accumulate unless there is good drainage - in the Al Ain oasis area some caliche horizons form impermeable barriers to downward drainage,

Table 4.5

Soluble salts in the saturation extract, unirrigated and irrigated profiles, Al Ain

Depth (cms)	Unirrigated Profile 19					Irrigated Profile 20				
	Conductivity mmhos/cm	Soluble anions meq/litre				Conductivity mmhos/cm	Soluble anions meq/litre			
		CO_3	HCO_3	Cl	SO_4		CO_3	HCO_3	Cl	SO_4
5-10	2.95	-	2.13	2.60	22.53	1.75	-	1.07	1.21	12.33
22-27	0.20	-	1.55	1.43	8.73	0.35	0.53	0.93	0.15	7.53
48-53	9.05	0.89	2.33	33.84	42.37	2.44	0.60	0.80	4.25	18.73
97-102	15.40	0.27	3.33	59.66	63.93	5.40	0.80	1.07	8.35	42.73

especially in the vicinity of Jebel Hafit. Furthermore, during the fallow period there will be upward movement of capillary moisture which will cause soluble salts to accumulate in the topsoil. Saline water has been used successfully for irrigated agriculture on very coarse textured soils, having less than about 8% silt and clay fractions, but if highly saline water is to be used successfully a correct ionic balance must exist between the sodium and potassium cations in the irrigation water (Boyko, 1966). This correct ionic balance should not be less than that which prevails in seawater (about 31% of the total solids in seawater are of sodium while about 1% are potassium) and Heimann (in Boyko, 1966) suggests that the concentration of potassium should be about 5-10% that of sodium. While salt tolerance of crops is very complex, it would seem unlikely that agriculture will succeed for any length of time on the medium textured soils south of Al Ain, particularly as the irrigation water has unbalanced ionic ratios, with the potassium concentration only being about 2-5% that of sodium.

4.4 Weathering within the soil solum

The addition of irrigation water radically alters the soil climate and affects the weathering of minerals within the soil profile. While the uncultivated soils are arid throughout most of the year (their only moisture is derived from dewfall and the sparse irregular rainfall), the soils of the traditional date gardens are subjected to periodic reducing conditions when each irrigation is applied. Furthermore, except for the surface centimetre or so, the profile remains moist during the intervals between irrigations. In contrast, the soils which have been cultivated for vegetables are subjected to a marked seasonal moisture regime with frequent periods when reduction is dominant, during the winter cropping season, while arid conditions prevail during the long summer fallow period. Lucerne has a very similar moisture regime to that of the date gardens during the first year or so of cropping, but, as the crop becomes patchier, the surface horizons will dry out between irrigations and the regime will become similar to that of vegetable crops in the winter period.

The effects of these different moisture regimes on free iron oxides are shown in Table 4.6, in which the two plots that had grown lucerne are included with vegetables, for both plots were at the end of lucerne cultivation. Although amounts of free iron oxide are low, there are substantially greater amounts present in the soils subject to the moister regimes. Profiles 15 and 20 were subjected to longer periods of continuous reduction than the other profiles and, although being 'cultivated' for much shorter periods of time than the traditional date garden, contain very similar amounts of free iron oxide. The amount of free iron oxide present in the soil is thus related to the frequency and intensity of reducing conditions. A similar conclusion has been made by Gerei (1968) for solonchak soils in Hungary, where uncultivated bog solonchak soils contained much higher quantities of 'readily soluble iron' than the freely draining solonchak soils whose upper horizons were dry for much of the year.

Table 4.6

Soluble iron (%) related to type of cultivation. All figures are an average of a minimum of 2 samples except for Profiles 15 and 20

Depth (cms)	Uncultivated	Vegetables and lucerne	Dates (16 years) Profile 15	Continuous irrigation Profile 20	Long established Date Gardens
0-10	0.35	0.38	0.57	0.46	0.48
20-30	0.28			0.52	
30-40		0.31			
40-50	0.28		0.46		0.48
50-60	0.25	0.36		0.37	
70-80		0.28	0.34		0.32
90-100	0.22	0.29		0.35	

The silica-sesquioxide ratios (Si/R) of the clay fraction give an indication of the amount of weathering that has taken place within the solum, in particular the relative rates of removal/accumulation of iron, aluminium and silicon. Bloomfield (1953, 1954 and 1957) in his studies of podsolisation has shown that the water extracts of plant residues tend to dissolve iron and aluminium hydroxides and that carboxylic acids and polyphenols are important in the dissolution and reduction of sesquioxides. Bloomfield considered that these processes took place when the soil was at a neutral, or near-neutral reaction and under aerobic conditions. In the long-established date gardens, where there is a regular addition of organic matter and the soil remains moist, though aerobic, for the greater part of the year, it would seem that conditions might be suitable for the dissolution and reduction of sesquioxides. As will be seen in Chapter 6, the early stages in the decomposition of organic matter from Tamarix aphylla are characterised by a marked depression in the pH values as the hemicelluloses decompose and while experimentation on the decomposition of litter from date palms, lucerne or lubia was not carried out, the same trend will undoubtedly occur, though not so marked. The heavy irrigation, applied at frequent intervals to these relatively light textured soils, would leach out the sesquioxides and thus prevent any accumulation at depth within the profile. The data presented in Table 4.7 reflect the dissolution and reduction of the sesquioxides in the surface horizons of the two profiles located in the long-established date gardens. It would seem that this

Table 4.7

Comparative silica-sesquioxide ratios for the clay fractions of an uncultivated xerosol and two profiles from long-established date gardens

	%			Gram molecular ratios			
	SiO_2	Fe_2O_3	Al_2O_3	SiO_2 : R_2O_3	SiO_2:Fe_2O_3	SiO_2:Al_2O_3	Al_2O_3:Fe_2O_3
	Date Gardens						
Depth (cms)	Profile 16						
0-5	53.40	2.45	23.44	3.6	59.5	3.9	15.3
15-20	72.90	2.14	23.41	4.9	93.0	5.3	17.7
40-45	69.60	2.12	20.38	5.5	89.1	5.8	15.4
55-60	69.20	1.74	15.29	7.1	104.8	7.7	13.6
75-80	70-80	1.53	14.27	7.9	118.0	8.4	14.0
	Profile 17						
5-10	64.0	3.50	20.40	4.8	48.6	5.3	9.2
38-43	66.30	3.02	18.36	5.6	59.4	6.2	9.9
75-80	76.80	2.38	16.32	7.9	86.5	8.7	9.9
	Uncultivated Xerosol						
	Profile 12						
0-5	71.40	1.84	18.35	6.2	99.1	6.6	15.0
25-30	72.20	1.43	17.35	6.7	133.3	7.1	18.9
50-55	72.80	1.63	17.31	6.7	121.0	7.1	17.0
95-100	74.20	1.12	14.27	8.4	178.5	8.8	20.0

effect is restricted to the top 50 cms or so of the profile and beneath this depth the Si/R ratios of both cultivated and uncultivated profiles are virtually the same. From the SiO_2: Fe_2O_3 ratios, it would seem that the iron oxides are more susceptible to weathering than the aluminium oxides.

In order to substantiate the theory that cultivation causes a difference in the weathering regime of arid zone soils, the clay fractions of most samples from the soil profiles at Al Ain were subjected to X-ray diffraction analysis by the author in the Durham soil laboratories. Results were somewhat inconclusive owing to the fluvial and aeolian modes of deposition of the parent material but the greatest contrasts were exhibited between profiles 12 and 16. These are the uncultivated and date garden members, respectively, of the soil transect at Hili and the relevant diffraction traces are shown in figure 12.

Each crystalline mineral in the clay fraction has its own atomic structure which diffracts X-rays in a characteristic pattern unique to that substance. For instance, illite has a main peak at about 10 A[1] with subsidiary peaks at 4.98A and 3.31A. These spacings are usually sufficient to diagnose the presence of illite and, in theory, it should be possible to identify each of the minerals present in the clay fraction by its characteristic diffraction pattern. In practice, there are considerable problems, particularly when interpreting traces from soils of arid regions:-

(i) Arid zone soils have low weathering indices e.g. Jackson

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[1] A = Angstrom unit

(1968) as shown in Table 4.8. Consequently, minerals such as gypsum and carbonates of calcium and magnesium tend to dominate, even in the clay fraction, and form the major peaks on the diffraction traces. Strong peaks, such as those at 2.84A or 2.64A which may be attributed to gypsum and/or calcium/magnesium carbonate tend to obscure weak diffraction peaks of mixed-layer clays and attapulgite respectively.

(ii) Clay minerals rarely occur in 'pure' form and, in arid zone soils, mixed layer minerals are common. This results from the dessication to which the soils are subjected and the high base status that prevails, in particular the presence of relatively high levels of exchangeable K. This allows the following weathering sequence to take place, as noted by Fine et. al. (1941).

montmorillonite ⟷ vermiculite ⟷ illite

As this progression is reversible, montmorillonite/vermiculite mixed-layers occur whilst the presence of chlorite, recognised by peaks at 14.3A and 4.72A, leads to the presence of montmorillonite-vermiculite-chlorite intergrades.

(iii) X-ray diffraction peaks confirm the presence of minerals but the absence of a sequence of peaks does not necessarily mean that that mineral is absent. For instance, the characteristic quartz peaks, at 3.34A, 4.26A, 2.44A and 2.28A, occur when only minute quantities ($<5\%$) of quartz may be present in the clay fraction, while chlorite peaks, at 14.3A and 4.72A, may not be represented even when 10% of the clay fraction is composed of chlorite. In the samples investigated, the problem is further

Table 4.8

Weathering indices of clay-size minerals in soils (after Jackson, 1968)

Weathering index	Clay-size minerals	soils
1	Gypsum (also halite, sodium sulfate, etc.)	Aridisols
2	Calcite (also dolomite, aragonite, apatite, etc.)	CCa horizons
3	Hornblende (also olivine, pyroxenes e.g. diopside, anorthite, analcite, etc.)	From glacial-derived till and loess
4	Biotite (also glauconite, mafic chlorite, antigorite, nontronite, etc.)	From periglacial loess
5	Albite (also plagioclase, microcline, volcanic glass, etc.)	From periglacial deposits
6	Quartz (also cristobalite, tridimite, etc.)	From till and loess
7	IMd dioctahedral micas, (also muscovite and 10 Å zones of sericite, etc.)	From till or loess derived from micaceous shale
8	Vermiculite (also collapsible 14 Å interstratified zones)	Weathered from shale or granite
9	Montmorillonite (also beidellite, etc.)	Mafic rock-derived, and in basins or drains
9	Pedogenic dioctahedral chlorite (including interstratified 2:2 zones)	Commonly pedogenic in expansible layer silicates
10	Allophane (sesquioxic, halloysitic, etc.)	Ando soils; Ultisols
10	Kaolinite (also halloysite, etc.)	Ultisols
11	Gibbsite (also boehmite, etc.)	Oxisols
12	Hematite (also goethite, limonite, lepidocrocite, magnetite, etc.)	Oxisols
13	Anatase (also rutile, ilmenite, leucoxene, zircon, corundum, etc.)	Oxisols

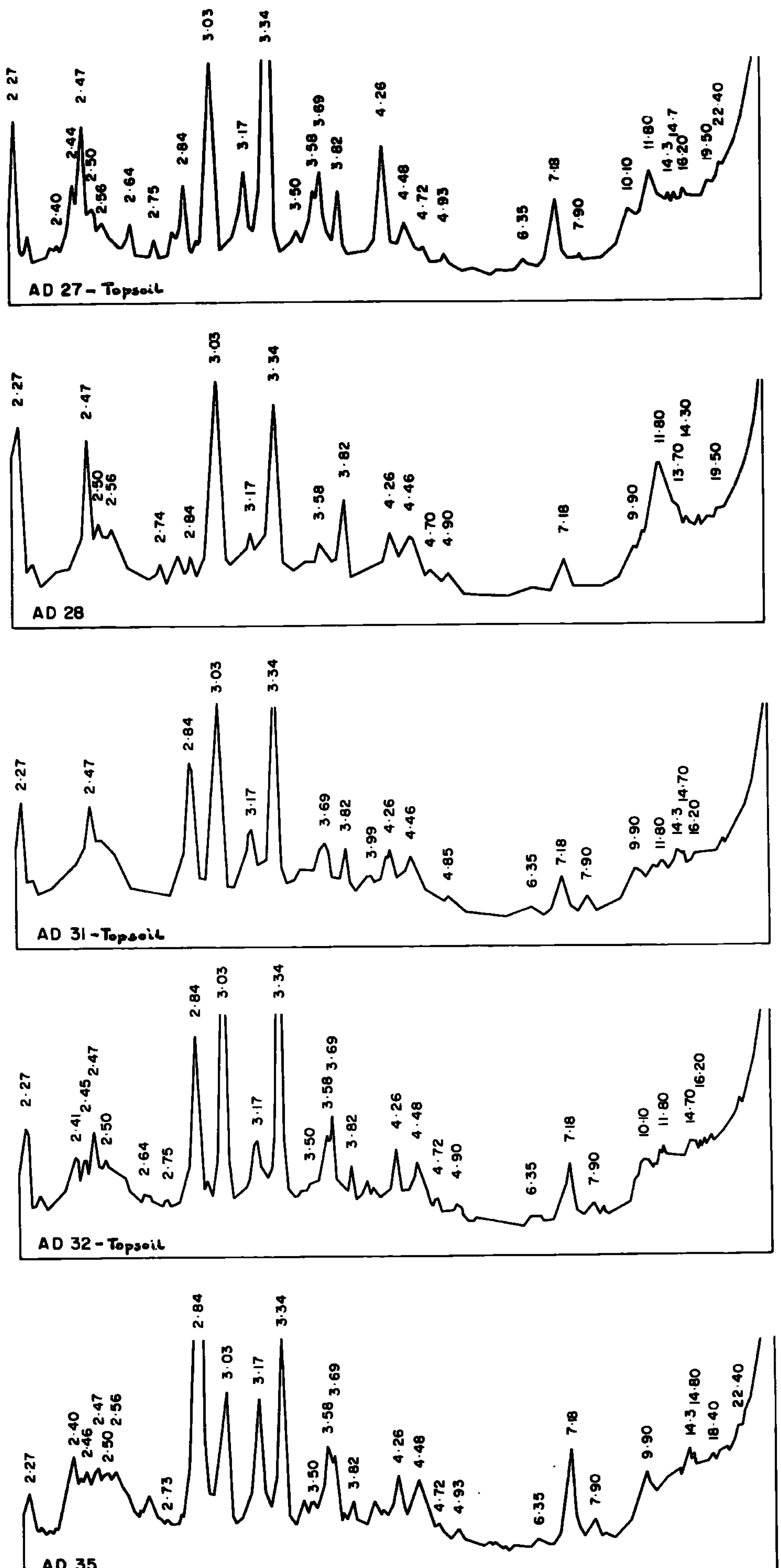


Fig.12

X-ray diffraction traces for profiles 12 (AD27 and AD28) and 16 (AD31, AD32, AD35), Al Ain.

accentuated, as most contain less than 15% clay and it may be relatively easy to miss a mineral.

However, bearing in mind the above points, some significant differences between an oasis soil and an uncultivated soil, as exemplified by profiles 12 and 16 (figure 12), may be postulated:

(i) The broader and more diffuse peaks that occur in the topsoil samples of profile 16 (the cultivated oasis soil) suggest that the clay minerals are more weathered than in the uncultivated soil. This is particularly true of peaks greater than 9A. As weathering proceeds, the mineral structures alter and the sharp peaks of unweathered minerals become broader and more diffuse, and, as new minerals form, the peaks themselves alter.

(ii) The uncultivated soil has a distinct peak at 11.8A. As there are also peaks at 4.45A and 2.98A, it is concluded that this is a form of basic aluminium silicate present in either a mixed-layer clay or an intergrade. The 11.8A peak occurs in much reduced form in the cultivated profile and it is suggested that this mixed-layer or intergrade clay mineral is the least stable and weathers most readily to form other clay minerals.

(iii) Siderite, an iron carbonate, with peaks at 2.79A and 3.59A appears to be present in profile 12, but its occurrence in the surface horizons of the oasis soil is much less certain. It may thus be a source of the soluble iron discussed earlier in this section.

Few studies have been made of weathering within the sola of soils under different intensities and length of cultivation. While the current studies show that there are differences in the weathering regimes of uncultivated and cultivated arid zone soils, these differences would appear to be more subtle than were originally envisaged by the author. It may be that, in an environment such as that at Al Ain, the heterogeneity of the parent material masks important mineralogical changes in the soil solum that result from weathering processes.

CHAPTER 5

Tendaho Plantations, Lower Awash Valley, Ethiopia: Cotton cultivation

5.1 The Physical Environment

The lower Awash Valley, forming part of the East African and Red Sea Rift System, lies at an elevation of less than 500 metres. While the area is, and has been, one of accumulation of material brought down by the River Awash, there has been a complex geomorphological history. This has been outlined by SOGREAH (1965). In a former pluvial period, lacustrine conditions existed in the area and deltaic deposits were laid down, these being reflected in the shell banks that occur, for instance, to the west of Assayita. Surface depressions were gradually filled up by the very varied deposits brought down by the River Awash and, as rainfall became less effective, the area of the lakes was gradually reduced. Following the pluvial period, there was some deposition of aeolian sands, for example along the western edge of Dubti Plantation, and this phase was followed by the present deposition pattern of the River Awash. The deposits of the River Awash show considerable variability for the course of the river has been constantly changing, possibly as a result of volcanic and tectonic activity that still occurs, while hillwash and minor stream sediments have also added to the diversity of the deposits. Fumarolic activity occurs in several parts of the lower Awash valley, especially on the northern edge of the Dubti Plantation, while earthquake activity is by no means unknown. In 1969, an earthquake caused considerable damage and killed 39 people at the town of Sardo (Dakin et.al, 1971), while, near Logiya, lava flows of Recent age overlie alluvium. The

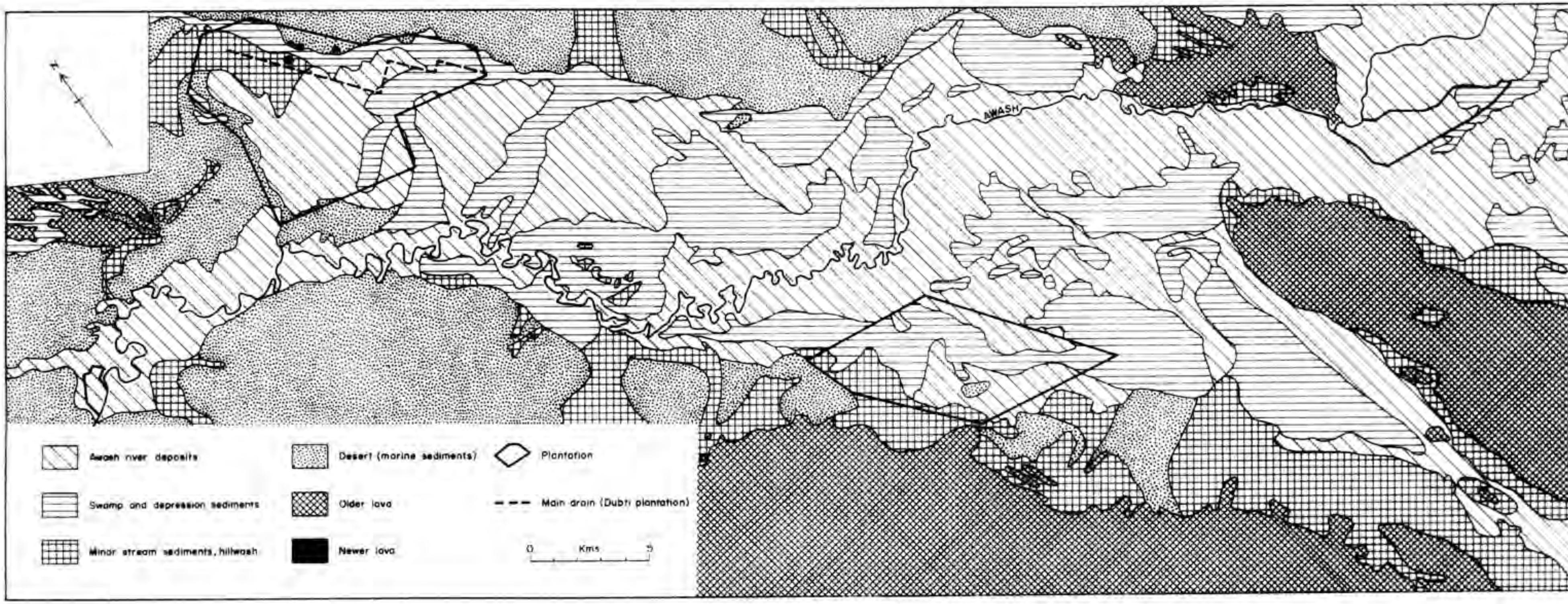


Fig.13

Geomorphic units, Lower Awash Valley, Ethiopia. (Modified from Curry, 1972) geomorphic regions of the lower Awash valley are shown on figure 13.

The climate of the lower Awash valley is arid with rainfall mainly occurring in the late summer as a result of the monsoonal circulation, but the 'little rains' may occur in the spring. Table 5.1 gives a summary of the meteorological data recorded at Dubti over the period 1964-1972. SOGREAH (1965) regard it as extremely rare for more than one shower to fall in any one day, though the duration of the shower may be as much as 4-5 hours. Showers are often accompanied by electrical disturbances in the atmosphere. In any one month, at Dubti, both the evaporation rates from an open pan and evapotranspiration as calculated by the Thornthwaite Method (1948) are significantly higher than the rainfall and, consequently, the latter can only be regarded as a fortuitous addition to irrigation. Furthermore, any rains that occur in March and April are lost in terms of crop utilisation, for the bulk of the cotton picking has been completed by March and most of the fields are in fallow until June or July.

The high summer temperatures lead to a rapid drying out of the soils during the fallow period, and also to a high rate of oxidation of any organic matter present in the soil. It was noted, for instance, in profile pit 22, on the Barga plantation, that the soil was dry to 45 cms and only very slightly moist beneath this, in August. This slightly higher moisture content at depth is considered to be moisture remaining in the soil from the previous season's cultivation. During the fallow period,

Plate 6

Vertisol at Barga, lower Awash valley, Ethiopia (profile 22).

Table 5.1

Summary of Meteorological Data, Dubti, 1964-1972 (based on information supplied by Tendaho Plantations Share Company Ltd.,)

MONTH	RAINFALL mms	TEMPERATURE °C MAX	TEMPERATURE °C MIN	REL. HUMIDITY %	PAN EVAPORATION mms	EVAPOTRANSPIRATION (Thornthwaite) mms
January	3.1	32.2	17.1	58.6	180	95
February	11.6	33.3	18.4	60.9	174	112
March	18.9	36.1	18.7	57.2	236	148
April	28.8	37.6	21.1	55.7	231	164
May	5.3	40.7	22.6	44.5	264	188
June	5.9	42.3	24.6	38.4	267	190
July	50.0	40.2	24.5	50.0	251	191
August	56.5	39.2	24.9	52.3	230	183
September	8.1	39.4	23.9	49.7	231	176
October	1.7	37.2	20.9	53.7	227	157
November	3.8	34.0	17.3	60.3	189	108
December	2.0	31.9	16.1	60.5	183	107

evaporation from the open pan averaged over 0.75 cms a day and as the soil dries out, biological activity will be severely restricted, though not completely eliminated (Cameron, 1969).

Because of their size (Dubti plantation is over 5,000 hectares and Dit Bahari plantation is nearly 2,750 hectares) the plantations tend to modify the local climate. This is particularly true in the period July - February when the plantations are irrigated thus tending to reduce temperatures and increase humidity. Huffnagel (1961) commented on the frequency of 'spirally ascending dust storms' but these now only affect the northern edge of Dubti plantation where they blow in off the bare desert. The young cotton plants may be affected by the high winds that are sometimes associated with these storms but they also serve to trap aeolian material. However, it is only the two or three fields closest to this northern perimeter that are affected, as the net effect of a cooler ground surface, caused by irrigation, is to deflect the dust storms in a westerly direction. The author has even seen dust storms bifurcate as they encounter the plantation boundary.

While the rainfall received by the plains of the lower Awash valley is of little direct importance in the cultivation of cotton, it is extremely important that there is regular rainfall on the rift valley escarpment during July and August so that the River Awash has a prolonged autumn flood. The river has a perennial flow but the flow is necessary for the growth of such grasses as Aristida spp, Andropogon spp and Sporobolus spp, on which the nomadic Danakil tribesmen depend to maintain their herds of cattle during the winter months. Unless there is adequate grazing, the Danakil look upon the plantations as a source of cattle feed and much damage can be caused. Irrigation of the cotton crop also makes considerable demands on the flow of the River Awash. The first irrigation applied to the Dubti plantation between June 18th and August 15th, 1971, before the cotton crop was planted, required 18,175,000 cubic metres of irrigation water, equivalent to about 36 cms distributed over the plantation. Cotton requires about 0.35 cms/day up to the flowering period but during the main flowering period it requires about 0.9 cms/day. (Tendaho Plantation Share Company, Research Report, 1967-1968).

The main flood waters are provided by such tributary rivers as the Logiya, Mille and Borkenna which drain the very heavily eroded land of the escarpment. Consequently, during flood flow, the River Awash is heavily charged with sediment. Furthermore, upstream of Tendaho, the gallery forest which formerly fringed the river has been destroyed and bank collapse is frequent and also contributes to the sediment load when the river is in spate. SOGREAH (1965) consider that most of the deposition of the coarser particles takes place in the section of the River Awash between Metehara and Tendaho, but even so the sediment load at Dubti is probably over 30 million tons annually. Consequently, the irrigation waters applied to the plantations have a high sediment content and, while much of this is deposited in the irrigation channels, a considerable amount is also added to the fields each year. Apart from the sediment, the River Awash is relatively low in soluble salts (it has an electrical conductivity of about 0.35 mmhos/cm at $25^{o}C$) and is also low in exchangeable sodium. It has been classified as being in the C_2S_1 category for irrigation, i.e. it has a medium salinity hazard but a low sodium hazard.

5.2 Cultivation Techniques

Four commercial cotton plantations were established in the lower Awash Valley in the early 1960s with the two main plantations being at Dubti (over 5,000 hectares) and Dit Bahari (2,750 hectares), and two smaller ones at Barga (a joint venture with the Crown Prince of Ethiopia) and Logiya (fig.13). Dubti and Dit Bahari Plantations were developed on what was virtually bare desert for vegetation was restricted to a narrow belt fringing the river which was subject to annual floods (there is a secondary flood in spring as a result of the 'little rains' but it is not always reliable). By 1970/71, nearly 9,000 hectares of cotton were being cultivated on the four plantations, while a further 10-12,000 hectares were grown by outgrowers. The latter obtain poor yields of cotton, for their irrigation methods are perfunctory (some growers rely solely on moisture remaining in the soil after the autumn floods), fertiliser applications are minimal and plant disease is common.

The main variety of cotton now grown on the plantations is Acala 1517D, though formerly Acala 1517C was important, which is a medium staple cotton that is relatively resistant to blackarm disease. In the early years of cultivation, cotton yields were affected by lack of fertiliser applications and the

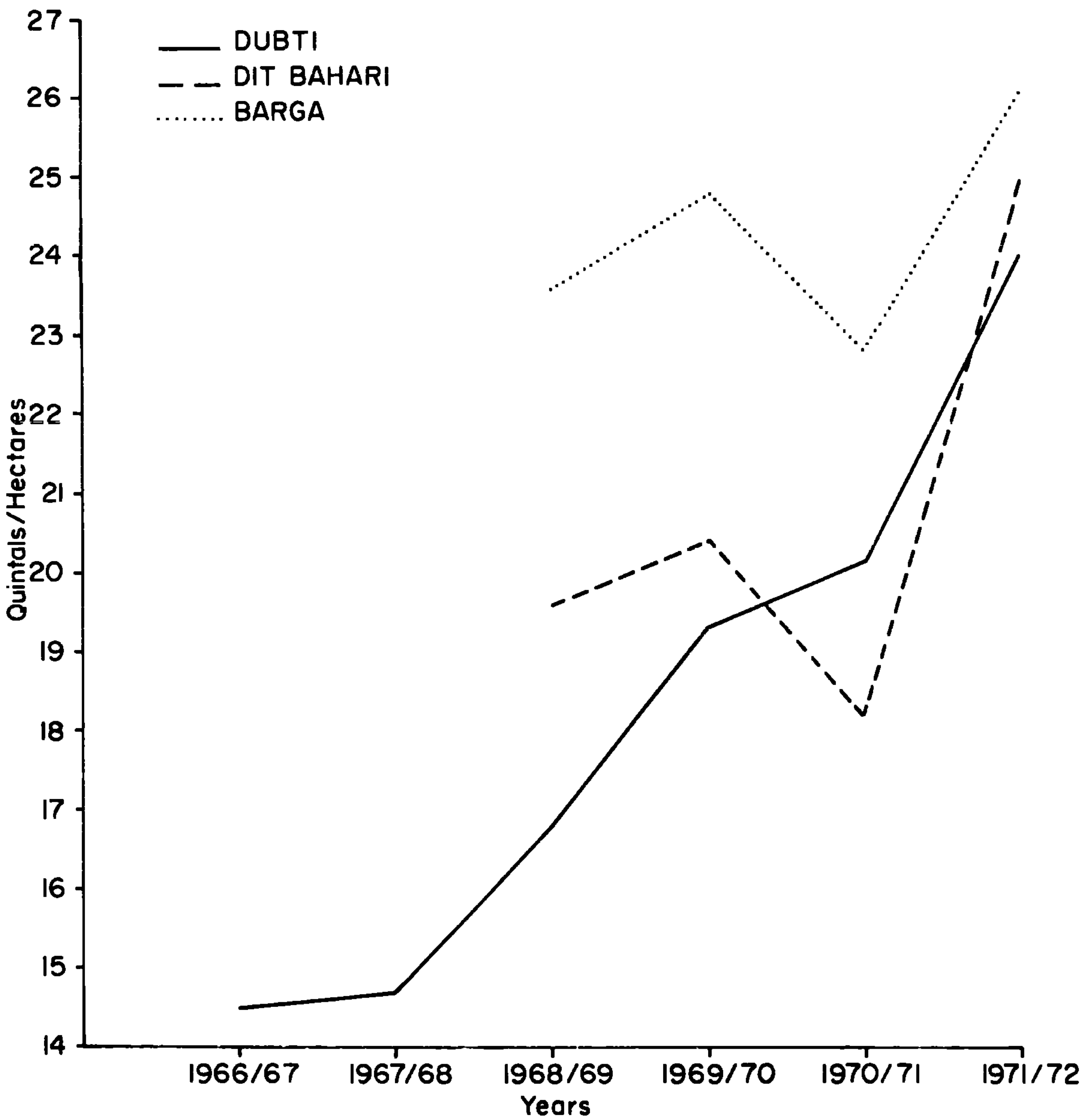


Fig.14

Cotton yields on the major plantations, lower Awash valley, Ethiopia crop not being planted at the optimum time of the year. As a result, jassid attack and blackarm disease, caused by high humidities, were prevalent. Since 1968, planting of the main crop has been carried out in July and August. Germination of the seeds takes place about 4-6 days after planting while the main flowering period occurs about 42 days after germination. The crop is ready for picking after a further 11 weeks and this is carried out by hand labour. There has been a steady increase in the yield of seed cotton per hectare on the plantations, with yields at Dubti rising from 14.5 quintals/hectare in 1966/67 to 20.1 quintals/hectare in 1970/71 (fig.14).

The first irrigation takes place about 8-14 days before the crop is planted, between May and July, and this serves to flush out of the rooting depth any soluble salts that have accumulated on, or near, the surface during the fallow period. The 25 hectare fields are flooded to a depth of about 40 cms and the water is allowed to stand for at least 24 hours. It is then allowed to drain away into the next field which is then further flooded so that, it too, receives approximately the same amount of irrigation water. Much of this first irrigation infiltrates into the soil but planting can only take place when the topsoil is sufficiently dry so as to allow mechanical operations. The fields dry out at a very variable rate depending on the texture of the soil - for instance, some of the clay loam soils may take over a fortnight for them to drain sufficiently to allow tractors on the fields, while the sandy soils may take only 5-7 days.

During the period between irrigation and planting, there is vigorous weed growth, especially of Cyperus rotundus, though in some parts of the plantations the growth of Sesbania sp, a legume, is important. Rapid weed growth reflects the moist conditions in the soil and the high air temperatures. It has been found that discing the fields immediately prior to planting, not only removes the weeds but also that few problems arise from this source during crop growth, though hand weeding is usually carried out at least once during the crop growth. The cotton seeds are sown in rows with an inter-row spacing of 70 or 90 cms, dependant upon the quality of the soil. The closer spacing is used on soils that give poorer yields so as to maintain plant populations. (One of the reasons for the maintenance of plant populations is that if these are allowed to decrease, then the weed population will increase and even further reduce the crop yields). In some fields, a double row of seeds has been planted in 1971 with about 120 cms separating the double row from the next double row. Not only does this give an increased plant population but trials have suggested that higher yields of seed cotton, per hectare, may be obtained.

Additional irrigations take place at three weekly intervals, commencing about four weeks after the cotton has been planted. These irrigations are substantially lighter than the first irrigation, prior to planting, with the fields only being flooded to a depth of about 20 cms. While this figure may even be excessive over parts of the plantations, it is not enough for the corase textured deposits which represent former courses of the Awash or its defluents and stunted growth of cotton bushes is often evident in such localities.

During the early years of the plantations, no fertilisers were applied to the soils, but fallow years were incorporated into the cropping pattern. The effect of a fallow year on the crop was to more than double its yield in the year after the fallow, compared with the pre-fallow year. By the second year after the fallow, the yields had returned to only a little above their former level (Table 5.2). The soils are naturally deficient in nitrogen (see analyses of profiles 22-31, Appendix 1) and one of the effects of the fallow period would have been to cause an increase in the level of nitrogen in the soil. Not only would this increase be associated with decomposition of organic matter from the previous cotton crop, but also atmospheric nitrogen would have been an important source. It was not until 1970 that any nitrogen fertiliser was applied when urea (46%N) was spread over fields that had recorded consistent low yields. The rate of application was 1 quintal/hectare but the crop response was very mixed. In some fields, marked improvements were apparent, but in other cases, a further depression in yield resulted, thus suggesting that factors other than soil nitrogen also contributed to the low yields. In 1971, all fields had an application of urea at a rate of 1 quintal/hectare while the poorest fields received an application of double this rate. The urea is applied immediately prior to the second irrigation, about four weeks after the crop was planted, and it is mixed in with the topsoil by a cultivator. This mixing with the topsoil reduces the loss of nitrogen, as ammonia, through volatisation, and it also tends to slightly ridge the

Table 5.2

Yields of fields following fallow years, Dubti Plantation

Field	Size	Yield (in Quintals)				
	(hectares)	1965/66	1966/67	1967/68	1968/69	1969/70
1/6	24		304.8	Fallow	621.1	392.0
4/24	19	156.3	Fallow	Fallow	391.9	191.2
5/10	24	219.7	Fallow	450.9	238.4	396.0
6/11	24	304.9	185.7	Fallow	476.2	243.3
6/20	25	290.1	155.9	Fallow	435.8	303.1

cotton crop. Results on the experimental plots suggest that ridging also helps to improve crop yields (Tendaho Plantation Share Company, Research Report, 1970-1971).

5.3 The Soils

In 1965 SOGREAH published their Survey of the Awash River Basin in which they classified the soils of the basin in 9 groups. These major groups were subdivided into:

(i) sub-groups. The basis of this division was the type of parent material including the age of the deposit (recent or old) and whether or not it was calcareous.

(ii) series. Soil series were defined according to horizon characteristics which included texture, structure, salinity and alkalinity.

(iii) phases. Microrelief, depth of soil, frequency of flooding and salinity were used as criteria to distinguish series which were only mapped on scales of 1:100,000 or greater.

Six of the major groups are to be found on the two major plantations of Dubti and Dit Bahari: aluvial soils, vertisols, hydromorphic soils, organic hydromorphic soils, saline soils and regosols.

The Awash Valley Authority are currently preparing a plan for the integrated development of the valley, including the building of a major dam at Tendaho. Included in this plan is a report on the soil-geomorphic relationships in the Lower Awash Valley (Curry, 1972). A map, based mainly on air-photo interpretation, shows a number of soil-geomorphic associations, of which five occur on the two major plantations:-

(i) Awash River sediments. These deposits, of very varied texture, reflect not only the contemporary depositional pattern of the River Awash but also the sediments left behind by its former courses and their major defluents. A typical levee pattern has developed with most of these courses.

(ii) Minor stream sediments and hillwash. Deposition of these sediments is very erratic and when it does occur, it usually takes place in fan form. Some levees are also apparent.

(iii) Swamp and depression sediments. The low areas between the hillwash fans and the levees of the Awash River system are occupied by heavy textured clays which crack when dry. The water table may be within a metre of the surface, though not in the area of the cotton plantations.

(iv) Desert (marine) sediments. Curry regards the desert sediments as being originally of marine origin. He postulates that faulting caused an arm of the Red Sea to be blocked off and cites the presence of shells in the deposits as evidence for this. These sediments are often saline.

(v) Newer lavas. Small areas of the newer lavas occur on the northern edge of the Dubti Plantation where there is fumarolic activity, associated with an old fault line. A number of these fumaroles have been reactivated by the downward percolation of irrigation water.

There is only very limited correlation between the SOGREAH scheme and that of the Awash valley Authority, and consequently difficulties exist when trying to fit the soils into the FAO groupings. The difficulties are accentuated by

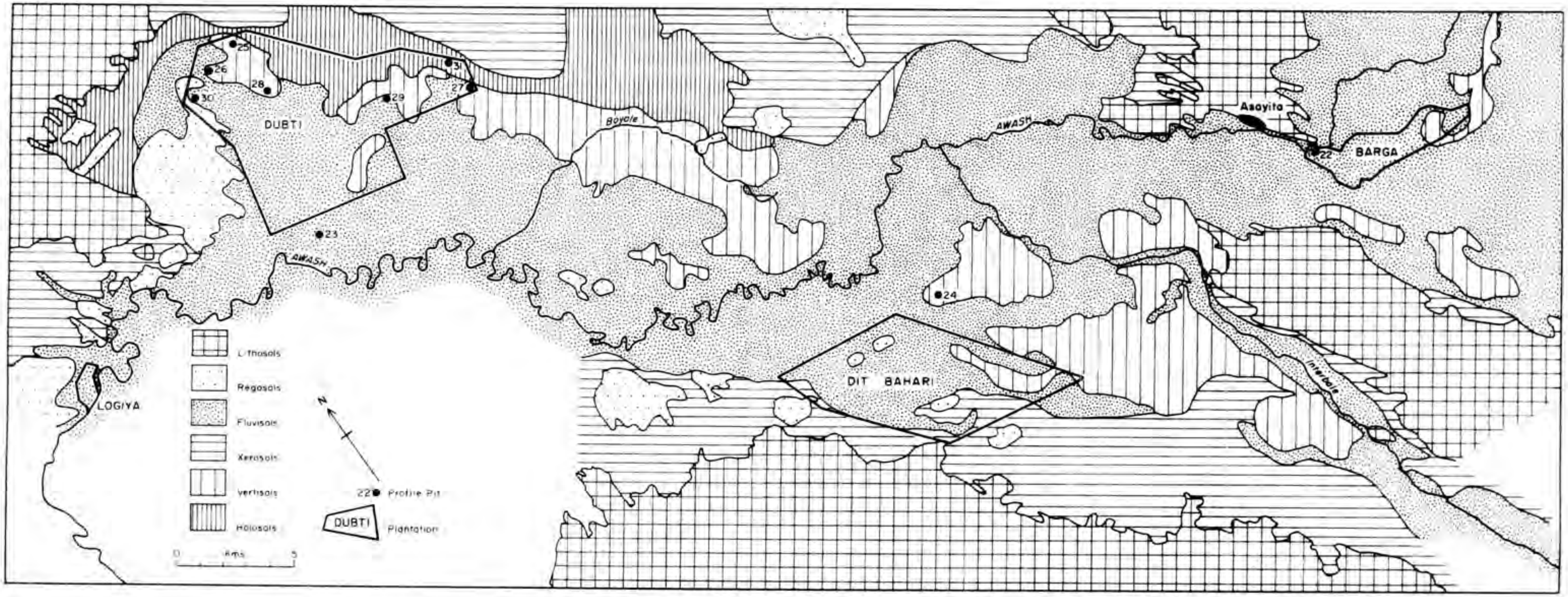


Fig.15
Major soil groups, lower Awash valley. (Based on SOGREAH, 1965, Curry, 1972 and author's fieldwork.

the intergrade nature of many of the soils, due to the depositional nature of their parent material and the relatively slow rate of pedogenesis. Approximate correlations as outlined by the present author are shown in Table 5.3, while the distribution of the soils is given on figure 15. This soil map is mainly based on the 67 soil profiles examined in the field by the author. Only 14 of these profiles were uncultivated.

Soil profile 23 is representative of an uncultivated fluvisol. The profile pit was located in heavily grazed riverine woodland (the main bush/tree species were Callotropis procera, Euphorbia sp. Tamarindus spp. and Salvadora persica) and the site was subject to annual flooding. While heavier textures prevailed in the surface horizons of this profile, this was by no means common to all fluvisols. Structure is also variable but moderate medium angular blocks may occur when there is a reasonable vegetation cover (in the case of profile 23 it amounted to about 20%) and in particular where the roots of grasses such as Cyperus rotundus aid structure formation. Depositional laminations were visible throughout the profile. Except where they are formed adjacent to depressions, fluvisols tend to have low conductivities and are hence low in soluble salts. Organic matter contents are higher in fluvisols close to the River Awash, where there is thicker vegetation, and they may reach over 3% in the surface horizons. In contrast, organic matter contents of fluvisols which are not subject to annual flooding, and hence where vegetation may be very sparse, are often less than 1% throughout the profile.

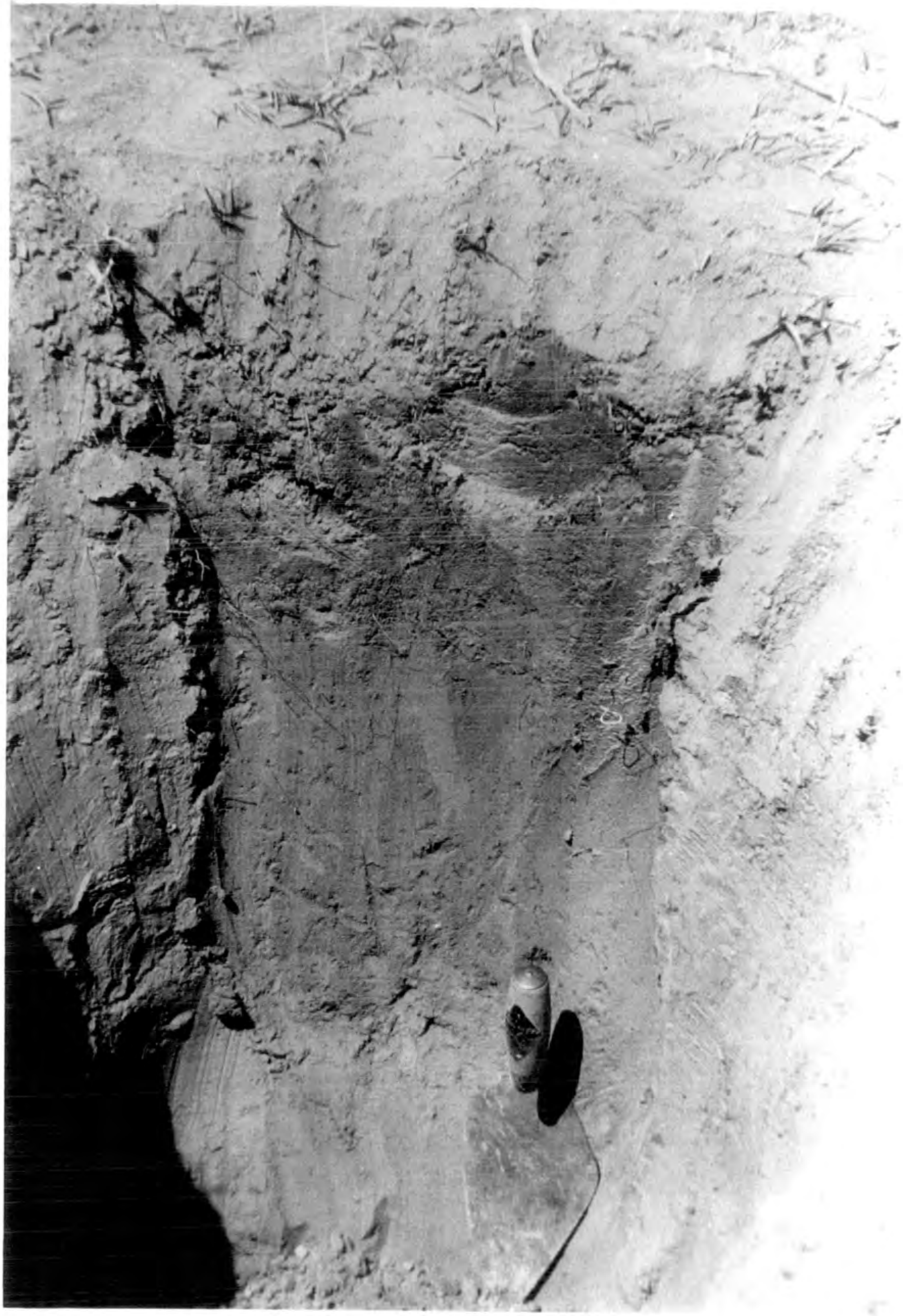


Plate 7

Uncultivated Fluvisol, lower Awash valley, Ethiopia (profile 23).

Table 5.3

Correlations between FAO, SOGREAH and Awash Valley Authority soil classification schemes, Dubti and Dit Bahari Plantations, as recognised by the author.

FAO	SOGREAH	AWASH VALLEY AUTHORITY
REGOSOLS	Regosols	Desert (marine) sediments pp.
FLUVISOLS	Alluvial soils	Awash River sediments
	Hydromorphic soils pp.	Swamp and depression sediments pp.
	Vertisols	Minor stream sediments and hillwash pp.
VERTISOLS	Vertisols pp.	Swamp and depression sediments pp.
	Hydromorphic soils pp.	
	Organic Hydromorphic soils pp.	
HALOSOLS	Saline soils pp.	Desert (marine) sediments pp.
		Newer lavas
XEROSOLS	Saline soils pp.	Minor stream sediments and hillwash pp. Desert (marine) sediments pp.

pp. - pro parte

The clay contents of the vertisols are in excess of 25%, and may be as high as 65%, and are dominated by clay minerals of the expanding lattice type. As a result, cation exchange capacities are high (in some cases over 100 meq/100 grms soil), while large cracks appear in the soil as it dries out. These cracks may extend to more than 1 metre in depth while slickensides are frequent at depth. The uncultivated vertisol has a thin, very dark grey (10YR3/1-3/2) surface horizon, which may be up to 15 cms in thickness, containing as much as 10% organic matter. The high organic matter contents are a reflection of the fairly thick (up to 80% cover) tussock grassland, mainly composed of Aristida spp, which is the natural vegetation of these soils. Conductivities rarely exceed 2 mmhos/cm at 25°C throughout the top metre of the profile, though pHs may be high (over 8.3) on account of secondary calcium carbonate enrichment that occasionally occurs. The description and analytical data for a typical vertisol (profile 24) are given in Appendix 1).

5.4 The effect of cultivation practices on soil properties

In contrast to the other case studies from the Arabian Peninsula, a certain amount of soil analytical data is available for the Dubti Plantation. Soil samples were collected in 1967 and analysed by Hunting Technical Services, but care must be taken when comparing this data with the results obtained by the author in 1971. This is because methods of analysis were slightly different and also because there is great textural variability in the soils over even a few metres which makes exact comparisons difficult. Furthermore, the samples collected for analysis by

Hunting Technical Services were composite samples over 30 cms wide bands (0-30 cms, 30-60 cms and 60-90 cms depth), and included in a sample will have been depositional horizons of very different textures. Such a sampling interval is suitable for agronomic investigations but considerably finer sampling intervals are required for studies relating to pedogenesis. The author sampled 52 profiles at four major depths, relating to the rooting depth of cotton:-

5-15 cms. This sample is representative of the cultivated horizon of the soil, and also the seedbed.

25-35 cms. Young cotton plants root mainly at this depth. This sample is also representative of the main rooting depth of alternative crops such as maize or rice.

45-55 cms. The roots of mature cotton are mainly found at this depth. There was little field evidence to show that cotton rooted much below this depth, even on the sandier soils.

65-75 cms. This sample was indicative of soil conditions below the rooting depth of cotton. If there were marked textural variations within these sampling depths, a slight adjustment was made, so that there was textural uniformity within a sample. This is a rather more rigid sampling programme, compared to either of the two preceding case studies, but it has value where there is consistency in the cropping techniques practised, as on the cotton plantations. Analyses were carried out in the laboratory, by the author, on 208 samples.

5.4(i) Soil physical properties

A feature of semi-arid and arid zone soils is the presence of a thin surface crust. In the lower Awash valley, on uncultivated

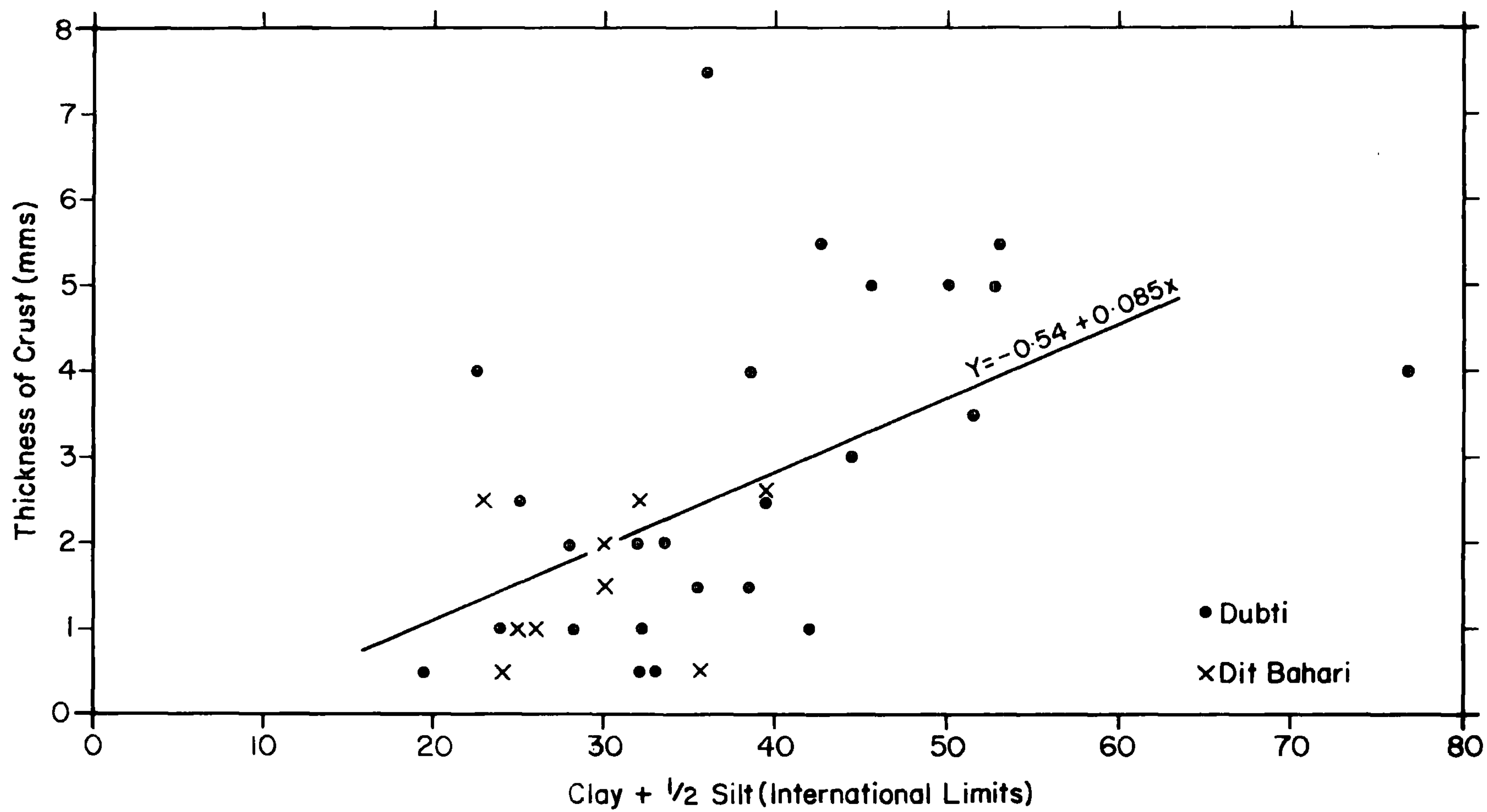


Fig.16

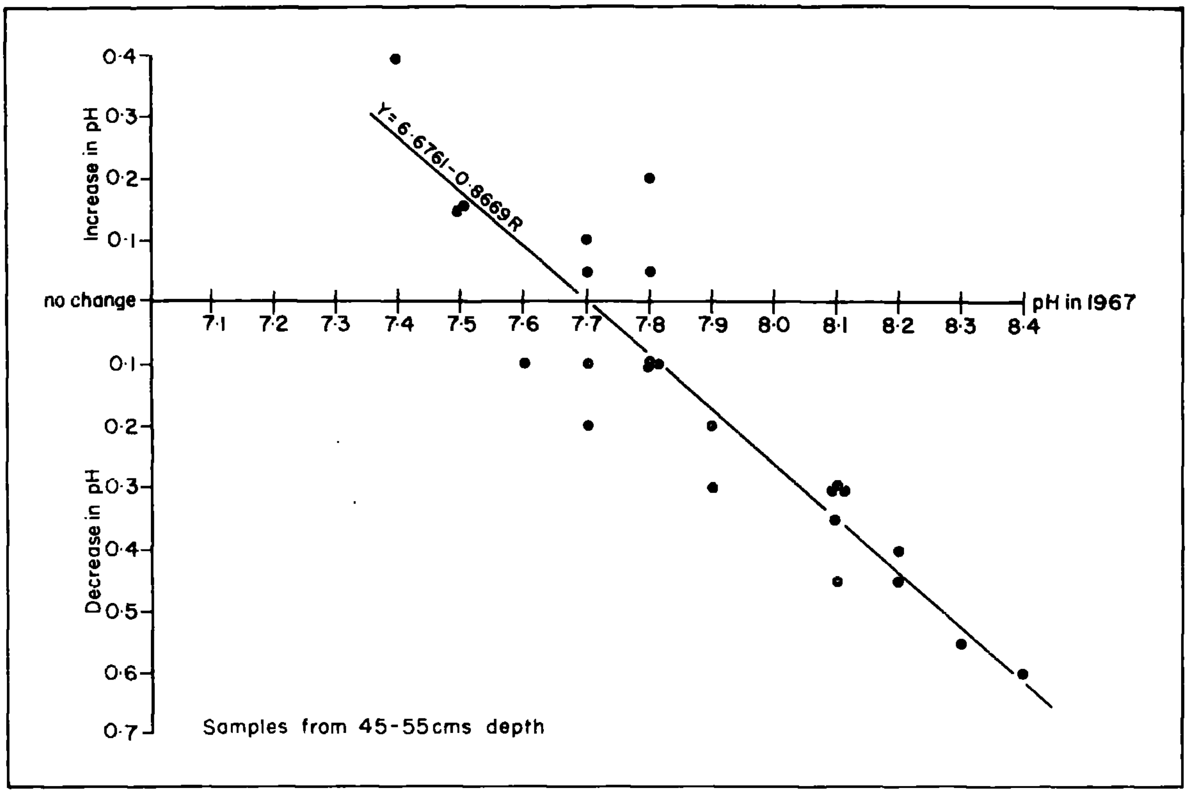
Relationship between thickness of soil crust and soil texture, Dubti and Dit Bahari Plantations profiles, this crust is usually weakly developed and less than 0.1 cms in thickness, though where annual flooding occurred it was slightly thicker (0-1.5 cms). Observations suggested that these thicknesses were irrespective of soil type.

The crust, dominated by silt-sized particles, with their long axes having an horizontal orientation, set in a matrix of finer particles, is formed by the impact of falling raindrops, which not only causes a compaction of the surface but also results in the fine particles taking up a preferred horizontal orientation. Weak development of this crust is also a reflection of the lack of organic colloids. With increasing proximity to the river, vegetation is denser, the land is subject to flooding and the accumulation of silt (and consequently the crust) thickens.

On the plantations this mechanism is even more pronounced. The crust is not only strongly developed, but can also be of considerable thickness (up to 0.75 cms) and figure 16 suggests that there is a close correlation with the finer fractions of the soil. Irrigation from the River Awash water contains a considerable sediment load which is deposited on the surface of the soil, where it remains undisturbed as the soil dries out. This sediment is mainly composed of silt, with some clay, and because of its relatively large surface area compared to its weight, the silt particles tend to have a preferred horizontal orientation in the water. They are thus deposited in the best position to aid crust formation and this is accentuated by surface flow as the irrigation waters subside. There also tends to be a higher quantity of organic colloids in the cultivated soils and this aids stability and cohesion of the crust.

Mechanical operations also contribute to crust formation, as they break down structural elements into their component particles but, at Tendaho, they have not caused the crust to interfere with the growth of the cotton crop.

The surface crust, when dry, exhibits a mosaic of fine cracks but the soils, as they dry out, also crack to considerable depths. This is due to the fact that the clays are of an expanding lattice type, dominantly montmorillonite, and shrinkage of the lattice due to the removal of inter-layer moisture causes the cracks to form. Shrinkage cracks are most marked in soils of heavy textures, particularly if the clay content is in excess of about 30%. In the uncultivated vertisol (profile 24) the cracks are up to 10 cms in width at the surface while extending to at least 100 cms in depth. However in cultivated profiles, it is rare for these cracks to extend much below 40 cms for, below this depth, the soil seems to remain moist throughout the year. Even between irrigations, considerable cracking can occur as, for instance, in profile 25, where cracks were observed to a depth of 15 cms, only 14 days after irrigation. The importance of these cracks cannot be overstressed because whereas the crust reduces the amount of diffusion of soil air into the atmosphere, thus leading to a build up of carbon dioxide in the soil from the decomposition of organic matter and respiration of the plant roots, the cracks encourage diffusion. Furthermore, whilst crusts serve to reduce initial infiltration of moisture into the soil, the shrinkage cracks allow the rapid percolation of water to depth, at least prior to the clays swelling and the cracks closing. As the clays swell, they will cause a break-up of the soil crust and normal infiltration will then occur.



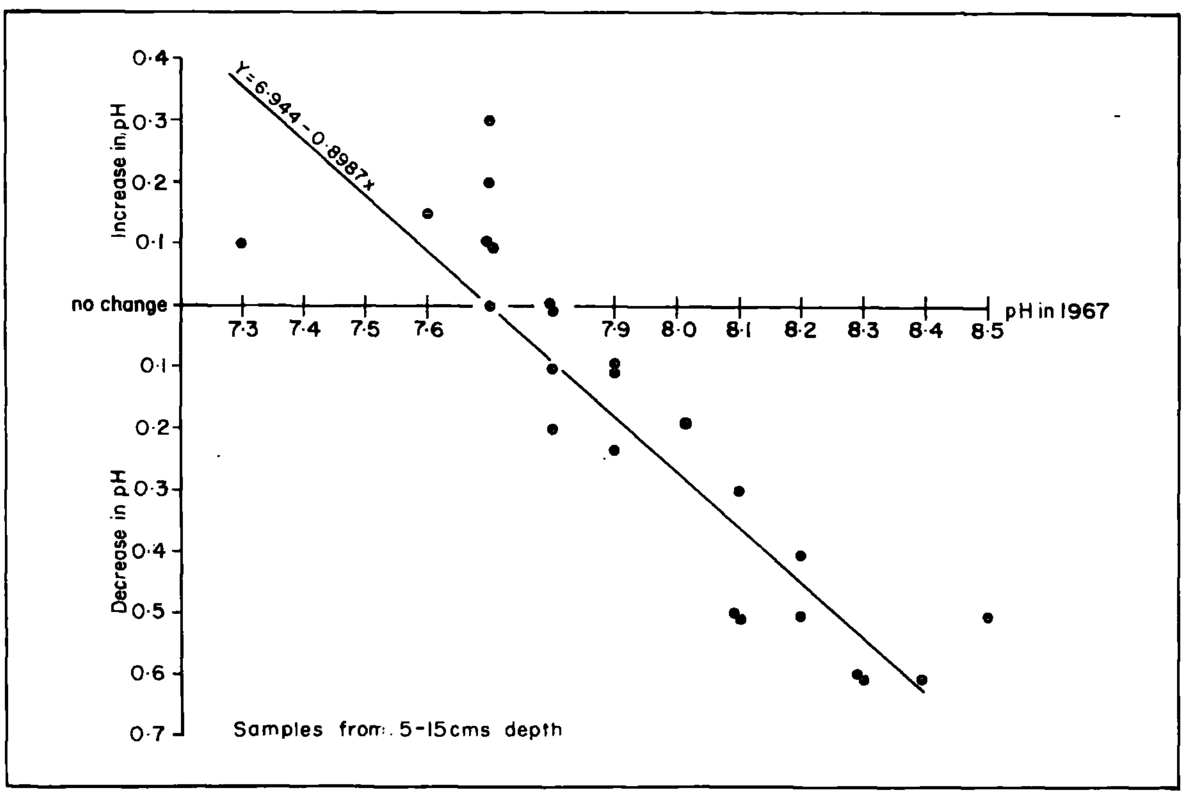


Fig.17
Changes in pH values, 1967-1971, Dubti Plantation

With each irrigation a considerable amount of silt is added to the soil. The first, heaviest irrigations are carried out between mid-May and July and, especially during the latter part of this period when the River Awash is rising, the irrigation waters are heavily charged with sediment. In 21 out of 29 profiles examined on Dubti Plantation, the silt content (USDA limits, 0.05-0.002 mms) was greater in the surface sample (5-15 cms) than in the sample from 25-35 cms depth. A consequence of this relatively high silt content in the topsoil is that structural aggregates are weak and not particularly water stable. As the aggregates break down, the material of which they are composed, in addition to the sediment in the irrigation water, is washed into the shrinkage cracks. The clays cannot expand laterally and instead expand upwards and the irrigated fields have what may be termed an 'incipient gilgai micro-relief', with both high and low spots occurring between the rows of cotton.

5.4(ii) Soil chemical characteristics

Irrigation appears to have had marked effects on both soil pH and conductivity values. Changes, since 1967, in both these values for samples from the Dubti Plantation are shown in figures 17 and 18. Both the 1967 samples, collected by plantation staff for Hunting Technical Services, and the 1971 samples, collected by the author, were obtained when the dominant moisture movement in the soil was downwards. (As the soil dries out after the cotton crop has been picked, an upward capillary movement is initiated.) Data presented in these two diagrams make no allowance for the length of time that the soils have been cultivated - in fact some of the soils were cultivated for the first time in 1970/71 while others had been cultivated prior to 1967. Fields that had only been cultivated for short periods of time showed the greatest change, and thus the major changes in these two values may take place during the first season of cultivation. Two factors are probably responsible for this. Firstly, as will be seen, there is a marked reduction in the amount of organic matter present in the soil as a result of initial clearance and cultivation of the land. Because of the high temperatures and the moist nature of the soil, decomposition of the organic material will be rapid with the production of acids which will tend to lower the soil pH values. With a single crop, the net effect of several years of cropping and subsequent decomposition of organic residues would be to stabilise the pH values of the soils. Figure 17 would suggest that this stability value is about pH 7.5-7.8. Some soils, whose pHs were below about 7.5 in 1967 have in fact increased their values. These soils tend to have heavier textures, silty clay loams, and prior to cultivation probably contained more organic matter in the soil than after cropping. The natural vegetation of such soils, subject to annual flooding by the Awash, was tussock grassland with some tree species, including Acacia spp, which would have provided more organic residues than cotton cropping. Consequently, the production of organic acids has been reduced and the pH risen.

The second factor that has affected these values, especially soil conductivity, has been the first irrigation. When the latter is applied, the soils are dry and contain extensive shrinkage cracks to about 40 cms, as a result of the summer fallow period. This latter period is also responaible for the accumulation, by capillary

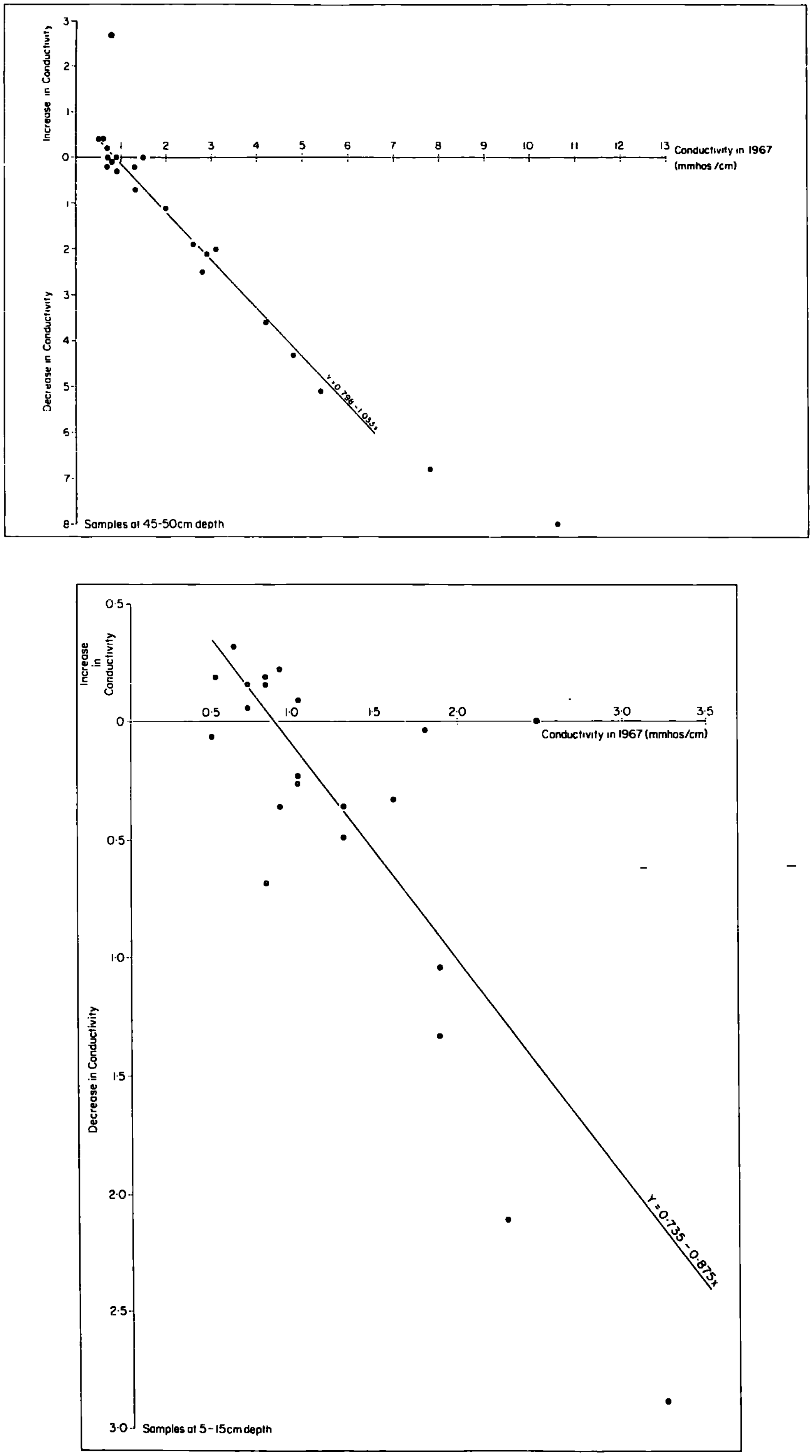


Fig.18
Changes in soil conductivity values, 1967-1971,
Dubti Plantation.

movement of moisture, of soluble salts in the topsoil, and the first irrigation washes these salts, along with some of the residual inherent salts, into the lower parts of the profile. Before the clays swell with wetting, the cracks form good channels for the translocation of the soluble salts in the irrigation water. No more than about 10 cms of the first irrigation is required by the crop and the effect of the surplus irrigation water has been to reduce the amount of soluble salts present in the soil. The decrease in conductivity is not nearly so marked in the topsoil samples as in the samples from 45-55 cms depth. In 1971, the samples were collected during July and August, before the whole of the plantation had received its first irrigation, and as a result soluble salts that had accumulated during the summer fallow had not been completely leached out of the topsoil.

Reduction in conductivity is also reflected in the changing pattern of soluble salts in the soil profile. Representative data for typical uncultivated soils are shown in Table 5.4 and in all three profiles carbonates are absent while amounts of bi-carbonates are low. The salinity in the soil is caused by an accumulation of chlorides and sulphates left behind as the ground-water table fell due to the progression towards aridity following the last pluvial period. SOGREAH (1965) comment that the 'deep water table in the Lower Plains (at a depth of 25-30 metres) contains far more salts', than in the Upper Basin, 'mainly consisting of sulphates and chlorides (conductivity up to 3.27 mmhos/cm)'. When Hunting Technical Services carried out their analyses in 1967, the area in which profiles 25 and 26 were located was regarded as being saline with conductivities in excess of 4 mmhos/cm at 25°C in the

Table 5.4

Representative salt data for uncultivated soils, lower Awash Valley

	Halosol[1]					Vertisol (Profile 24)						Fluvisol (Profile 23)				
Depth cms.	Conductivity mmhos/cm	Soluble anions meq/litre				Depth cms	Conductivity mmhos/cm	Soluble anions meq/litre				Conductivity mmhos/cm	Soluble anions meq/litre			
		CO_3	HCO_3	Cl	SO_4			CO_3	HCO_3	Cl	SO_4		CO_3	HCO_3	Cl	SO_4
0-30	1.6	-	3.0	1.1	10.7	5-15	1.0	-	2.5	1.7	12.1	0.7	-	2.0	2.6	4.3
						25-35	0.8	-	2.3	2.1	10.5	0.6	-	1.3	0.6	4.1
30-60	4.7	-	3.2	6.1	39.3	45-55	0.9	-	2.0	2.1	12.5	0.9	-	1.7	1.1	4.1
60-90	10.7	-	3.4	62.9	87.4	65-75	0.9	-	2.0	2.5	12.9	0.5	-	1.5	1.3	2.3

[1] Analyses of Halosol profile carried out by Hunting Technical Services, 1967.

soil samples taken from below 30 cms. Although no soluble salt analyses were undertaken then, other saline profiles showed that chlorides and sulphates were the dominant soluble anions. Analyses of profiles 25 and 26 now show that while the conductivity has been markedly reduced, there has been a slight increase in carbonates. The profiles are now characterised by a virtual absence of chlorides and low quantities of sulphates (Table 5.5). An exception is the sample from 65-75 cms depth of profile 25 where the conductivity remains in excess of 4 mmhos/cm at 25°C and 42 meq/litre of sulphates are present. With increasing conductivity, the ratios of chloride to sulphate anions in halosols increases, as can be seen in Table 5.4, and the first effect of irrigation has been to wash out the chloride anions. This is supported by data from other fields where cultivation has only been taking place for a few years e.g. profile pits 22 and 27 where the amount of chlorides is low or even absent in the topsoil samples. Only after there has been an appreciable reduction in the chloride anions are the sulphate anions removed and it is evident that the conductivity of cultivated soils is a reflection of the amount of sulphates present.

The main drainage canal of Dubti Plantation is shown on figure 13, but it does not exactly follow the topographic depression. A former course of the River Awash, or a major defluent, can be traced in some of the fields immediately to the south of it. The fields adjacent to the main drainage canal are mainly of heavy texture (clay loam or silty clay loam) and, since the old river course probably still forms the natural drainage channel for subsurface moisture, the soils remain moist even through the summer

Table 5.5

Salt distribution in two cultivated profiles, Dubti

	PROFILE 25						PROFILE 26					
	CONDUCTIVITY mmhos/cm		SOLUBLE ANIONS meq/litre				CONDUCTIVITY mmhos/cm		SOLUBLE ANIONS meq/litre			
Sample depth (cms)	1967	1971	CO_3	HCO_3	Cl	SO_4	1967	1971	CO_3	HCO_3	Cl	SO_4
5-15	)	0.11	2.6	2.4	0.4	2.7	)	0.93	1.1	4.4	-	2.2
	)0.8						)0.8					
25-35	)	1.48	0.6	2.3	0.4	12.5	)	1.35	-	2.0	-	12.1
45-55	4.2	0.56	-	2.0	-	2.9	4.8	0.47	-	1.8	-	1.3
65-75	7.5	4.35	2.0	1.1	-	42.5	5.2	0.43	-	0.4	-	1.3

Soluble anions determined on samples collected in 1971 fallow due to their poor internal drainage. Much of the drainage water from fields along the northern edge of the plantation contains a greater quantity of soluble salts and exchangeable sodium than from other areas due to fumarolic activity. The fumaroles and mud volcanoes are, themselves, partially the result of cultivation, since irrigation water, percolating to deeper levels of the alluvial deposits, has reactivated some fumaroles, while others are known to have become reactivated through mechanical operations. One dormant mud volcano, for example, became reactivated through a tractor getting stuck in it, and digging a large hole, before being winched out (New Zealand Geothermal Survey, Private Communication). The fumaroles have temperatures of 90-110°C and some evaporite deposition is associated with, at least, the earlier stages of their genesis. Drainage water from the fields containing this fumarolic activity has caused a potentially dangerous situation to develop in the heavy textured fields along the main drainage canal. Because they remain moist throughout the year, there has been some preferential absorption of sodium on the exchange complex. This is reflected in profiles 28 and 29 in which the ESP values amount to 12-17% compared with figures of 6-8% for unaffected soils. Furthermore, the sodium adsorption ratios (SAR, which is an expression of the relative activity of the sodium cations in exchange reactions), are in excess of 15 compared with values of less than 10 for soils not affected by these drainage waters. This would suggest that the amount of exchangeable sodium in the soil is likely to increase and the soil may well become alkaline over a period of time. This is the classic situation of salinity and alkalinity problems developing

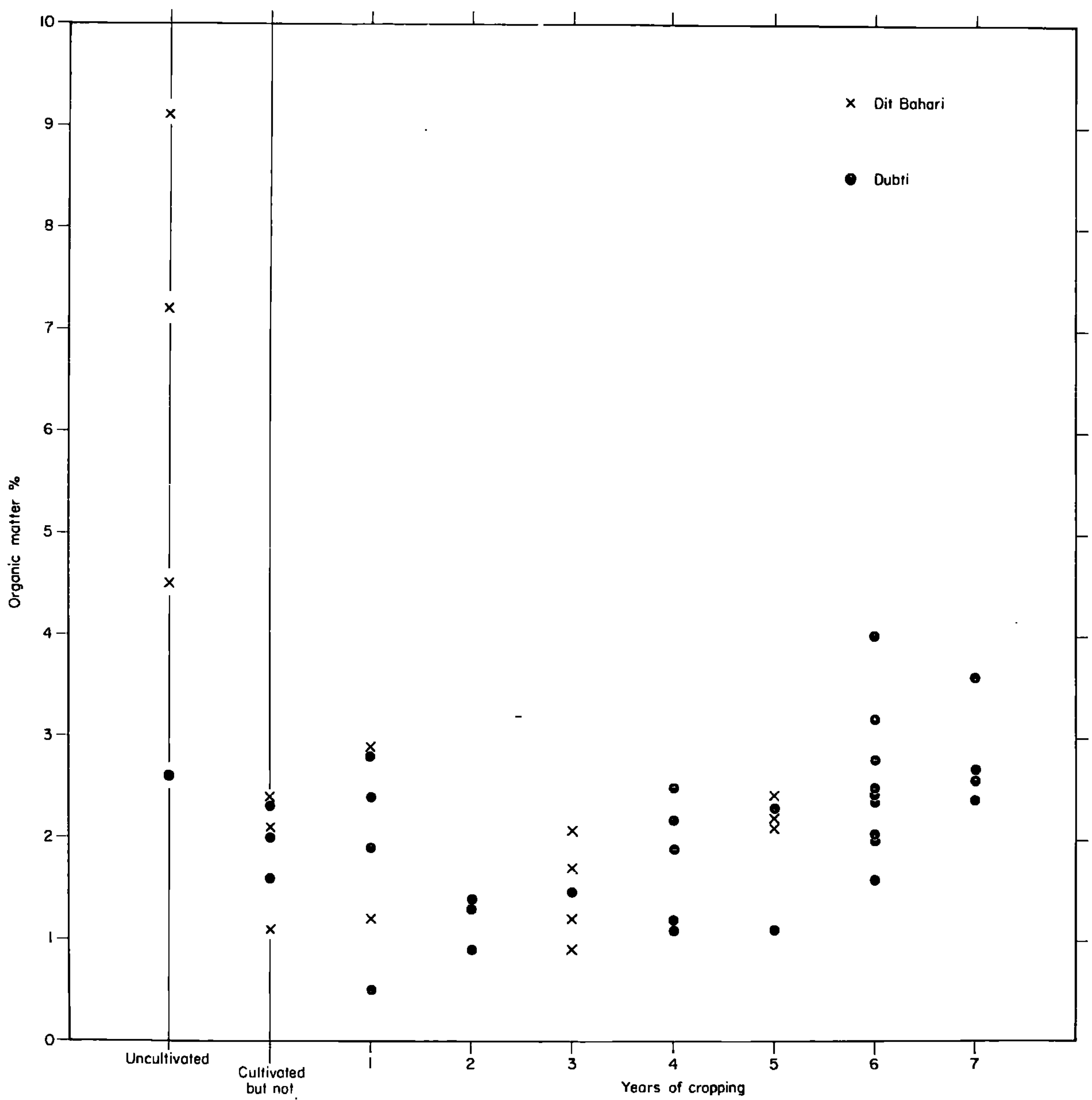


Fig.19

Changes in soil organic matter content related to number of years of cropping, Dubti and Dit Bahari Plantations as a result of poor drainage conditions, albeit on a minor scale here, and which have affected so many of the irrigated areas of the Middle East, notably in Egypt and Iraq.

5.4(iii) Soil organic matter

As in the other examples of cultivated soils in arid regions, an important effect of cultivation has been to alter the organic matter content of the soil. In the lower Awash valley, there is no simple relationship between cultivation and the amount of organic matter present in the soil - some virgin soils, particularly those of heavy texture under tussock grassland, have organic matter contents in excess of 15%, while others, in areas almost devoid of vegetation have contents of less than 1.5%. Kononova (1961) quoting the work of Gel'tser and Lasukova in the 1930s, states that a virgin serozem soil 'after ploughing for cotton for a period of 3-7 years, loses about one-half of its total reserve of organic carbon'. Gel'tser's figures are given in Table 5.6 and it would appear that there is a progressive decline in the amount of organic matter in the soil until at least the seventh year of cultivation.

The current work of the author would suggest that Kononova's conclusions do not always hold as is shown in figure 19. The first effect of cultivation on virgin soils is to cause a decrease in organic matter content but after about two years of cropping the levels of organic matter in the soil start to rise. Disturbance of the topsoil of uncultivated soils, in particular, the crust, allows the rapid oxidation of the organic matter. Even prior to any irrigation water, this decomposition is aided by an increased

Table 5.6

Percentage contents of organic carbon and nitrogen in virgin serozem soils and in serozems growing cotton in 0-20 cm layer. (Figures from Kononova, 1961, based on the work of Gel't ser and Lasukova 1934).

	Organic C %	Nitrogen %
Virgin land I (Serozem)	0.78	0.097
Cotton - 1st. year after ploughing	0.60	0.086
" - 2nd. " " "	0.48	0.076
" - 3rd. " " "	0.37	0.059
Virgin land II (Serozem)	1.16	0.106
Cotton - 3rd. year after ploughing	0.77	0.111
" - 7th. " " "	0.56	0.095

amount of dew within the top few centimetres of the soil. Because the uncultivated fields are surrounded by irrigated areas, the humid gradient of dew deposition will predominate for the greater part of the year. Duvdevani (1953) found that, during the arid summer months, the amount of dew deposited on gauges increased from ground level upwards. The humid gradient is the reverse situation, occurring during the winter months, but it is also present in irrigated areas during the summer months, and at Tendaho will be aided by the hygroscopic nature of the salts accumulating on or near the soil surface. The presence of this moisture will stimulate the microbial decomposition of organic residues. Following the first irrigation, the latter is accentuated for a very favourable environment for soil micro-organisms is now present - adequate moisture, an alkaline soil reaction and high temperatures throughout most of the year.

The amount of organic matter in the topsoil continues to decline during the first year or two of cultivation as the organic residues from the natural vegetation continue to decompose. After each crop of cotton, the standing plants are slashed close to the ground and this is followed by disc ploughing to a depth of 20-24 cms. Not all the aerial portions of the old cotton crop are allowed to decompose,as cattle, belonging to Danakil tribesmen, invade the plantations during January-March and consume a considerable proportion of the cotton trash. It would thus appear that it takes a number of years for the organic residues from cotton to affect the level of organic matter in the soil, and the equilibrium level may not be established until after several seasons of cropping. Figure 19 would suggest that this equilibrium level may be approached after six or seven years of cropping.

A further effect of the increased organic matter content, in association with mechanical operations, has been to modify the structural characteristics of the heavy textured soils. Profiles 25, 26 and 27 were located in such areas in fields which had been cultivated for at least 7,6 and only 1 year respectively. While large and medium angular blocks predominate in the topsoil of all three profiles, the former two profiles contain an appreciable quantity of small granules in the seedbed while the angular blocks are also not so harsh as in profile 27. This is due to the increased organic matter in the structural aggregates allowing the greater, and stronger, retention of moisture.

5.4(iv) Soil Nutrient Status

In contrast to cultivated soils of more humid areas, the level of organic nitrogen present in the soil is low, rarely exceeding 0.1%, reflecting the generally low levels of organic matter in the soil. The total nitrogen figure does not, however, reflect the amount of available nitrogen present at a given time but it does give an indication of reserve supplies. Under natural conditions, the carbon:nitrogen (C:N) ratios are about 10-11 in the topsoil decreasing to about 6-8 in the subsoil especially where the vegetation is of a grassland type. The C:N ratios give an indication of the speed at which nitrogen becomes available from the organic matter present in the soil - the lower the ratio the quicker the nitrogen will be made available. In contrast to the uncultivated soils, those of the plantations tend to have C:N ratios of about 17-21 in the topsoil where cotton trash has been ploughed in. However, if the previous crop had been maize, the C:N ratio is likely to be wider - for example in profile 30, the C:N ratio of the topsoil was 24.0. It has been found at the Melkar Werer Research Station (Annual Report, 1968-1969) that maize residues contain a large amount of carbohydrates which tie up the nitrogen reserves in the soil. The implications of these relatively wide C:N ratios in the topsoil is that there will be a slower release of nitrogen to the soil from the decomposition of crop residues than from natural vegetation residues, and it will be less in the case of maize residues than cotton trash.

Because of the generally low levels of nitrogen present in the soils, urea, containing 46%N, has been applied to all fields in 1971 for the first time. It was applied at a general rate of 1 quintal/hectare but fields which had a record of low yields received 2 quintals/hectare. Urea rapidly releases nitrogen in water-soluble organic form. The water-soluble form changes to ammoniacal nitrogen within a few days of application through microbiological activity. An advantage of ammoniacal nitrogen is that it takes part in cation exchange and can consequently be held on the clay micelle, thus retarding its free movement through the soil. The rapid response of cotton to the application of urea was noted at profile 31 where, at the time of sampling, the cotton was very yellow in colour. As can be seen from the analysis, the amount of nitrogen was very low (0.04%) and, within four days of the application of urea, greenness was restored to the crop.

Plate 8

Cultivated Fluvisol previously under rice and maize cultivation, Dubti plantation, lower Awash valley, Ethiopia. Note the deterioration in structure in the surface horizon caused by rice cultivation.

It must not be thought that the ammoniacal nitrogen is held indefinitely on the clay micelles, with any not utilised by the crop enhancing the nitrogen status of the soil. It is considered (Volk, 1971) that bacterial action converts the ammoniacal nitrogen to nitrate nitrogen within about four weeks but the speed of this conversion is slowed down when the soils are saturated with moisture. Nitrate nitrogen is available to plants, but it is soluble and consequently the applied nitrogen fertiliser will gradually get washed out of the soil.

Levels in the soils of the other two major nutrients, potassium and phosphate are adequate for crop production. In the past, several analyses have been carried out on the potash and phosphate status of soils on the Dubti Plantation but a direct comparison with the author's data is not feasible as the methods of determination are not known. There is a general tendency for the amount of available phosphate to increase with depth despite a decline in the amount of total phosphate present. A reverse trend is apparent with available potash. While it might be expected that amounts of available phosphate would be low, due to the free calcium carbonate present in the soil and also to its use by the cotton crop, this does not appear to be the case. The availability of phosphatic nutrients may be attributed to their release due to the decomposition of the cotton residues. Not only will this release organic phosphate compounds which can be readily assimilated by plants, but also the production of humic acids will cause the breakdown of some insoluble calcium phosphates into available forms.

CHAPTER 6

Al Hasa Oasis, Saudi Arabia : Sand Stabilisation Scheme

6.1 The origins of the Sand Stabilisation Scheme

The oasis of Al Hasa is located in the Eastern Province of Saudi Arabia, about 150 kms south-west of Dammam, at an altitude of about 140-160 metres above sea level. It has always been an important agricultural centre and currently there are about 225,000 people living in the two major settlements of Hofuf and Mubarraz, as well as in about 50 small villages scattered throughout the oasis area. The oasis is L-shaped with Mubarraz and Hofuf being located at the junction of the two arms (fig.20). The cultivated area can be divided into a northern part and an eastern part and now amounts to about 8,000 hectares, though in former times it was much more extensive. A large new irrigation and drainage scheme has just been completed and, when this is fully operational, a further 12,000 hectares will be added to the cultivated area.

Al Hasa, according to Hava's dictionary means 'swampy ground covered with sand' (Vidal, 1955) and it has probably been settled since at least Neolithic times. Spear points and pottery of this age have been found while there are a number of tumuli in the oasis area. Al Hasa eventually became the largest single oasis in the Arabian Peninsula with water being supplied by artesian flow. The original sources were a number of springs, the four most important being Umm Sab'ah, al Harrar, al Haql and al Khudud. The latter is the largest of the springs and, together with al Harrar and al Haql, was mainly responsible for

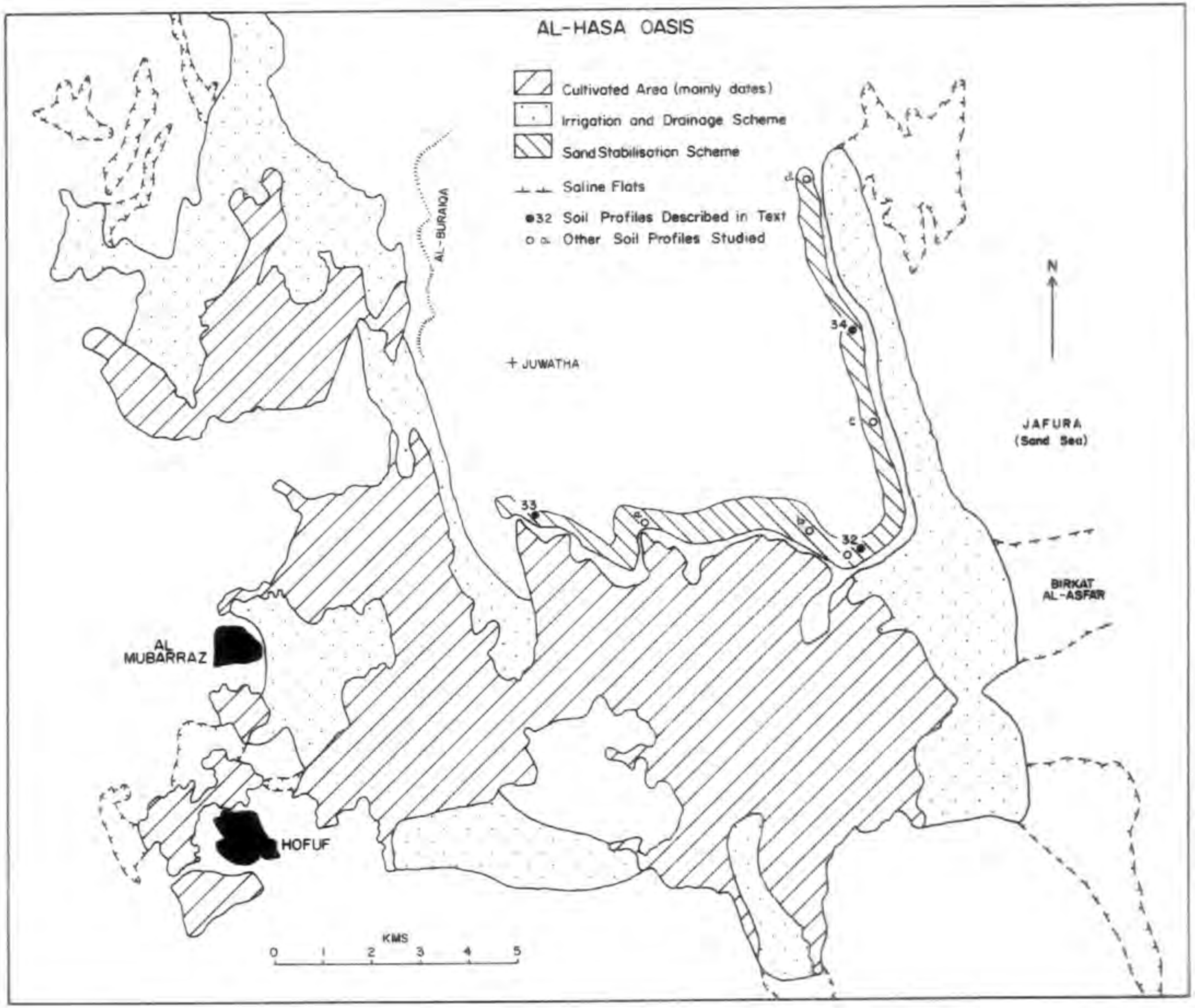


Fig.20
Al Hasa oasis, Saudi Arabia.

the irrigation of the eastern portion of the oasis. Its water is derived from the 'Neogene' aquifer which is found at about 150 metres below ground surface though there may be some seepage into this aquifer from the deeper 'Khobar' aquifer, at about 250 metres (Wakuti, 1970). The water is warm (about 35-37°C) and has a conductivity of about 3.3 mmhos/cm at 25°C.

The oasis became noted for its cultivation of dates, though alfalfa and rice were important subsidiary crops. Over-irrigation was commonly practised and, while drainage was naturally eastwards, the salinity of the irrigation water also increased to over 6 mmhos/cm at 25°C in the extreme eastern part of the oasis. The combination of over-irrigation, an impermeable horizon of Neogene limestone at shallow depth and the high salinity of the irrigation water have meant that large areas have either gone out of cultivation or, as in the extreme east of the eastern portion of the oasis, only date cultivation of very poor quality could be practised, (Vidal, 1955). Furthermore, the Birkat-al-Asfar formed a natural drainage line and with the vast amount of water being applied, not only did the water table rise, but it also became very saline. Similar problems were manifest along the eastern edge of the northern portion of the oasis, and here, as in the east, much of the waterlogged land has now been drained and reclaimed. During drainage and reclamation, the waters from this portion of the oasis had conductivities in excess of 20 mmhos/cm at 25°C, and Wakuti (1970) considers that the water in the main drainage canal of the reclaimed portion of the northern part of the oasis will probably remain in excess of 8 mmhos/cm at 25°C when cultivation takes place.

These high salt figures are the result of poor irrigation practices in the past which allowed salts, introduced in the irrigation water, to cause a build up in soil salinity to such an extent that cultivable land went completely out of agricultural use and became marshy areas forming breeding grounds for malarial mosquitoes.

A second factor that has affected the livelihood of the inhabitants of the oasis has been the problem of aeolian blown sand. Al Hasa is situated on the western edge of the Jafura sand sea and, while the rocky ridge of Jebel Buraiqa, rising to over 220 metres, furnishes some protection to the northern portion of the oasis, the eastern portion juts out into the sand sea. Northerly winds predominate for much of the year and these have caused sand dunes to encroach on, and overwhelm, parts of the eastern portion of the oasis. These dunes rise to a height of at least 25 metres above the saline flats and their movement causes the direct loss of at least 2 hectares of cultivated land each year. In addition, the wind-blown sand blocks irrigation and drainage canals, causing water shortages and enhancing the salinity problems of the oasis, as well as damaging crops when high winds blow. This loss of good agricultural land has been going on for several hundred years and Vidal (1955) comments that 'perhaps even during the Middle Ages, the cultivation area reached much further to the north along the eastern border of al-Buraiqi and at least as far as the locality called Juwatha.'

The problems of the saline and waterlogged parts of the oasis have been tackled through a large irrigation and drainage scheme.

While not utilising any new sources of irrigation water, more efficient utilisation will eventually allow the area of the oasis to increase by a further 12,000 hectares of cultivated land. However, these improvements will be wasted unless the problem of aeolian sand is overcome, and to this end, the Sand Stabilisation Scheme was initiated by the Ministry of Agriculture and Water in 1962.

6.2 Techniques of sand stabilisation

In the early years of the project, a number of nurseries were established in which trials were carried out in order to determine the suitability of the different tree species to the prevailing environmental conditions and also to provide young stock. Trees planted in the initial stages of the project included:

- *Tamarix aphylla*
- *Tamarix galica*
- *Acacia cyanophylla*
- *Parkinsonia aculeata*
- *Prosopis juliflora*
- *Eucalyptus camaldulensis*

All these species are tolerant to both drought conditions and to the use of saline water, while they can also withstand the high winds and wide temperature extremes that occur. Over the period January 1966-December 1969, the maximum temperature recorded at Hofuf was 47.8^{o}C, the minimum temperature -1.1^{o}C while the annual rainfall totals for the four years were 30.4 mms, 59.2 mms, 59.4 mms and 121.7 mms respectively. All the species also grow quickly, but it has been found that the most effective was *Tamarix aphylla*. This species does not require any irrigation after about 3-4 years due to a very extensive and deep rooting system allowing it to tap the water table within the dune. Also, it can be propagated successfully by taking cuttings from growing trees, thus obviating the necessity for having extensive nursery areas.

The first stages of the stabilisation process is the construction of brushwood fences along the length of the scheme. These brushwood fences, now established over a length of 25 kms, are manufactured locally, and they give some protection against the surface movement of sand grains. Although the sand rapidly piles up on the windward side of the fences, they do provide the initial protection necessary for the establishment of the woodland. Damage to the fences is frequent during periods of high winds and, unless quickly repaired, newly planted woodland can be extensively damaged.

The sand dunes behind the brushwood fences are levelled by bulldozer. Topsoil from the saline flats is then spread evenly over the levelled dunes and this gives initial stability to the dunes. When applied, the soil is moist and saline (it may have a conductivity in excess of 20 mmhos/cm. at 25°C) and, even if Tamarix aphylla is not planted immediately, the formation of a thin crust as it dries out prevents wind erosion. It is usual, though, for the trees to be planted very soon after, and an irrigation is applied on planting. Water is applied all the year round at a rate of about 10 cms every 7 days in summer and every 15 days in winter, for the estimated average annual total potential evapotranspiration amounts to 2450 mms (Wakuti, 1970). 500 hectares

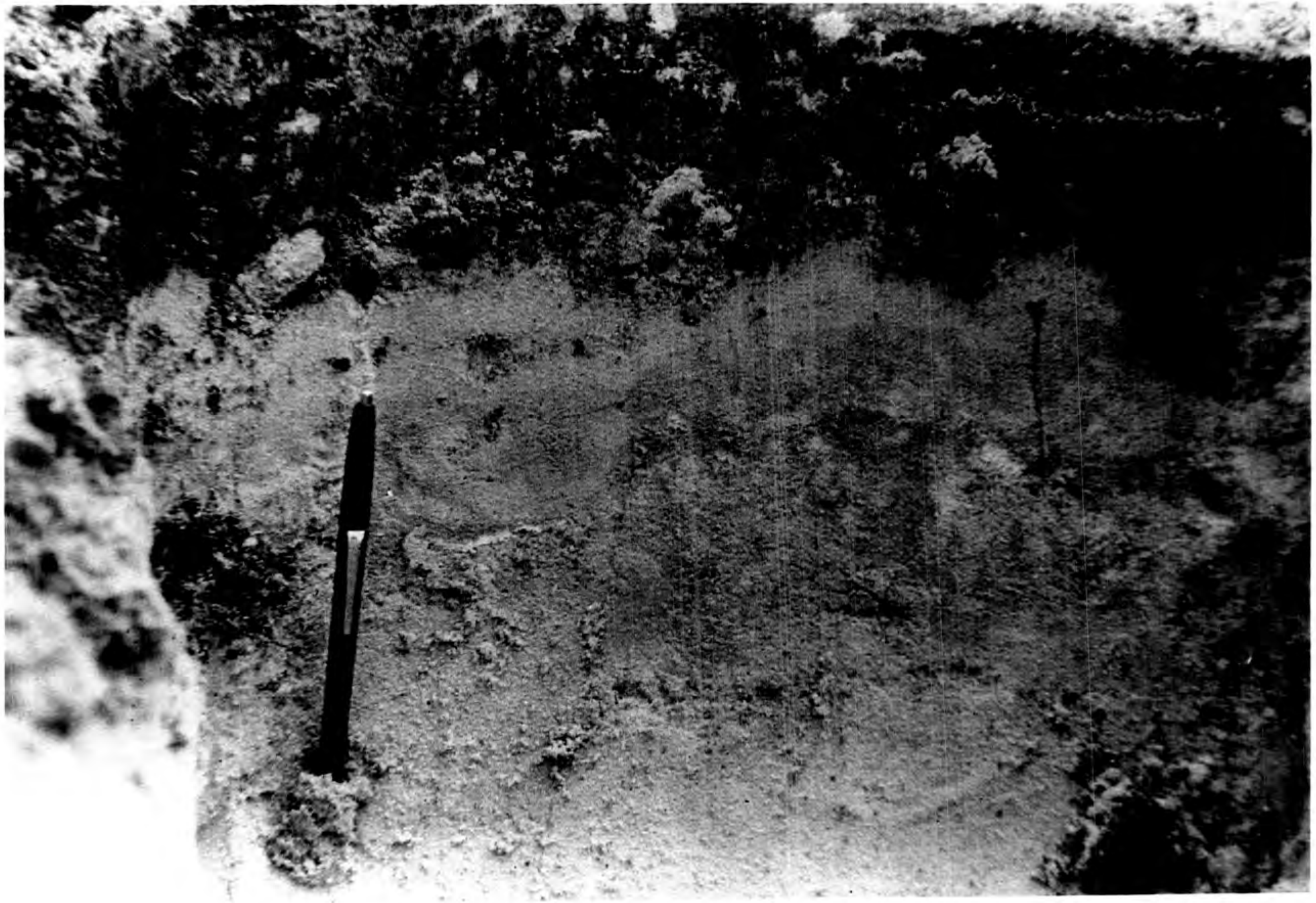


Plate 9

Saline topsoil overlying aeolian sands, Al Hasa oasis, Saudi Arabia. No trees had been planted when this photograph was taken though an irrigation had washed some soluble salts into the sands, hence the 'puffy' nature of the soil around the base of the biro.

of woodland have now been planted and, to provide irrigation water, 57 artesian wells and 25 surface wells have been dug. Main irrigation channels, and also the subsidiary channels, are cement lined to reduce transmission losses through the very porous soils.

The trees are planted about 4 metres apart and they form a belt of woodland about $\frac{1}{4}$ km in width between the aeolian sands and the agricultural area of the oasis. While the tree roots and leaf litter stabilise the moving dunes, the aerial portions of the quick growing trees trap fine particles, being blown in the air, before they reach the cropped lands, thus reducing the hazard of sand blocking irrigation canals and drains. However, apart from its prime purpose of stabilising the moving dunes, the scheme also has a number of secondary benefits. These include:-

(i) the provision of a small timber industry

(ii) recreational facilities for the inhabitants of the oasis. In this context, ornamental shrubs have been planted along some of the roads within the project area

(iii) an improvement of the micro-climate, in particular a reduction in wind speed

(iv) a reduction in the number of insect-borne diseases due to a reduction in the saline swamp areas.

6.3 The formation of a soil

8 soil profiles were examined in the field by the author - these profiles being located in woodland that had been established for varying lengths of time. 20 mineral samples were obtained from

Plate 10

Soil profile under Tamarix aphylla woodland established for five years, Al Hasa oasis, Saudi Arabia. Note root development in profile, the slight downward diffusion of the grey topsoil and the formation of a litter horizon.

these profiles as well as from the unstabilised sand dunes. A composite sample was also taken from piles of topsoil prior to spreading on the dunes. Routine analysis was carried out by the author on these samples while ancillary analyses such as free iron determinations were also made. Three organic samples were also obtained for special analysis. These samples were taken from the litter horizon and the horizon of decomposing leaf fall from eight year old Tamarix woodland, and from the organic/mineral surface horizon under three year old woodland.

6.3(i) The physical properties

In the early stages of the project, the topsoil was obtained from the saline flats of Birkat-al-Asfar and spread directly on the smoothed dunes to a depth of 15-20 cms. In recent years, as Birkat-al-Asfar has been reclaimed for agricultural use, less topsoil has been obtained from this source while an increasing amount has been obtained from small saline flats amongst the sand dunes and near Juwatha. Some of these flats have probably been cultivated in the past before becoming too saline and/or being overwhelmed by the encroaching dunes. This topsoil is also no longer spread directly on the dunes, but is mixed with aeolian material. Samples of topsoil, obtained in April 1971 prior to its being spread on the dunes, had the following composition:

	Sand	Coarse Silt	Silt	Clay
Locality[1]	2.0-0.05 mms	0.05-0.02 mms	0.02-0.002 mms	0.002 mms
4	74.4	7.0	10.0	8.6
9	70.0	7.8	12.3	9.9

The figures are given as percentages of the fine earth sample ($<$2mms), but all samples collected on the sand stabilisation project passed

1. For location, see Table 6.1.

Plate 11

Soil profile under Tamarix aphylla woodland established for eight years, Al Hasa oasis, Saudi Arabia. Note the extensive root development and the less distinctive nature of the topsoil.

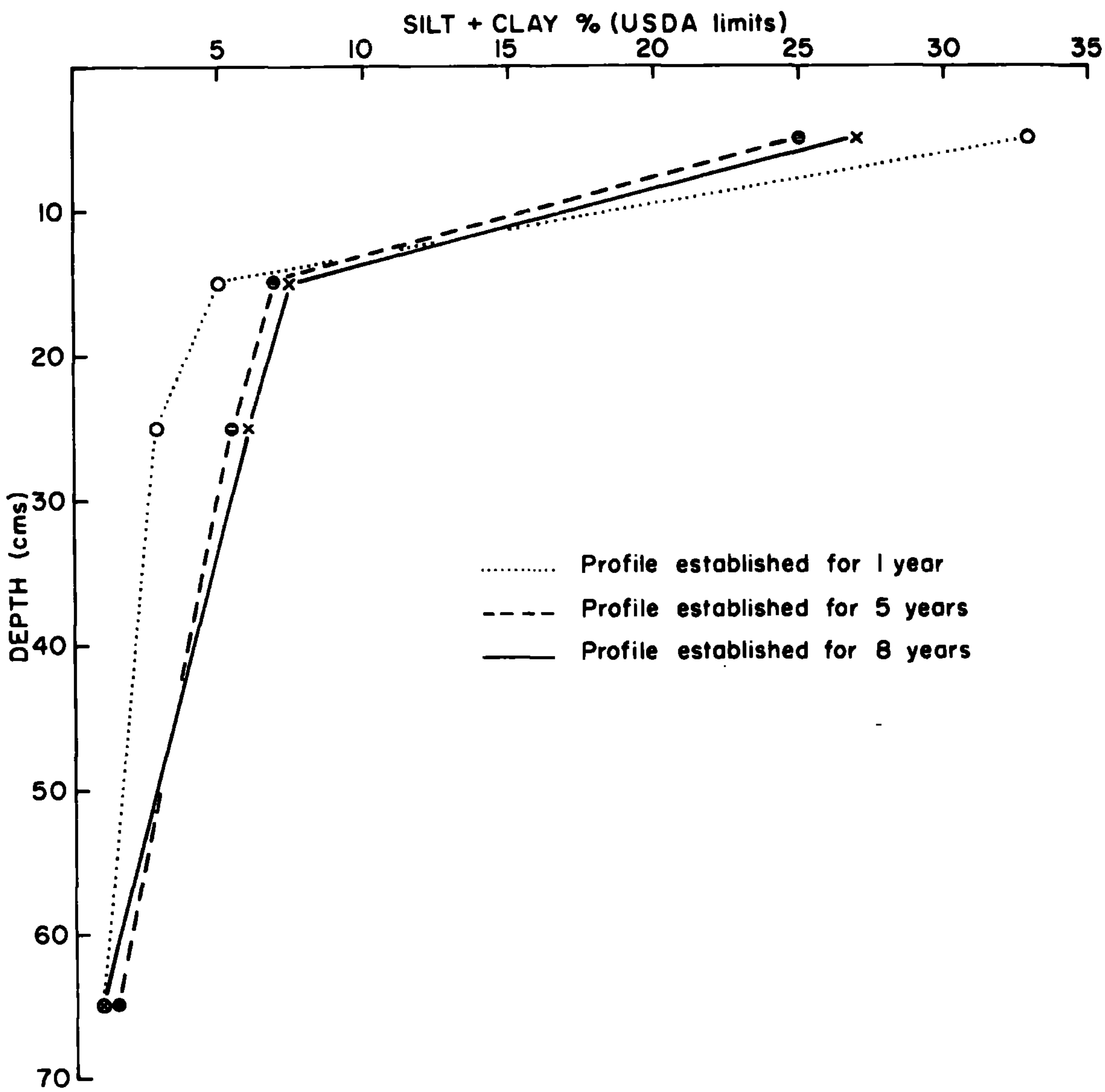


Fig.21

Distribution of fine material in profiles at Al Hasa oasis through the 2 mm sieve. The size limits of the fractions are defined according to the United States Department of Agriculture and the topsoil may thus be regarded as a sandy loam, but the normal properties of a sandy loam, such as weak structural aggregation, are modified by the high soluble salt contents. As previously described a thin salt crust quickly develops as this material dries out, thus giving initial stability to the dunes.

In contrast, the aeolian sands only contain miniscule amounts of silt and clay. The compositions of fine earth samples, from six localities, shown on figure 20, are given in Table 6.1. In each case, over 90% of the particles are of coarse and medium sand size and there is no structural aggregation.

When the topsoil is spread over the dunes, the <u>Tamarix</u> trees are usually planted immediately and irrigation water applied. Because the topsoil is kept moist, the effects of the soluble salts, previously described, are reduced and in fact they are washed out of the topsoil. The weak structure of the sandy loams breaks down and allows lessivage of the fine fractions as shown in fig. 21. It is noticeable that the horizon of aeolian material, immediately underlying the sandy loam, quickly accumulates some silt and clay, but it would appear that this rate of accumulation slows down. This can be interpreted by the larger pores in the aeolian material quickly becoming blocked by the silt sized particles, thus effectively reducing the rate of lessivage. When there has been some accumulation of fine material lower down the profile, it is predominantly composed of fine silt and clay (profiles 32 and 33).

Table 6.1

Mechanical composition of aeolian sands, Al Hasa. Descriptions of the fractions are those of the U.S. Department of Agriculture and figures are given as percentages

Location	Sand			Silt		Clay
	Coarse	Medium	Fine	Coarse	Medium and Fine	
	2-0.5 mms	0.5-0.25 mms	0.25-0.05 mms	0.05-0.02 mms	0.02-0.002 mms	0.002 mms
2	34.3	58.6	5.1	0.8	1.0	0.2
4	39.6	55.8	2.5	0.3	0.9	0.9
5	42.4	52.0	2.6	2.6	0.4	-
6	38.8	57.8	2.4	0.4	0.6	-
7	38.7	52.2	7.9	0.8	0.4	-
8	43.6	51.8	2.6	0.6	1.4	-
Mean value	39.6	54.7	3.8	0.9	0.8	0.2

Key to location of samples

1. Near office (Profile 32)
2. Adjacent to Birkat-al-Asfar (c)
3. Site of profile 34
4. N. limit of scheme (d)
5. Near office
6. On west/east limb of project (a)
7. On west/east limb of project (b)
8. Site of profile 33.

As the woodland cover develops (Tamarix aphylla had reached a height of about 8 metres, with a closed canopy, within 8 years of planting) natural structural aggregates develop, initially in the mineral horizon immediately beneath the litter and/or humus. The soil remains undisturbed after planting, except for irrigation, and consequently conditions for natural structure aggregation are favourable. A test, similar to that used at Al Ain (Chapter 4) was applied to the structure at two sites, one which had been under woodland for 8 years and the other for 3 years, and the results are shown in Table 6.2. The colour of the organo-mineral horizon immediately beneath the organic matter was 2.5Y5/0 (grey) and 10YR4/2 (dark grey brown) respectively and the structural aggregates amounted to about 65% and 40% of the exposed sections of the two profiles respectively (Profiles 32 and 34). When the test was applied, the soils were moist and even though the additional wetting caused the breakdown of many of the structural aggregates, a significant number were relatively water stable. Whether structural stability will increase to any great degree, as the woodland ages, is not clear for the close canopy would tend to preclude the growth of any dense ground vegetation, while, at certain times, as will be seen in Section 6.3(ii) the organic matter can be acid. It was observed that under the longer established woodland, the only ground cover present was the occasional weed species and some grass where there was a break in the tree canopy and/or where there was an absence of litter.

Table 6.2

Water stability of structural aggregates occurring immediately beneath the surface organic horizons, *Tamarix* woodland, Al Hasa

	Tamarix aphylla - 8 years	*Tamarix aphylla* - 3 years
Profile pit	1	
Number of aggregates investigated	50	50
Type of aggregate	Weak small and medium angular blocks	Weak small and medium angular blocks
Number of aggregates water stable	12	5

6.3(ii) Organic matter

Perhaps the most important catalyst in any changes that occur in the soil is the organic horizon present on the soil surface. In the arid zone, this is usually absent due to the sparse vegetation, and consequent low levels of organic matter addition, and the rapid rate of decomposition, particularly after any rainfall. The woodland of Al Hasa is unusual in having a distinct layer of organic material on the soil surface and, even on plots which had been planted with Tamarindus species for 8 years, this layer was frequently more than 1 cm in thickness at the time of sampling (April 1971). Furthermore, on these longer established plots the organic layer showed distinct horizonation as, for instance, at the site of profile 32:-

1.25-0.5 cms,	undecomposed Tamarix litter including both needles and seed pods; dry; clear change,
0.5-0	10YR2/1 (black); decomposing litter; needles humified towards the base of horizon but any seed pods retained their form throughout; fungal activity in evidence; moist; clear change
0-50 cms +	mineral soil

Where the profile has not been so long established (e.g. profile 34), the layer of organic matter is not so thick, usually less than 0.5 cms, and, in particular, the litter layer is virtually absent. Instead, there is a tendency for the organic layer to be composed solely of decomposing needles as the young trees have not yet shed any seed pods.

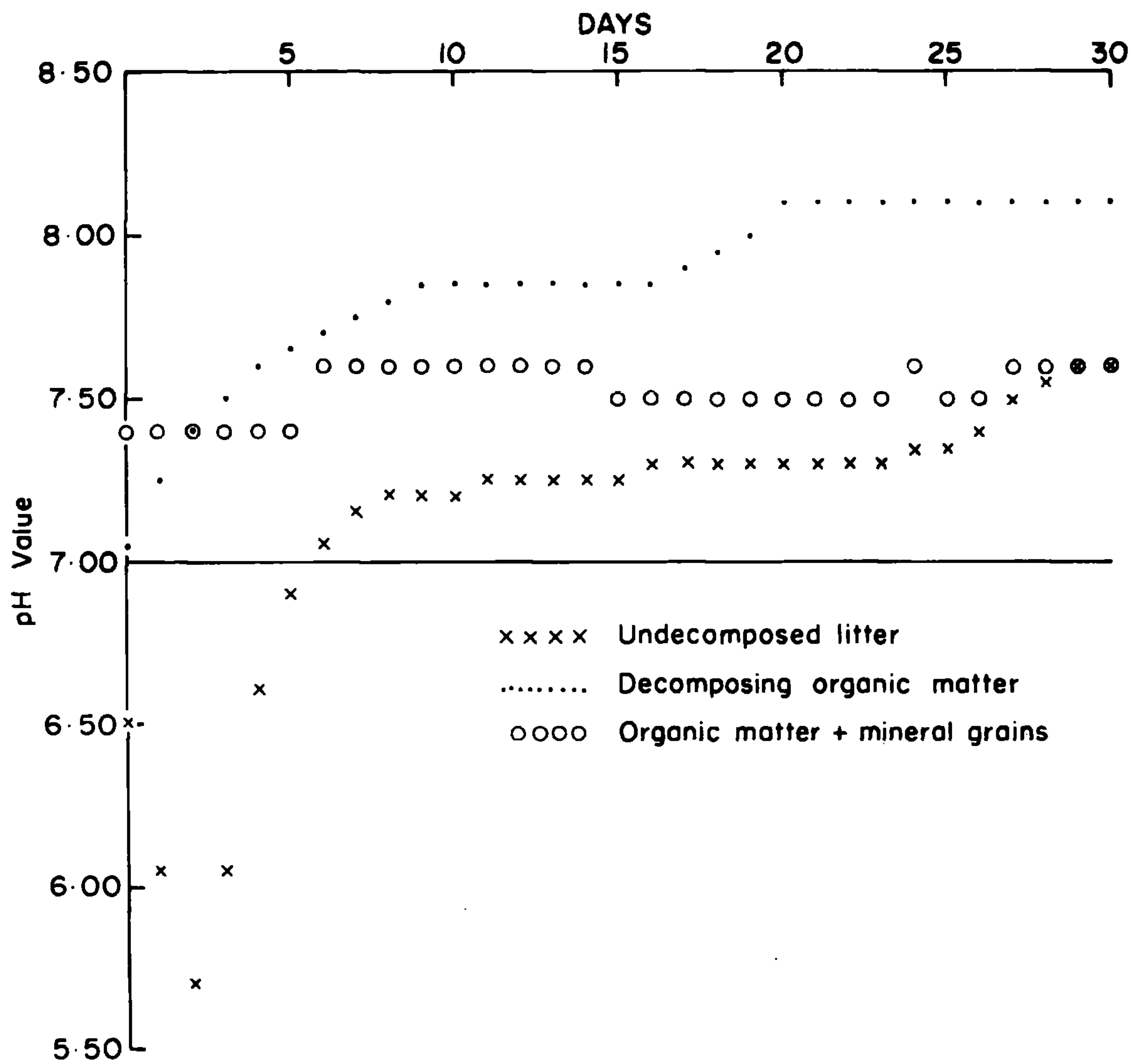


Fig.22
Changes in pH values of organic material from
Tamarix aphylla, Al Hasa oasis.

In the initial stages of the formation of the organic horizons, the limited litter fall from the young trees is usually washed to one end of the plot by irrigation, but as the litter fall increases a more even organic layer develops. Three representative organic samples were collected for analysis in the laboratory:-

(i) a sample of the litter horizon, composed of needles and seed pods.

(ii) a sample of decomposing material, in which there was evidence of considerable fungal activity.

Both these samples were obtained from under *Tamarix* woodland that had been established about eight years prior to sampling. Sample (i) was dry while sample (ii) was moist at the time of collection.

(iii) a mixture of mineral matter and partially decomposed litter, representing the situation that exists in the early stages of the establishment of woodland before the organic layer fully develops. The sample was moist when collected and weak structural aggregates, of medium subangular blocks, were present in the horizon.

In the laboratory, each of the samples was kept permanently moist, though not waterlogged, with distilled water, to simulate the environmental conditions that develop as a result of irrigation. pH values were recorded at 24 hour intervals, over a period of one month, and the results are shown in figure 22. At the outset of the experiment, the undecomposed litter sample had a pH value of 6.5, but the initial effect of the application of irrigation water was to cause a marked reduction in pH value. The maximum acidity recorded was 5.70 after two days but the sample maintained an acid reaction for a further 4 days. This acidity may be attributed to the decomposition of the hemicelluloses resulting in the evolution of CO_2 and a consequent depression in pH values. (Not all the hemicelluloses, which are very heterogeneous, would decompose during this period and after the completion of the main experiment, the sample was air dried and placed in an oven for 24 hours at a temperature of $110^{o}C$ to remove any remaining moisture. It is significant, that on rewetting, a similar pattern of pH values emerged, though the acidity recorded was not so great (pH 6.40) thus suggesting that the greater proportion of hemicelluloses had been decomposed during the first cycle). Six days after the start of the main experiment, the litter once again had an alkaline reaction and the pH continued to rise until the ninth day. Between the 9th and 25th days the pH became relatively constant with values of 7.20-7.35. During this phase of decomposition it is considered that the decomposition of celluloses was predominant, though some decomposition of hemicelluloses continued. After the 25th day, the rise in pH values that occured may be attributed to the lowering in amount of cellulose decomposition, though this would continue for several more months, while lignin decomposition, which is much slower becomes more important.

A similar pattern is evident with the sample of decomposing litter. The depression in the curve at the start of the experiment may be attributed to the decomposition of residual hemicelluloses, while the generally higher values reflect the more advanced state of decomposition i.e. there is a greatly reduced production of CO_2.

In contrast to the undecomposed litter and the decomposing organic matter, the sample which comprised a mixture of mineral matter and partially decomposed organic remains (the sample had an organic matter content of 59.4%) showed a fairly constant pH which only rose from 7.40 to 7.60 during the course of the experiment. This can perhaps be attributed to a much lower rate of biological activity due to an adverse soil environment. The mineral particles are dominantly composed of quartz while the sample had a conductivity of 1.54 mmhos/cm at 25^{o}C at the start of the experiment.

These conclusions are further supported by an analysis of the composition of the humus. The bulk of the humus in the soil, as distinct from the undecomposed plant litter, is composed of resynthesised material resulting from the breakdown of simple organic substances such as cellulose, sugar, fats, resins, etc. Cellulose, for instance, is eventually converted to a humic acid, one of the main components of humus, and, from table 6.3, the sample from the decomposing litter showed the greatest quantity of humic acid, confirming that there had been a greater decomposition of cellulose and hemicellulose than in the other samples. Thus one would not expect any great release of carbon dioxide and consequently higher pH values.

The other two major components of humus are fulvic acid and humin. The latter is an insoluble form of humic acid and one of the major processes contributing to its formation is dessication. Thus, in arid areas, the contents of humin tend to be higher than in the humid counterparts. The three samples analysed had humin contents of 61.3-64.5% and these figures contrast with those

Table 6.3

Analysis of the humic material, Al Hasa

	Litter horizon	Decomposing material	Decomposing material and organic matter
Organic matter	100%	100%	59.4%
% of humic material			
Humin	63.30	64.47	61.30
Humic acid	11.02	13.38	10.56
Fulvic acid	26.68	23.15	29.34
Humic acid / Fulvic acid	0.41	0.58	0.36

of 48.2% for krasnozems (moist tropical soils) or 56.5% for an irrigated serozem, under cotton, quoted by Kononova (1961). With newly evolved humus, fulvic acids tend to predominate over humic acids, as is evident in the samples. Fulvic acid is soluble in water and contains a considerable proportion of active acid groups. Rode (1937), for instance, considered that fulvic acids are responsible for the migration of sesquioxides in podzol soils, mainly in the form of complex compounds. It is significant that the lowest values of Fe_2O_3, in topsoil samples, tend to be found in those areas where woodland has been established for longest and, consequently, there has been greater time for fulvic acids to decompose silicates and release iron which is leached down the profile (Table 6.4).

The conclusion that must therefore be drawn is that the formation of a distinct organic horizon, under Tamarix woodland, produces an acid environment at least in the early stages of humus accumulation. The implications of this acid environment include:-

(i) There will be a progressive decalcification of the soil. The reduction in the quantities of $CaCO_3$ with increasing age of woodland is evident in Table 6.4 in which the topsoil samples of those areas that have been under woodland longest show the lowest $CaCO_3$ content.

(ii) As the environment becomes less calcareous, the availability of plant nutrients will increase. At present the amount of available phosphate is less than 7 mgms/100 gms with considerably more being in unavailable form (See analyses in Appendix 1). As the amount of $CaCO_3$ is reduced, an increase in available

Table 6.4

% $CaCO_3$ and % acid extractable Fe_2O_3 in the topsoil (0-15 cms) of profiles under different ages of woodland, Al Hasa

Age of woodland (years)	8	8	5	3	3	1	1	1
% Fe_2O_3	0.08	0.07	0.07	0.09	0.11	0.14	0.13	0.16
% $CaCO_3$	20.00	12.00	22.30	25.00	26.50	26.70	32.30	28.20

phosphate would be expected, as there is less free $CaCO_3$ to form insoluble calcium phosphate complexes.

(iii) In the early stages of humus formation, when there is an excess of fulvic acid, there will be rapid translocation of nutrients out of the rooting zone of plants. However, as the amount of humic acid increases nutrient availability will be increased, in particular the availability of phosphate will be enhanced.

6.3(iii) Soluble salt content

A sample of soil material piled up prior to spreading on the surface of the sand dunes had a conductivity of 22.6 mmhos/cm at 25^{o}C with the soluble anions being dominated by chloride and sulphate (144.2 meq/litre and 90.6 meq/litre respectively) as shown in Table 6.5. Other topsoils, which had been applied to the aeolian sands for a year or less, had conductivities within the range 4.65 - 27.40 mmhos/cm at 25^{o}C though saline soils at Al Hasa have recorded conductivities in excess of 90 mmhos/cm at 25^{o}C (Leichtweiss Institute, 1972) and undoubtedly such soils may have been used for sand stabilisation in the past. Saline soils with these exceptionally high conductivities may well have been applied as topsoil in the samples taken from woodland established for three years (Table 6.5). This table shows that once the saline material has been spread over the dunes and irrigated, there is an immediate change in the composition of the soluble salts. No longer do chloride ions dominate the anions in the saturation extract - instead, the sulphate anion is more important. This is very much in line with the findings of the Leichtweiss Institute (1972) who showed

Table 6.5

Soluble salt contents of saturation extract of topsoil samples, Al Hasa

Length of use	CONDUCTIVITY mmhos/cm	SOLUBLE ANIONS (meq/litre)			
		CO_3	HCO_3	Cl	SO_4
Unused Topsoil	22.60	–	2.2	144.2	90.6
1 Year (a)	27.40	–	1.5	88.2	186.4
(b)	4.65	–	3.6	12.6	25.3
(c)	10.40	–	1.5	32.3	73.8
3 Years (a)	17.50	–	1.8	18.4	156.3
(b)	19.40	–	1.8	63.6	126.7
5 Years	0.25	–	1.5	0.7	5.7
8 Years (a)	1.14	–	2.7	2.7	8.1
(b)	0.99	–	1.8	2.7	12.3

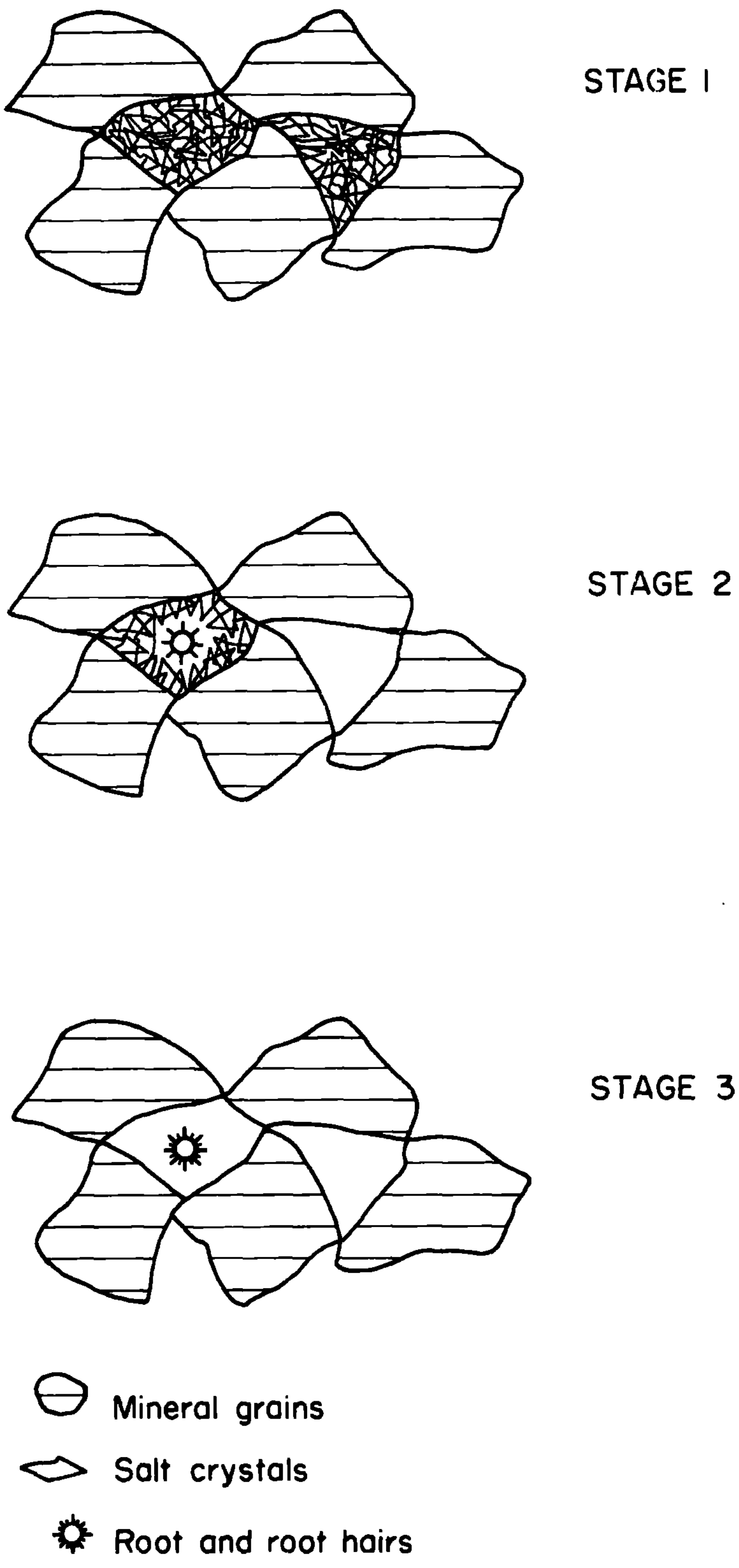


Fig. 23

Diagramatic representation of leaching of soluble salts and development of plant roots.

experimentally that soils exposed to a continuous salinization process tended to accumulate chloride ions while soils that are frequently leached have a higher percentage of sulphate ions.

The aeolian sands have a very low conductivity prior to reclamation and, while the application of saline topsoil may cause a temporary increase in salinity, their porosity is such that they soon revert to their former salinity status. This is shown in Table 6.6. It is considered that the time factor has been insufficient to cause any increase in soluble salts in the profile under woodland that had been established for a year or less, and that the increase in salinity is at a maximum after about three years. Those profiles under woodland established for at least five years only have minimal quantities of soluble salts in the topsoil.

On these porous aeolian sands, the application of a highly saline topsoil has been very successful as a reclamation technique and the trees, Tamarix species, appear to suffer no harmful effects, even when they are only recently established. A mechanism, similar to that put forward by Boyko (1966) for the successful utilisation of saline water, is suggested, only in reverse. Prior to the first irrigation, the pore spaces are filled with salt crusts. The first irrigation dissolves some of these soluble salts, washing them down the profile, and creates a fine pore within the salt crust (figure 23). The fine roots of the newly planted Tamarix can develop in the void for there is a ready supply of oxygen and the plant, being salt tolerant, can withstand any concentrations of salt into which it comes in contact. Successive irrigations continue to enlarge the pore spaces by

Table 6.6

Salinity status (measured by conductivity in mmhos/cm at 25°C) of soils under woodland of different ages, Al Hasa

Age of Woodland (years)	8	8	5	3	3	1	1	1
Sample depths cms.								
5-15	1.14	0.99	0.25	17.50	19.40	27.40	4.65	10.40
25-35	0.06	0.49	0.19		3.55	1.45	0.17	0.12
60-70		0.11	0.11		2.68			0.11

dissolving the soluble salts and leaching them down the profile. Owing to the high porosity of the underlying aeolian sand, they do not form accumulations within the rooting depth of the growing tree.

PART THREE

ANALYSIS AND CONCLUSIONS

CHAPTER 7

The Similarity of Cultivated Arid Zone Soils in the Middle East

7.1 Methods

It is generally considered that a major effect of cultivation is to cause soils, at least in their cultivated horizon, to become more alike each other (e.g. Bunting, 1965). In an arid environment the natural soil forming factors have a very restricted influence on soil development because of the absence of moisture. Hence, with irrigation, it might be expected that the effect on man on soil formation would be apparent with only a short period of time. The case studies described in the preceding chapters provide examples of soils that man has affected for hundreds, if not thousands, of years as well as those that he is only just in the process of reclaiming. In order to test the hypothesis that man, as a soil forming factor, can create distinct similarities in arid zone soils within only a very short period of time, with regard to a variety of cropping and management conditions, cluster analysis was carried out on analytical data derived from 62 soil profiles in the areas of the case studies (Table 7.1). The apparent over emphasis on profiles from Dubti, Ethiopia, reflects the wide textural range of soils that are being cultivated there.

Methods employed in the cluster analysis were based on those first established by Hole and Hironaka (1960), and subsequently refined by Bidwell and co-workers (1964a,b,c), Sarkar et al.(1966), Rayner (1966) and Muir et al. (1970). Hole and Hironaka concluded

Table 7.1

Number of profiles involved in cluster analysis in relation to area and type of cropping

Crop	Ras-al-Khaimah	Al Ain	Al Hasa	Dubti Texture Heavy	Dubti Texture Medium	Dubti Texture Light	Total
Date Gardens	3	3					6
Vegetables	5	3					8
Fodder		2					2
Cotton				7	13	4	24
Woodland			7				7
Uncultivated	8	3			4		15

that 'Although it may be argued that ordination of soil profiles yields conclusions predetermined by the selection of data by the soil scientist, and his interpretation of the results, nevertheless this method holds promise (a) as a means of recording judgements and insights of soil classificationists and geneticists, and (b) as a means of testing these judgements and insights.' Prediction might also be added, for if it can be shown that there is a high degree of similarity between these soils as a result of cultivation, irrespective of the agricultural and irrigation techniques applied, then the results may be used as a guide in development work.

7.1(i) The Index of Similarity

19 soil characteristics for each of the 62 soil profiles were used for determining the index of similarity. While some authors (e.g. Rayner, 1966, Muir et al. 1970) have used over 50 characteristics, Sarkar et al. (1966) found that highly similar groups of soils remain together, even when the number of characteristics are reduced. The 19 soil characteristics that were used, and which relate to the cultivated horizon of each of the profiles unless otherwise stated, were:-

(a) the thickness of the cultivated horizon (or surface horizon of uncultivated soils).

(b) pH

(c) the ratio of the pH in the topsoil to that in the subsoil.

(d) % $CaCO_3$

(e) the ratio of % $CaCO_3$ in the topsoil to that in the subsoil.

(f) % clay

(g) the ratio of % clay in the topsoil to that in the subsoil.

(h) % silt and clay (U.S.D.A. limits).

(i) the ratio of silt and clay in the topsoil to that in the subsoil.

(j) electrical conductivity (E.C. in mmhos/cm at 25°C)

(k) the ratio of E.C. in the topsoil to that in the subsoil.

(l) cation exchange capacity (in meq/100 grms)

(m) % exchangeable calcium.

(n) % exchangeable sodium (E.S.P.)

(o) the ratio of ESP in the topsoil to that in the subsoil.

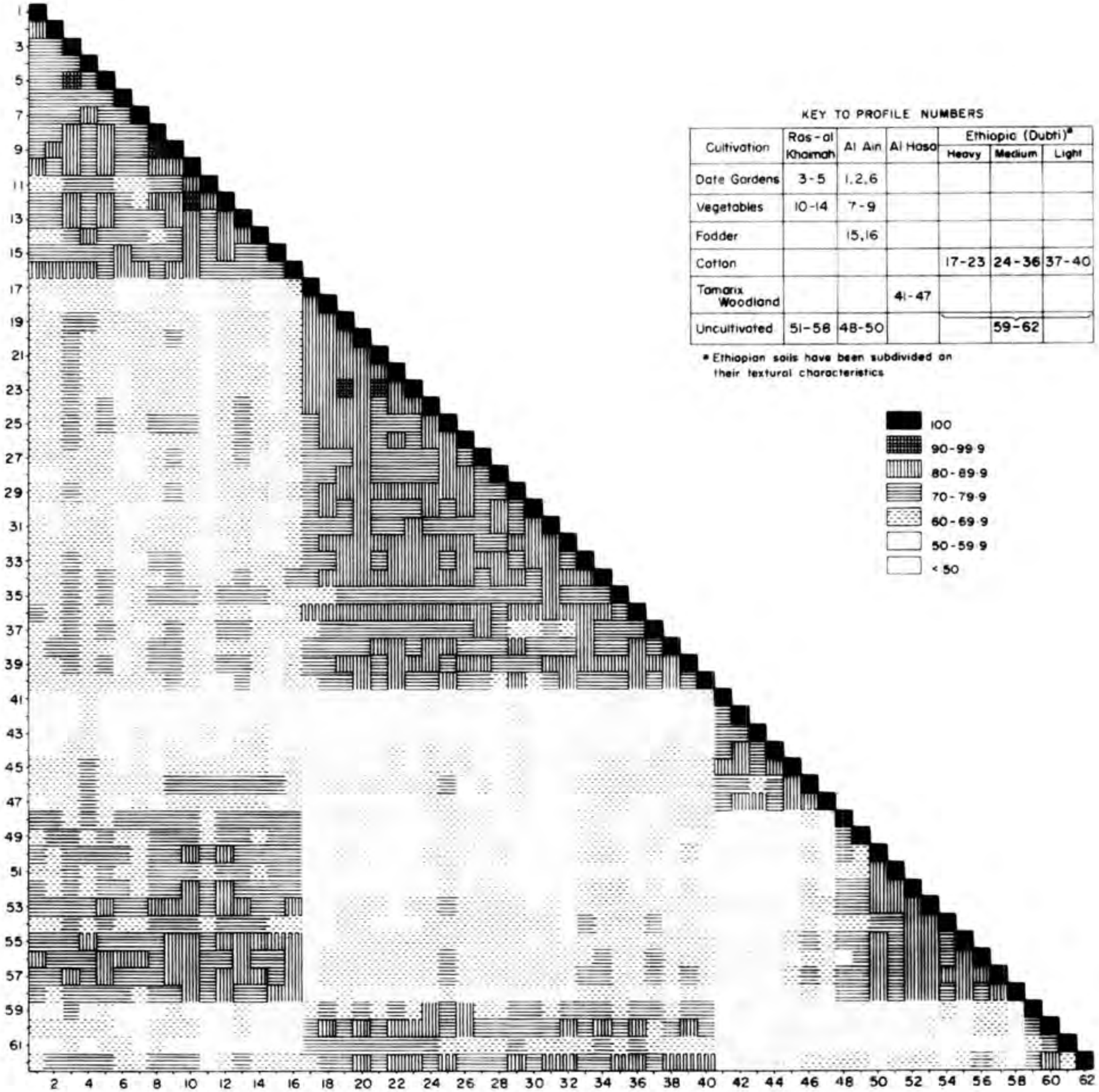
(p) % organic carbon

(q) % total nitrogen

(r) the carbon:nitrogen ratio

(s) available phosphate (mgs/100 grms)

For the values of each of the characteristics, a proportional figure between 0 and 100 was calculated according to the method of Hole and Hironaka (1960). The minimum value of each characteristic recorded was given the figure 0, while the maximum value was assigned 100. The matrix that was derived for the 62 profiles is given in Appendix II. The column of figures under the first soil profile was summed and the summation value called A. This was repeated for the second soil profile (B), while a third column was then compiled, made up of the lower figure of each pair of figures. This was summed and called W. The index of similarity was obtained from the formula $2W/A \div B$ and was expressed as a percentage (100% would indicate soils that were totally alike). This index expresses the theoretical similarity between the different soils, according to the characteristics chosen. The indices of similarity were calculated on the NUMAC computer and are also given in Appendix III.



KEY TO PROFILE NUMBERS

Cultivation	Ras-al Khaimah	Al Ain	Al Hasa	Ethiopic (Dubti)* Heavy	Ethiopic (Dubti)* Medium	Ethiopic (Dubti)* Light
Date Gardens	3-5	1,2,6				
Vegetables	10-14	7-9				
Fodder		15,16				
Cotton				17-23	24-36	37-40
Tamarix Woodland			41-47			
Uncultivated	51-58	48-50			59-62	

* Ethiopian soils have been subdivided on their textural characteristics

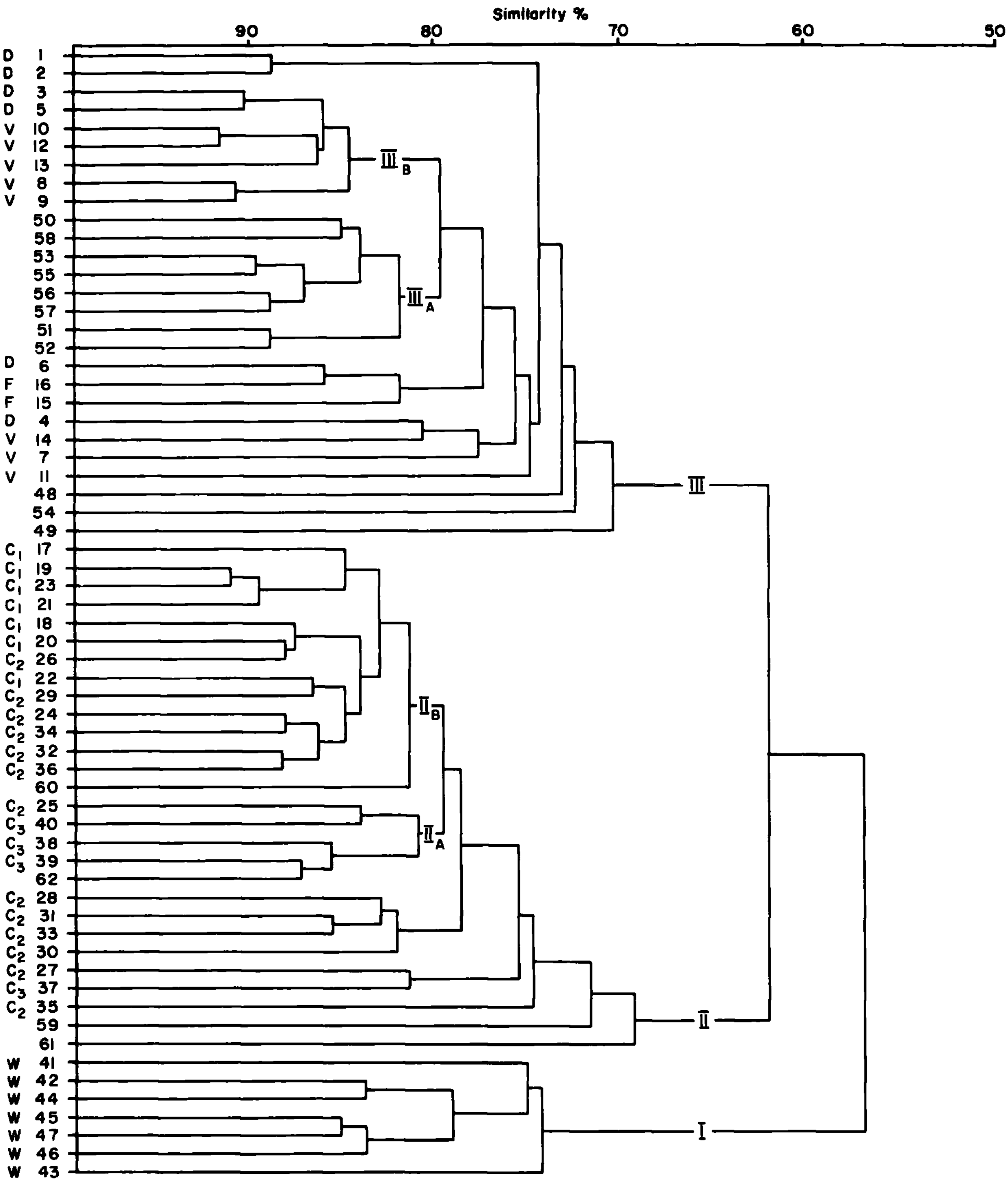
Fig. 24
Shaded matrix of similarity indices for 62 soil profiles

7.1(ii) The similarity matrix

As well as the numerical similarity matrix (Appendix III), a shaded similarity matrix of the indices of the 62 soil profiles with each other has been prepared and is shown in figure 24. This allows a preliminary assessment to be made of the similarity of the soils under consideration and it is clear that there are comparatively few similarity indices of less than 50 - in fact the lowest index of similarity recorded is 39.1 between an uncultivated xerosol in Ras-al-Khaimah and a profile from under woodland, established for 8 years, at Al Hasa. While it is immediately striking that soils from each of the different study areas have the greatest similarities with soils from within the same area, relatively high degrees of similarity are also recorded between some soils of different areas. For instance, some of the cultivated light and medium textured soils at Dubti have relatively high indices of similarity (70-79.9) with some of the cultivated soils in Ras-al-Khaimah and at Al Ain. The greatest dissimilarities, as exemplified by the lightest shading, would appear to be between the soils from under woodland at Al Hasa and the other profiles, but, even here, some similarities of up to 79.9 are recorded with both cultivated and uncultivated soils in Ras-al-Khaimah and at Al Ain. However, this matrix only shows similarities between individual soil profiles and not between groups of profiles.

7.1(iii) Dendrograms

For greater refinement, taxonomic dendrograms have been prepared and these are shown in figures 25 and 26. Sokal and Rohlff (1962) compared four different clustering methods for the



D Date Garden
V Vegetables
F Fodder Crops
W Woodland

C_1 Cotton - Heavy Texture
C_2 Cotton - Medium Texture
C_3 Cotton - Light Texture
Others Uncultivated

Fig. 25
Dendrogram of 62 soil profiles

construction of dendrograms - weighted pair-groups using Spearman's sums of variables, weighted variable-groups, unweighted variable-groups and weighted pair-groups using averages - and found that this latter method gave the highest correlation with the original indices. The pair-group methods, too, allow the minimum distortion to be caused to the original matrix (Sokal and Sneath, 1963).

The weighted pair-group method using averages, has been generally adopted by the pedologist, as it does not allow extreme weighting to individuals joining the main group late, and it has been used in this study. In any clustering cycle, only the two most highly correlated stems may link and, after each cycle, a recomputation of the matrix is necessary between the cluster and the other individuals in the matrix. These calculations were carried out on the computer and dendrograms constructed for 62 profiles (figure 25) and for 16 cultivated profiles located in the Federation of Arab Emirates (figure 26).

7.2 Analysis of Dendrograms

7.2(i) Dendrogram of 62 Profiles

This dendrogram (figure 25) clearly shows the clustering of the soils into three major groups which neatly correlate with the three main study areas (Al Ain and Ras-al-Khaimah may be considered as one geographic region for this study). In view of the apparently similar environmental conditions that prevail at Al Hasa and Al Ain/Ras-al-Khaimah and the generally light textures of the soils that occur in both these areas, it is perhaps surprising that there is such a low level of similarity between these two groups, (I and III on the figure) though the dendrogram does support the visual assessment of the shaded similarity matrix noted above. In fact, there is a greater similarity between the soils of Dubti Plantation, Ethiopia (Group II) and the Al Ain/Ras-al-Khaimah soils, and the relative low similarity between groups I and III is interpreted in terms of the management factor; at Al Hasa the soils studied were anthropogenic and woodland development is far more drastic in terms of pedogenesis than other forms of agriculture.

Group I, the soils from the sand stabilisation scheme at Al Hasa, has the greatest similarity as a discrete group being in excess of 74.4%. Two main reasons may account for this:-

(i) Management of the soils is more uniform, with all the profiles sampled being under Tamarix woodland. Only the minimum physical disturbance is actually caused to the soils, once the topsoil has been spread over the aeolian sand and the trees have been planted, though changes are rapid in these coarse textured soils.

(ii) The small size of the population relative to the other groups.

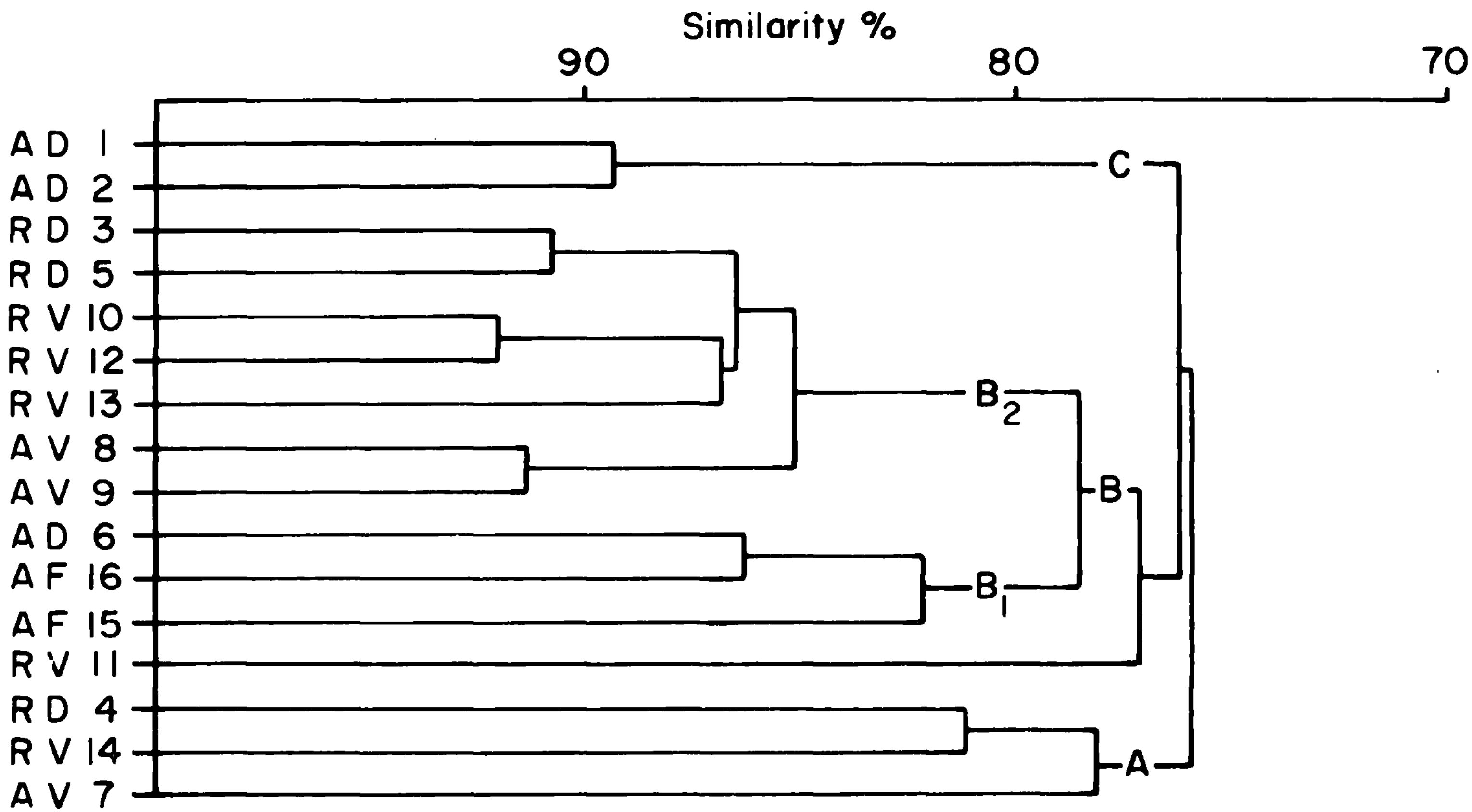
However, within the group, there is a greater degree of dissimilarity between individual profiles than occurs in other groups with the first linkage occurring at 85.1% between profiles 45 and 47 on the dendrogram. While the subsoil, as has been seen, is homogeneous aeolian sand, the topsoils are very heterogeneous, as, for instance, in the amount of soluble salts. It is noticeable that the two profiles which show the greatest dissimilarity within the group (profiles 41 and 43 on figure 25) are soils which had only been under woodland for one year at the time of sampling.

It is anticipated that, over a comparatively short period of time, the mechanisms, described in chapter 6, will result in the redistribution of soluble salts, clay and iron throughout the profile and there will be a greater similarity between individual soil profiles.

The effects of uniform management, over particular lengths of time, are also apparent in Group II which comprises soils on the cotton plantation at Dubti, Ethiopia. The heavy-textured soils (C_1 on figure 25) have a relatively high degree of similarity (they have all linked by 83%) and form a discrete sub-group within the main group. While they tend to have a relatively homogeneous profile morphology in contrast to their lighter-textured counterparts, they have also been cultivated for a longer time span. All the heavy-textured profiles used in ordination were in at least their seventh season of cropping while the medium-textured soils (C_2), which also link at 83%, had, with one exception, at least four seasons of cropping, prior to sampling. In contrast, the remaining medium-and light-textured soils (C_2 and C_3), have generally not been under cultivation for as long, while their more variable profile morphology also contributes to their lower levels of similarities and less discrete grouping.

Of particular interest are the positions of the four 'uncultivated' soils within the group. In fact only one is a semi-natural soil (profile 60 on the dendrogram) while the other three (62, 69 and 61) were being prepared for a cotton crop at the time of sampling. Profile 60 is a fluvisol with a relatively heavy texture in its topsoil and a heavy texture in the subsoil and was the last to join the discrete sub-group II_B, comprised mainly of heavy-textured soils, at 81.4%. Profile 62 is light-textured (16% clay in the topsoil) and was cultivated for one or two years when the plantation was first established, though low yields were obtained. Since then it has been in fallow for seven or eight years and yet, with only seedbed preparation including pre-irrigation, it exhibits a high degree of similarity (87.3%) with a light-textured profile that had been under cultivation for five years and forms the nucleus for the light-textured sub-group (II_A). It must, therefore, be supposed that once cultivation has been undertaken, the soils retain any anthropogenic characteristics for a considerable period of time, for the natural soil forming factors are too weak to further modify the soils. Profiles 59 and 61 were being cultivated for the first time - the former being light-textured (clay content of 8% in the topsoil) and the latter heavy-textured (clay content 60%) - and these are the last two profiles to join the Dubti cluster at similarity values of 71.7% and 69.3% respectively.

The soils of Group III comprise those from Ras-al-Khaimah and Al Ain and they come together at 71.5%. The main feature of this group is the linkage of the uncultivated soils (the linkage of the cultivated profiles will be discussed separately in 7.2(ii)). The discrete sub-group of uncultivated soils (mainly xerosols and yermosols) at 81.8% (III_A) is composed of soils from Ras-al-Khaimah, with the single exception of profile 50. This sub-group forms an early linkage (79.6%) with sub-group III_B of



D Date Gardens
V Vegetables
F Fodder Crops
A Al Ain
R Ras-al-Khaimah

Fig. 26

Dendrogram of cultivated soils from the Federation of Arab Emirates cultivated soils (both dates and vegetables), again mainly composed of Ras-al-Khaimah soils; though profiles 8 and 9 are exceptions. The three remaining uncultivated soils have relatively low similarities with other profiles in Group III and are the last to join the group-profile 48 at 73.1%, profile 54 at 72.4% and profile 49 at 71.5%.

7.2(ii) Dendrogram of 16 cultivated profiles at Al Ain and Ras-al-Khaimah.

Figure 26 differs from Group III on figure 25 in that the uncultivated soils have been omitted from the cluster. This has meant that not only is there now greater similarity between profiles 6,16,15,11,4,14,7 and the remaining profiles in the group (the similarity is now 75.5% compared with 74.3%) but also there has been a minor rearrangement in the positioning of individual members of the group. Profile 11 now comes between profiles 15 and 4 instead of after profile 7, but this change is not considered of major significance. The change is caused by the relatively high degree of dissimilarity between profile 11 and the uncultivated profiles which caused it to join the group late (at 74.9%) on figure 25. Omitting the uncultivated profiles allows the similarity between profile 11 and the other cultivated profiles to be emphasised and it now joins sub-group B at 76.7%.

Three distinct sub-groups may be distinguished. A is composed of three profiles, two from Ras-al-Khaimah and one from Al Ain, under vegetables and dates while C includes only two date garden profiles from Al Ain. Sub-group B is the largest and includes cultivated profiles from both Al Ain and Ras-al-Khaimah, under dates, vegetables and fodder crops, though it can be further subdivided.

Sub-group A includes one date-garden profile (4) and two soil profiles from vegetable plots. The date garden was old - many of the palm trees had been cut down for fuel or had fallen down, through old age or disease, and there was some evidence that the garden had been used for either fodder crops or vegetables. At the time of sampling, it was unclear whether the garden had been abandoned, but some of the basins that had formerly surrounded palm trees had been enlarged for alternative crops. Profile 14 was being given over to citrus, though it had in the past grown water melons, while profile 7 had been under vegetable crops for eleven years. Geographically, both profiles 4 and 14 are peripheral to cultivation in Ras-al-Khaimah and this probably accounts for the relatively low level of similarity between the individual profiles in the group.

Sub-groups B_1 and B_2 are more discrete and exhibit higher levels of similarity. B_1 is composed of soil profiles from two plots which had grown fodder crops (lucerne) since their establishment, whilst profile 6 was under dates. However, the date palms were only 16 years old and fodder crops had been grown as a ground crop; at the time of sampling, the remains of a lubia (Dolichos lablab) crop were in evidence, though lucerne had been grown in former years. It is thus concluded that the early stages of date cultivation have few specific effects on soil properties and, if the latter are to be influenced, the cause will be the cultivation of a ground crop. In the instance cited, the growing of fodder crops is responsible for the clustering of profile 6 with other profiles that had had similar management.

B_2 is a mixed sub-group composed mainly of soils under vegetable cultivation from both Ras-al-Khaimah and Al Ain but it also includes two profiles from the date gardens at Ras-al-Khaimah. Of particular interest is the inclusion of the latter two profiles (3 and 5) and the two profiles from Al Ain (8 and 9) which are the last to join the group at 84.6%. No clear reason can be put forward for the inclusion of the two date garden profiles in this cluster - both were regarded as being traditional date gardens, though they did have a thicker ground-cover of grasses than was usual and these grasses were periodically grazed by cattle, sheep and goats. Profiles 8 and 9 had been given over either to vegetable cultivation or to cereal growing for about four years prior to sampling, and their late linkage to the remaining profiles in the sub-group is ascribed not to length of cultivation (vegetable cultivation is a relatively recent phenomenon in Ras-al-Khaimah and Al Ain) but to differences in parent material.

Prior to attempting clustering, it was thought that profiles 3 and 5 would have the greatest similarities with the soils from the long-established date gardens at Al Ain (sub-group C). In fact, the two profiles from the Al Ain date gardens (1 and 2), while having a high degree of similarity between themselves (88.8%), are among the last to join the Al Ain/Ras-al-Khaimah cluster and are rather distinct soils. It may be that the Ras-al-Khaimah date gardens have not been established for as long as those at Al Ain, for at present there are no significant management differences between the two areas. Certainly, it would be expected that date gardens established for hundreds or even thousands of years would have influenced pedogenesis to a greater extent than vegetable gardens established for less than twenty years - Al Ain date gardens are regarded as the norm, Ras-al-Khaimah date gardens the anomaly.

7.3 Numerical classification and cultivated arid zone soils in the Middle East

Muir et.al.(1970), in their study on the classification of soil profiles by traditional and numerical methods, consider that the results of numerical classification have been used either to justify the method or to question the validity of major soil groups. They then went on to compare soil classification at the series level with numerical groupings. In this present study, the author has extended the use of numerical classification to employ it in the establishment of linkages between soils under differing management techniques, i.e. as a tool in assessing the influence of one of the pedogenic factors.

In a study of this type, the similarity indices, and hence linkages, are determined by the choice of characteristics to define each soil. A change in choice of characteristics might be reflected in shifts of members both within and between clusters, though highly correlated members are likely to remain together. Care was taken in the choice of characteristics for this study in that only measurable properties of the surface horizon and the subsoil immediately underlying it were considered, as these are the horizons that will be most affected initially by the different types of management. Some problems did arise in sampling, where the cultivated horizon was underlain by a series of thin depositional horizons of varying texture, and in such circumstances a composite sample was taken. The selected characteristics included not only those which would emphasise the natural soil properties even after being under cultivation for considerable periods of time e.g. texture, carbonate contents, but also those properties likely to be affected by only a year or two of cropping e.g. pH, nitrogen levels.

It is considered that the use of numerical linkage techniques has considerable validity when considering soils of arid areas for the major soil groups tend to be ill-defined. For example, Bidwell and Hole (1964) found that, in their study of Kansas soils, there was a high degree of similarity between some soil series regarded as brunizems and others regarded as chernozems. In applying numerical linkage to soils of the Middle East, the author has restricted his studies to yermosols, regosols, fluvisols, xerosols and vertisols, omitting halosols, as the latter tend to have a low priority in development studies and can be readily defined. If halosols are cultivated, special techniques need to be employed for their successful management. The other soils are the ones that have the most significance in agricultural development and man can, in only a short period of time, affect soil properties to such an extent that similarity with the uncultivated soil is rapidly reduced. This is clearly shown in figure 25 where the uncultivated soils either form discrete sub-groups or join clusters late, as individuals.

Numerical linkage also suggests that, within a given geographical area, each type of cultivation has its own distinct set of effects on soil properties. This results in linkage according to management practise rather than soil type as shown on both figures 26 and 25 - on the latter figure the soils comprising sub-group II_B include notonly cultivated vertisols but also cultivated xerosols and fluvisols of medium texture.

CHAPTER 8

Conclusions

8.1 Introduction

Two approaches have been used in this thesis:-

(i) The effects of different types of cultivation on soil properties have been examined with respect to specific areas of the Middle East. These studies have been presented in Chapters 3-6 and no attempt was made to contrast any one area with the others. Instead, the mechanisms responsible for the changes occurring within the soil profile were isolated in the context of the area being considered.

(ii) An attempt, using cluster analysis, was made to assess the similarity or dissimilarity, of cultivation effects on different arid region soils. This technique has hitherto been employed mainly in the taxonomic classification of soils and it has been discussed in Chapter 7. It is clear, though, that a particular form of management does have specific effects on the soils of an arid area, irrespective of their classification type. However, it would seem that effects vary from area to area as, for example, the lack of 'clustering' of date garden soils in Al Ain and Ras-al-Khaimah.

Both these approaches have considerable implications in assessing land for agricultural development within the arid zone. The implications of the former approach are of greatest importance when project plans are being finalised, while the latter has relevance not only in the reconnaissance and semi-detailed stages of land evaluation, but also in the detailed planning stage.

8.2 Soil studies and land evaluation

In land evaluation for agricultural development, assessment of the physical environment is usually carried out at three main levels of intensity - reconnaissance, semi-detailed and detailed (project). The first of these is to provide a basic inventory of the physical resources and the type of approach that is usually favoured is similar to the Land Systems first used by Christian and Stewart (1952). The land system is an assemblage of land units which are geographically and genetically related and in which there is a recurring pattern of topography, soils and vegetation. Such an approach is essentially descriptive and there is little attempt at explanation. It is essentially a data storage system and paves the way for more detailed studies.

At the more detailed levels of land evaluation, the role of soil studies has not been altogether clear. In the past, prior to the use of the U.S. Bureau of Reclamation Land Classification scheme or the U.S. Department of Agriculture Land Capability Classification, there was perhaps an over-emphasis on the approach of Clarke (1957) who stated that 'a good soil description on the 'site and profile' principle should be so complete that no further information is required to arrive at a technically perfect system of rational utilisation'. If this approach is to be meaningful, the numbers of attributes in the soil and surrounding environment that have to be considered are extremely numerous.

Land evaluation is a holistic appraisal of the environment, usually with a fixed purpose in mind, and soil surveys form an integral part of such feasibility studies. There has been considerable discussion in the literature on what soil surveys are trying to achieve (e.g. Gibbons, 1961, Mulcahy and Humphries, 1967), though Mulcahy and Humphries consider that in underdeveloped areas where there is little agronomic experience surveys based on general soil classifications will be of more use than special purpose surveys. However, such classifications are usually monothetic (i.e. individual characters are essential for membership of a group) and Butler (1964) regards any close correlation between soil type and plant production a matter of chance when using such classifications. Furthermore, the characters essential for membership of a group are those that are present in the natural soil profile and may, or may not, occur in cultivated soils.

In contrast, the approach of numerical classification, as used in this thesis, is polythetic in that it places together individuals having the greatest number of characters in common and no single character is either essential or sufficient for membership of the group (Sokal and Sneath, 1963). If one includes both cultivated and uncultivated profiles in such an analysis, linkages between the soils can be established and the dichotomy, albeit unintentional, between cultivated and uncultivated profiles is avoided. Cultivated areas tend to be avoided in land evaluation studies as the latter concentrate on areas where there is potential for development. Nonetheless, the comment by Hartshorne (1959) regarding the division of geography into human and non-human factors as being 'extraneous in purpose, prejudicial to sound research and disruptive of the fundamental unity of the field' is equally applicable to soil studies in land evaluation.

There will doubtless be differences between uncultivated soils and cultivated soils as happens on figure 25, but this can be used in predicting changes that will occur with given types of management. For instance, cultivation of profile 60 (Group II) will result in it having greater similarity with the cultivated profiles which comprise sub-group II_B. Furthermore, such clustering may be of help in determining the management of a particular group of soils within a project, i.e. should a specific area be given the same treatment as another area? The soils of Dubti Plantation all receive exactly the same management when cotton is grown except that some fields may receive 2 quintals/hectare of urea whereas others receive only 1. It could be argued that profiles 27 and 37 on figure 25 are sufficiently dissimilar to the major sub-group II_B, to warrant a further look into the management they receive. However, care must be taken to ensure that the dissimilarity is of agronomic significance. Factor analysis may provide an indication of the principal causes of dissimilarity.

In an approach of this nature, care must be taken in the choice of characteristics so that only those likely to influence, or be influenced by, management are chosen. The use of computers allows the rapid processing of data and while land evaluation at semi-detailed or project level is proceeding, linkages can be established and questions posed which will give guidance to the direction of further investigations.

8.2(i) Conclusions relating to the use of cluster analysis

The possible use of cluster analysis in land evaluation studies has been outlined; and the work carried out on arid zone soils of the Middle East for this thesis would suggest the following:-

(i) Using the methods described, cluster analysis does separate cultivated and uncultivated soils into discrete groups and is sophisticated enough to show meaningful linkages between the sub-groups. Furthermore, it has been shown (Chapter 7) that there are valid reasons for the linkages of individual uncultivated soil profiles. For this technique to be generally applicable in development studies, additional research is required into the choice of characteristics involved in the calculation of similarity indices and also possible alternative methods of cluster analysis.

(ii) With poorly defined major soil groups, and where natural pedogenesis is slow, the influence of man is out of all proportion to the time he has affected the soils. As a consequence, the use of numerical taxonomy at project level results in linkages that reflect management practises rather than major soil groups, though the significance of the linkages, will vary from one situation to another.

(iii) The soil profiles subjected to this form of analysis clearly cluster according to their geographical locations (figure 25). The implication of this is that the introduction of California -

style agriculture into the Middle East situation will cause different effects on the soil to those in California. This highlights the comment, made in the Preface, that constant monitoring of soils of agricultural development schemes is essential.

(iv) Even within geographical areas, there are anomalous results in the linkages. The significance of these anomalies have to be investigated but it is clear that from Chapters 3-6 some of the effects of cultivation are specific to a particular area and result from local environmental features, both physical and human.

8.3 The effects of cultivation on the properties of arid zone soils in the Middle East

If land evaluation for agriculture is to be successful, prediction has to be accurate and this involves a thorough understanding of the processes operating within the soil. The soils, and the environment in which they occur, are extremely variable and complex relationships result. Processes that are operative in one area may not be operative to the same extent in another, not only as a result of variations in the physical environment but also due to man's use of the soil as a resource.

The establishment of irrigated agriculture in areas where the soil is naturally dry for most of the year leads to profound changes in the types of pedogenic processes that take place in soils of the affected areas. With irrigated agriculture, a variety of processes operate depending on the moisture conditions of the soil. Instead of being dry, the subsoil now remains moist for the major part of the year while the surface horizons are subjected to a highly variable moisture regime. There is surplus moisture when the soil is irrigated, but immediately prior to irrigation drought conditions prevail. Furthermore, the texture of the soil has important implications on water movement. Many of the soils of the arid areas of the Middle East are coarse textured with only the minimum development of structure, and with such conditions intense leaching prevails when irrigation waters are applied. In contrast, there may be rapid initial downward movement of moisture with irrigation of vertisols but, as soon as the cracks close, this becomes extremely slow due to the preponderance of fine pores that occur in such soils.

The first stage in elucidating processes is to measure change, and this thesis has been concerned with determining the changes caused to soils due to the different cultivation practises. The effects of cultivation on arid zone soils fall into two categories - those which are general and irrespective of type of cultivation and those which are specific either to an area or to a type of cultivation.

8.3(i) General conclusions

(i) All the cultivation techniques discussed in this thesis result in an increase in the level of organic matter in the soil. However, prior to the first crop, there may be a decrease due to disturbance of the surface horizon by tillage and the high temperatures causing the 'burning up' of residual organic matter. Subsequent cultivation allows the organic matter content to increase to levels considerably in excess of those found in uncultivated soils.

The only exceptions to this are the former hydromorphic soils in the lower Awash valley, Ethiopia, that contained exceptionally high levels of organic matter prior to reclamation.

(ii) Consequent upon the increase in organic matter contents are the effects on soil fertility. These include a lowering of the pH (though this is often masked as in the cases of the soils of Al Ain and Ras-al-Khaimah due to the variability of the soil parent material), an improvement in the structural stability of the soils and greater availability of nutrients. The effects of individual cropping practices vary in their intensity - for instance, fodder crops (Chapter 4) are more effective in structural aggregation than the woodland at Al Hasa (Chapter 6).

(iii) In each of the case studies, the prevalence of over-irrigation results in a washing of soluble salts out of the topsoil. Chlorides tend to be lost earlier than sulphates. In some localities, secondary salinisation has occurred or is occurring e.g. Ras-al-Khaimah (Chapter 3), parts of Dubti Plantation, Ethiopia (Chapter 5).

(iv) Where the soils are coarse-textured, there is evidence of redistribution of fine material within the soil profile. Evidence of this is provided by profiles from the long-established date gardens at Ras-al-Khaimah (Chapter 3) as well as from the *Tamarix* woodland at Al Hasa (Chapter 6). Some fine material is added to the soil through suspension in the irrigation water, this being most noticeable in the case of the Tendaho Plantations.

8.3(ii) Conclusions specific to individual areas

(i) Ras-al-Khaimah. There is evidence for decalcification in soils under the long-established date gardens but if it occurs in similar situations at Al Ain evidence is obscured. Elsewhere, cultivation has not been established for a long enough period of time for this process to become evident or else carbonate contents in the soil are sufficiently low to make conclusions difficult.

(ii) Al Ain. Studies on soils from this group of oases suggest that cultivation can, over a long period of time, have an effect on weathering within the solum. The extreme differences in free iron oxides, in silica-sesquioxide ratios and in type of clay minerals occur between an uncultivated xerosol profile and profiles from the long-established date gardens. Other profiles, under different types of cultivation for much shorter periods of time than the date gardens, e.g. vegetable cultivation, lie between these two extremes.

(iii) Tendaho Plantations, Ethiopia. The first season of cotton cropping appears to cause profound changes in the pH and conductivity values of the soils occurring in the plantations. There is rapid decomposition of residual organic matter prior to cropping and this results in the production of organic acids. The latter are enhanced at the end of the first season of cropping when the cotton trash is ploughed in. As the quantity of organic matter added to the soil each year is relatively constant, the soil pH quickly reduces and reaches a stability value of 7.5-7.8. Only the reclaimed hydromorphic soils are an exception to this, increasing their pH values, but they had higher organic matter contents prior to cultivation.

The first heavy irrigation, prior to the initial planting of cotton, is of fundamental importance in control of soluble salts. On the medium and heavy textured soils, the deep shrinkage cracks act as channels down which soluble salts can be washed, but after a season of cropping these cracks may only extend to 40 or 50 cms, as beneath this depth the soil remains moist. In the dry, uncultivated vertisols the cracks may extend to 1 metre or even 1.50 metres.

Tillage of the soils has not, in itself, been a major cause in the formation of surface crusts. While these remain weak and do not affect plant growth, there is a correlation between thickness of the crust and the amount of silt and clay in the soil. There is a linkage noted in uncultivated soils, between crust formation and flooding by the River Awash. The crusts tend to be thicker on the plantations and it is concluded that irrigation, using Awash river water heavily charged with sediment, is a prime cause in crust formation.

(iv) Al Hasa oasis. The presence of a surface organic layer under the older Tamarix woodland (8 years old) is a feature unique in arid zone soils in the Middle East and accordingly greatest emphasis was placed on a study of the organic horizons. Distinct L and F horizons had formed under the older stands of woodland. The early stages of organic matter decomposition, in the presence of irrigation water, are characterised by an acid reaction (pH values of 5.7 were obtained in laboratory experiments) as the hemi-celluloses decompose. Analysis of the humus fraction showed that there were high levels of humin present, due to the dessication to which the organic matter is periodically subjected, while fulvic acid predominated over humic acid. This resulted in a high proportion of active acids being present in the soil leading to mobilisation of iron and a progressive decalcification of the soil. The role of decomposition of organic material and its effect on properties of arid zone soils has been little studied and this would appear to be a field in which further work is required - of particular interest would be comparative studies of decomposition of organic residues from different crops and their effects on the nutrient status of the soil.

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APPENDIX 1

DESCRIPTIONS AND ANALYTICAL DATA FOR PROFILES QUOTED IN TEXT

n.d. - no data

___ - amounts undetectable by analytical methods

LOCATION RAS-AL-KHAIMAH (Shimal) TITLE 1.

TOPOGRAPHY Gravel fans with irregular surface due to small wadis. Wadies dry at the time of sampling. Slope 3^{O}W.

VEGETATION Scattered Acacia spp - 5% cover

CULTIVATION

SOIL GROUP Yermosol

SURFACE Frequent large cobbles and gravel

PROFILE DESCRIPTION

0-20 cms	10YR4/4-5/4 (Dark yellowish brown); sandy loam gravel; generally single grain structure with rare small weak angular blocks; rare fine roots; clear change
20-90 cms+	10YR3/2 (very dark greyish brown); gravelly loamy sand; single grain structure; very rare fine roots 40-45 cms strong cementation (calcareous) with well-developed large rusty mottles.

No samples were obtained from this pit

LOCATION	RAS-AL-KHAIMAH (Shimal)	TITLE 2.
TOPOGRAPHY	Gravel fan. Slope 3^{o}W.	
VEGETATION	Scattered Acacia spp. - 5% cover	
CULTIVATION	Surface cleared for cultivation and plots demarcated by banks of stone. No evidence of any cultivation at time of sampling.	
SOIL GROUP	Xerosol	
SURFACE	Even surface with large cobbles cleared	

PROFILE DESCRIPTION

0-35 cms	10YR5/6 (yellowish brown) with patches of 10YR4/2 (dark greyish brown; sandy loam gravel; single grain structure with some small angular blocks; friable breaking to single grains; frequent fine roots; clear change.
35-70 cms	10YR4/1 (dark grey) - 10YR3/1 (very dark grey); sandy gravel; single grain structure; frequent fine roots; rare small dull diffuse ochreous mottles; rare small soft carbonate accumulations; clear change.
70 cms+	10YR3/1 (very dark grey); gravelly loamy sand; single grain structure; frequent fine roots; rare small soft carbonate accumulations

NOTE: The high organic matter content in the topsoil reflects the close proximity of the profile pit to an Acacia bush

LABORATORY ANALYSES

Profile ..2............ Location ..Ras-al-Khaimah (Shimal)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	10-16	73.0	82.2	10.0	74.2	18.0	7.8		8.80
	39-45	76.0	97.2	1.0	95.4	2.8	1.8		8.60
	84-90	77.5	93.2	5.0	92.2	6.0	1.8		8.80

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
9.2	2.6	1.6	0.6	14.0	11.4		0.17				
3.3	2.4	0.8	0.3	6.8	11.8		0.17				
6.1	2.2	1.0	0.6	9.9	9.9		0.19				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
0.93	0.54	0.04	13.5		2.3				
n.d	n.d.								
0.18	0.14								

LOCATION RAS-AL-KHAIMAH TITLE 3.

TOPOGRAPHY Edge of gravel outwash fan. Pit located in irrigation basin

VEGETATION

CULTIVATION 30 year old date palms with thick grass cover grazed by cattle

SOIL GROUP Yermosol (cultivated variant)/Xerosol

SURFACE Slight crust due to irrigation

PROFILE DESCRIPTION

0-30 cms	10YR4/3 (dark brown) - 10YR4/2 (dark greyish brown); silty fine sandy loam; moderate medium angular blocks; firm, breaking to small angular blocks and crumbs; moist; abundant roots; occasional worms; occasional sub-rounded stones; occasional grey patches of organic matter; merging.
30-35 cms	10YR4/3 (dark brown); gravelly silty loam; moderate medium subangular blocks; friable breaking to crumbs; moist; abundant roots; frequent sub-rounded cobbles with rare carbonate 'garlands' on undersides of such cobbles below 50 cms; clear change.
55cms+	10YR4/3 (dark brown); gravel with some silty loam; single grain with occasional sub-angular blocks; moist; frequent roots; abundant cobbles, some with 'garlands' of carbonates on undersides.

LABORATORY ANALYSES

Profile ...3........... Location Ras-al-Khaimah (Shimal)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	15-21	58.0	60.4	22.4	43.8	39.0	17.2		8.60
	39-45	57.0	52.8	24.4	40.8	36.4	22.8		8.55
	70-75	61.5	68.2	9.0	63.2	14.0	22.8		8.60

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
17.5	3.4	4.4	0.5	25.8	17.1		1.13				
14.6	3.2	2.4	0.5	20.7	11.6		1.29				
13.7	3.6	2.7	0.3	20.3	13.3		0.81				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.02	1.17	0.06	19.5		0.8				
n.d.	n.d.								
0.38	0.22								

LOCATION	RAS-AL-KHAIMAH (Fahlain)	TITLE	4.

TOPOGRAPHY Gentle slope - $1^{O}N$

VEGETATION

CULTIVATION Date garden - dates about 35 years old. Grasses grazed by cattle.

SOIL GROUP Cultivated Xerosol

SURFACE Irrigated with thin crust

PROFILE DESCRIPTION

0-40 cms.	10YR4/3 (brown); silty sandy loam; weak medium columnar and angular blocky structure; friable; breaking to small angular blocks; moist; occasional gravels; abundant roots; occasional channels of grey organic matter; occasional worms; clear change.
40 cms+	10YR4/3 (brown); laminated loamy sands, sands and sandy gravel; gravels become more dominant with depth; single grain structure; moist; abundant roots; occasional channels of grey organic matter to 1 metre.

LABORATORY ANALYSES

Profile ....4.......... Location Ras-al-Khaimah (Fahlain)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	15-22	54.0	62.6	18.2	44.6	36.2	19.2		8.60
	43-50	57.5	74.2	11.0	42.2	33.0	14.8		8.60
	98-105	60.0	82.6	7.6	70.2	20.0	9.8		8.65

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
16.2	1.5	2.4	0.7	20.8	11.5		0.85				
17.3	1.7	2.2	0.4	21.6	10.2		0.38				
4.7	1.0	1.6	0.5	7.8	20.5		0.38				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
1.27	0.74	0.04	18.5						
n.d.	n.d.								
0.21	0.12								

LOCATION	RAS-AL-KHAIMAH (Hassan bin Rachman's holding)	TITLE 5.

TOPOGRAPHY Extreme edge of outwash fans. Slope 1°W.

VEGETATION Nil

CULTIVATION Smallholding. Prepared for cultivation through plot not previously cropped.

SOIL GROUP Xerosol (cultivated variant)

SURFACE Thin crust

PROFILE DESCRIPTION

0-31 cms	10YR4/4 (dark yellowish brown); fine sandy loam; weak small angular blocks with depositional laminations towards base of horizon; friable, breaking to single grains; frequent fine rootlets; frequent fine gravel lenses; clear change.
31-90 cms.	10YR4/4 (dark yellowish brown); silty fine sandy loam; moderate medium angular blocks and columns; friable, breaking to small angular blocks and single grains; becomes compact with depth; rare fine roots; occasional small gravel lenses; rare small soft carbonate accumulations sharp change.
90 cms+	Laminated sands and gravels of variable lithology.

NOTE: Organic matter in topsoil rather lower than in uncultivated soil due to 'burning' up as a result of topsoil disturbance.

LABORATORY ANALYSES

Profile 5 Location Ras-al-Khaimah (Hassan bin Rachman)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	7-14	48.0	34.3	51.4	11.9	73.8	14.3		8.50
	37-44	48.0	13.9	65.8	13.2	66.5	20.3		8.25
	80-87	50.5	25.3	51.1	8.3	78.1	13.6		8.40

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
17.4	3.2	3.6	0.8	25.0	14.4		0.14				
13.6	8.4	5.6	2.8	30.4	18.4		0.15				
14.4	2.4	2.4	2.8	22.0	10.9		0.14				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
0.88	0.51	0.04	12.8		1.4				

LOCATION	RAS-AL-KHAIMAH (Digdaga Agricultural Trials Station)	TITLE 6.

TOPOGRAPHY Land prepared for irrigation - basin

VEGETATION Bare

CULTIVATION Previously uncultivated

SOIL GROUP Xerosol

SURFACE Loose

PROFILE DESCRIPTION

0-88 cms.	10YR4/3 (brown-dark brown); sandy loam; moderate medium subangular blocks with occasional platiness in top 8 cms; very friable; breaking to single grains; rare subrounded gravel; frequent fine roots; slightly compacted below 50 cms with frequent pinholes; merging.
88 cms+	10YR4/3 (brown) with 7.5YR tinge, loamy fine sand; compact and laminated with occasional gravel; occasional soft carbonate accumulations; frequent red sand grains.

NOTE: Low organic matter in topsoil result of preparation for cultivation.

LABORATORY ANALYSES

Profile 6. Location Ras-al-Khaimah (Digdaga)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	10-16	46.5	63.1	21.6	37.2	47.5	15.3		8.55
	39-45	51.0	50.4	19.9	20.7	59.6	19.7		8.70
	70-84	51.5	69.2	14.0	21.2	62.0	16.8		8.80
	105-111	51.5	63.5	20.9	28.6	56.8	15.6		8.70
	120-126	51.0	49.2	36.6	33.8	52.0	14.2		8.70

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
8.4	4.1	0.7	0.5	13.7	5.1		0.21				
10.8	3.1	0.7	0.4	15.0	4.7		0.29				
11.7	4.0	0.8	0.3	16.8	4.8		0.21				
15.1	4.3	1.1	0.2	21.7	5.3		0.20				
12.4	4.7	1.8	0.3	19.2	9.4		0.21				

Organic Matter Total %	Organic C%	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
0.28	0.16	0.02	8		0.4				

LOCATION RAS-AL-KHAIMAH (Digdaga Agricultural Trials Station) TITLE 7.

TOPOGRAPHY Pit located in irrigation basin

VEGETATION

CULTIVATION Plot growing tomatoes, squash, cucumbers. Had been cultivated for 9 years at time of sampling (1967)

SOIL GROUP Xerosol (cultivated variant)

SURFACE Slight crusting due to irrigation

PROFILE DESCRIPTION

0-42 cms 10YR4/3 (brown); fine sandy loam; weak large angular blocks and rare columns; friable, breaking to single grain slightly moist; occasional roots and fine rootlets; rare gravel; merging.

42-105 cms 10YR4/3-5/3 (brown); loamy fine sand; weak large columns somewhat compacted and locally exhibiting laminations; friable, breaking to single grains; moist; occasional sub-rounded stones; rare fine roots; occasional patches of gre staining; merging.

105 cms+ 10YR4/3 (brown); loamy fine sand - fine sandy loam; generally single grain structure, though slightly compacte slightly moist; rare fine roots; rare subrounded stones, some with 'garlands' of carbonate accumulation.

NOTE: Irrigation water had a conductivity of 3.4 mmhos/cm at 25°C. Cultivated horizon appeared to extend to 26 cms - this was the upper limit of the columnar structure.

LABORATORY ANALYSES

Profile ...7............ Location ..Ras-al-Khaimah (Digdaga)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	15-21	45.5	50.4	33.6	27.0	57.0	16.0		8.80
	45-51	46.5	38.2	44.8	23.4	59.6	17.0		8.75
	75-81	46.5	56.5	27.9	25.9	58.5	15.6		8.65
	94-100	46.0	63.6	21.2	33.8	51.0	15.2		8.80
	134-140	46.0	64.7	17.8	31.6	50.9	17.5		8.60

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
9.9	3.6	2.3	0.3	16.1	14.3		1.16				
12.2	2.4	3.0	0.4	18.0	16.7		2.40				
11.4	1.8	5.4	0.4	19.0	28.4		2.11				
11.0	2.2	2.4	0.4	16.0	15.0		1.50				
12.4	2.2	1.4	0.4	16.4	8.5		1.53				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
1.15	0.66	0.04	16.5		0.5				

LOCATION	RAS-AL-KHAIMAH (Ahmed Bassan) TITLE 8.
TOPOGRAPHY	Gentle slope to NW (2^o). Pit located just off eroded remnant of ancient gravel fan.
VEGETATION	Fallow plot
CULTIVATION	Prepared for melons. Cultivated for 3 years previously
SOIL GROUP	Xerosol (cultivated variant)
SURFACE	Slight crusting and clods

PROFILE DESCRIPTION

0-35 cms	10YR4/3 (dark brown) - 10YR4/4 (dark yellowish brown); fine sandy silty loam; moderate medium large angular blocks; fairly firm breaking to small angular blocks and single grains; dry; rare dead roots; frequent fine gravel; rare cracks; clear change.
35-77 cms	10YR4/4 (dark yellowish brown); depositional horizons of gravels and fine material; gravels becoming coarser with depth; single grain structure; dry; rare roots; occasional cobbles; rare carbonate accumulations especially as 'garlands' on cobbles; clear change.
77 cms+	Dark grey gravel; rare fine rootlets; frequent carbonate 'garlands' on undersides of larger gravel (cobble size).

LABORATORY ANALYSES

Profile ...8...........   Location Ras-al-Khaimah (Ahmed Bassan)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	8-15	33.0	57.9	29.9	40.3	47.5	12.2		8.40
	38-45	31.5	77.3	13.0	53.8	36.5	9.7		8.70
	75-82	36.5	65.9	34.0	44.5	45.4	10.1		8.65
	98-105	40.5	65.4	24.8	42.5	47.7	9.8		8.40

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
6.8	1.3	1.5	0.2	9.8	15.3		0.37				
4.4	1.3	1.1	0.5	7.3	15.1		0.36				
5.0	1.4	1.4	0.4	8.2	17.1		0.41				
4.0	1.4	1.6	0.2	7.2	22.2		0.40				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
1.33	0.78	0.05	15.6		0.4				

LOCATION RAS-AL-KHAIMAH (Hail) TITLE 9.

TOPOGRAPHY Possible former inland extension of Ras-al-Khaimah lagoon. No slope

VEGETATION Halophytic species giving about 5% cover

CULTIVATION

SOIL GROUP Halosol (solonetz)

SURFACE Hummocky, due to aeolian accumulations around plants. Thin crust often broken up by animals etc.

PROFILE DESCRIPTION

0-14 cms — 10YR5/4 (yellowish brown) - 10YR5/3 (brown); silty fine sandy loam; moderate medium plates with angular blocks towards base; friable; breaking to small angular blocks and single grains; slightly moist; frequent/abundant roots; occasional gravel; clear change.

14-25 cms — Colour as above; loamy sand - sandy loam; single grain structure; slightly moist; rare roots; gypsum crystals with some small earthy carbonate accumulations; clear change.

25-124 cms+ — 10YR5/4 (yellowish brown); clay loam; weak large columnar structure with some platiness; moist; occasional slickensides; occasional pinholes; gypsum crystals at top of horizon; occasional small earthy carbonate accumulations.

LABORATORY ANALYSES

Profile 9 Location Ras-al-Khaimah (Hail)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-13	55.0	55.1	30.1	42.2	43.0	14.8		8.40
	30-38	46.0	22.6	46.0	6.5	62.1	31.4		8.45
	112-120	46.0	10.1	52.7	6.1	56.7	37.2		8.40

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
5.3	3.6	4.1	1.7	14.7	28.9		9.98				
18.6	2.2	8.4	2.4	31.6	26.6		9.35				
18.2	3.2	8.2	0.8	30.4	26.2		11.10				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
0.21	0.12	0.02	6.0		0.09				

LOCATION	RAS-AL-KHAIMAH (Hail) TITLE 10
TOPOGRAPHY	On edge of outwash fan - slope 2^{o}W. Overlies lagoonal deposits.
VEGETATION	Bare
CULTIVATION	Disused cultivation
SOIL GROUP	Polymorphic soil. Non-saline material overlies Halosol.
SURFACE	Very slight crusting

PROFILE DESCRIPTION

0-22 cms	10YR5/4 (yellowish brown) with some patches of 10YR3/2 (very dark grey brown); loamy sands; weak angular blocks and single grain; dry; rare fine roots; occasional fine gravel; clear change.
22-85 cms	10YR5/4 (yellowish brown), frequent dark coloured sand grains; (silty) fine sandy loam; moderate medium columnar and angular blocky structure; slightly compacted breaking to small angular blocks; very slightly moist; rare gravel rare fine rootlets; occasional pinholes; rare small earthy carbonate accumulations; clear change.
85 cms+	10YR5/4 (yellowish-brown) - 10YR4/4 (dark yellowish brown); silty clay loam; depositional laminations; slight compaction; slightly moist; rare small earthy carbonate accumulations.

LABORATORY ANALYSES

Profile 10 Location Ras-al-Khaimah (Hail)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	7-14	75.0	75.4	18.4	61.4	32.4	6.2		8.15
	37-44	57.5	68.5	20.2	50.2	39.5	11.3		8.70
	67-74	39.5	72.4	15.6	51.6	36.4	12.0		8.45
	100-107	37.5	35.7	47.9	6.5	77.1	16.4		8.45

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
4.2	4.8	1.3	0.4	10.7	12.2		0.29				
4.5	4.2	4.2	1.1	14.0	30.0		1.26				
18.0	4.3	6.8	0.7	19.8	34.4		1.74				
13.3	4.5	9.7	0.4	27.9	34.8		8.29				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
0.27	0.16	0.02	8		0.01				

LOCATION	RAS-AL-KHAIMAH (Ruler's Garden, Hail)	TITLE 11.

TOPOGRAPHY	On edge of outwash fan. Slope 2°NW
VEGETATION	Haloxylon salicornicum - sparse cover (5%)
CULTIVATION	Being prepared for vegetable cultivation
SOIL GROUP	Halosol (Solonetz)
SURFACE	Hummocks of aeolian material around Haloxylon bushes. Weak crust and local gravel skiffs

PROFILE DESCRIPTION

0-23 cms	10YR4/3 (brown); loamy sand; generally single grain structure with some sand and gravel layers; soft; dry; occasional fine rootlets; rare gravel; clear change.
25-53 cms	10YR5/3-4/3 (brown); silty fine sandy loam; weak medium columnar structure; compact, breaking to small angular blocks and single grains; very slightly moist; occasional fine rootlets; frequent small cracks; occasional fine gravel; occasional pinholes; merging.
53-118 cms	107YR4/3 (brown);(silty) fine sandy loam; weak medium columnar structure; slightly compact, breaking to small angular blocks and single grains; slightly moist; occasional gravels; rare small carbonate accumulations; merging.
118 cms+	10YR4/3 (brown) with red and grey sand grains; loamy fine sand; compacted single grain structure; slightl y moist; rare gravel; rare small carbonate accumulations.

LABORATORY ANALYSES

Profile 11 Location Ras-al-Khaimah (Ruler's Garden, Hail)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	7-14	59.5	83.3	10.2	75.1	18.4	6.5		8.20
	35-42	55.0	63.4	26.4	43.0	46.8	10.2		7.85
	93-100	53.0	59.6	28.0	34.4	53.2	12.4		8.30
	126-133	50.0	86.4	8.8	39.6	55.6	4.8		8.55

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
4.8	3.8	1.1	1.1	10.8	10.2		2.96				
7.3	2.5	2.8	0.5	13.1	21.9		4.09				
9.3	2.0	2.3	0.7	14.3	16.0		5.23				
2.4	0.8	1.2	0.5	4.9	24.5		2.68				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
0.74	0.43	0.06	7.2		0.22				

LOCATION AL AIN (Al Jimi) TITLE 12.

TOPOGRAPHY Occasional low dunes (<1m). Slope 2^{o}S

VEGETATION Occasional bushes of Haloxylon salicornicum. Less than 5% cover.

CULTIVATION Uncultivated

SOIL GROUP Xerosol

SURFACE Loose with thin crust in parts

PROFILE DESCRIPTION

0-34 cms	10YR5/4 (yellowish brown); fine sandy loam; weak medium angular blocks; very friable, breaking to single grains; frequent fine roots; frequent small gravel; rare small carbonate concretions at base of horizon; local slight compaction; sharp change.
34-119 cms	Colour as above, sandy loam gravel with silt ahering to the gravel; single grain structure; rare fine rootlets; some carbonate garlands on gravel; carbonate accumulations increasing in frequency with depth; sharp change.
119 cms+	Calcrete gravel horizon; strong cementation at top of horizon.

LABORATORY ANALYSES

Profile 12 Location Al Ain (Al Jimi)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-10	35.5	90.0	3.4	80.4	13.0	6.6		8.8
	25-30	38.0	88.8	2.4	78.2	13.0	8.8		8.4
	50-55	29.5	88.6	4.1	69.4	23.3	7.3		8.75
	95-100	29.0	84.9	4.9	75.3	14.5	10.2		8.7
	127-132	43.5	83.1	2.6	72.4	13.3	14.3		8.8

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
n.d.	n.d.	n.d.	n.d.	n.d.	n.d.		0.12				
4.8	4.8	0.9	0.3	10.8	8.3		0.11				
6.0	4.5	1.1	0.3	11.9	9.2		0.15				
5.6	4.8	1.0	0.3	11.7	8.5		0.23				
5.4	4.8	1.3	0.1	11.6	11.2		0.41				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
1.64	0.95	0.09	10.5	n.d.	n.d.		n.d.		
1.58	0.92	0.08	11.5	22.0	2.0		40.2		
0.74	0.43	0.05	8.6	32.6	1.8		37.1		
0.76	0.44	0.05	8.8	25.1	1.8		21.4		
0.50	0.29	0.03	9.7	25.5	2.2		16.3		

LOCATION	AL AIN (Jimi - Saif Allah)	TITLE 13.

TOPOGRAPHY Gentle slope to S (2°)

VEGETATION

CULTIVATION Fallow plot which had grown cabbages the previous winter

SOIL GROUP Xerosol (cultivated variant)

SURFACE Loose gravel skiff

PROFILE DESCRIPTION

0-33 cms	10YR4/4 (dark yellowish brown); loamy sand - loamy fine s weak angular blocky structure; soft, breaking to single grains; dry; occasional fine roots; frequent fine gravel; merging.
33-45 cms	10YR5/4 (yellowish brown) with 7.5YR tinge; sandy loam; weak angular blocky structure with slight compaction at base of horizon; soft, breaking to single grains; slightl moist; dry; occasional fine roots; frequent small gravel especially 42-45 cms; weak carbonate cementation; clear change.
45-105 cms+	Grey 'dirty' gravel; slightly moist; rare fine rootlets; small infrequent earthy carbonate accumulations.

LABORATORY ANALYSES

Profile 13 Location Al Ain (Jimi - Saif Allah)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-10	34.0	88.0	6.5	74.1	20.4	5.5		8.70
	25-30	37.5	90.5	3.1	76.7	16.9	6.4		8.95
	35-40	36.0	76.9	18.2	66.7	29.4	4.9		8.95
	50-55	25.0	85.4	9.7	62.8	32.3	4.9		8.90
	95-100	27.5	89.9	5.2	83.7	11.4	4.9		8.85

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
6.0	5.4	2.4	0.1	13.9	17.3		0.21				
6.3	5.5	2.5	0.1	14.4	17.3		0.14				
6.4	5.2	0.8	0.1	12.5	6.4		0.15				
4.3	4.9	1.1	0.1	10.4	10.6		0.13				
2.5	4.3	0.8	0.4	8.0	10.0		0.22				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	Gypsum m.e/100g
2.28	1.32	0.05	26.4	24.2	3.1		8.2		0.17
2.12	1.23	0.05	24.6	27.8	3.1		9.4		0.07
1.05	0.61	0.04	15.2	26.4	2.2		12.3		0.05
1.07	0.62	0.04	15.5	23.8	0.9		23.1		0.14
1.05	0.61	0.04	15.2	32.6	1.3		52.4		0.01

LOCATION AL AIN (Jimi - Ibrahim Abboud) TITLE 14

TOPOGRAPHY Slope 1^{o}S

VEGETATION

CULTIVATION Lucerne crop, 6 years old, very patchy in appearance. Citrus planted in the lucerne 4 years prior to sampling (1969). Plot being irrigated at time of sampling.

SOIL GROUP Xerosol (cultivated variant)

SURFACE Slight crust as a result of irrigation.

PROFILE DESCRIPTION

0-71 cms	10YR6/4-7/4 (light yellowish brown); loamy sand - loamy fine sand; single grain and very weak angular blocky structure; slightly moist; frequent/abundant citrus and lucerne roots; rare fine gravel; local slight compaction towards base of horizon; merging.
71 cms+	10YR4/3 (brown); gravelly loamy sand; single grain structure; slightly moist; frequent fine roots; rare small carbonate accumulations.

LABORATORY ANALYSES

Profile 14 Location Al Ain (Jimi - Ibrahim Abboud)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5.10	38.0	87.5	7.2	78.0	16.7	5.3		8.75
	38-43	34.5	87.2	4.7	80.1	11.8	8.1		8.40
	63-68	34.0	88.6	4.0	83.9	8.7	7.4		8.65
	95-100	34.0	86.1	4.5	77.7	12.9	9.4		8.70

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
4.3	1.6	0.9	0.1	6.9	13.1		0.07				
3.2	3.0	0.9	0.1	7.2	12.5		0.12				
3.6	5.4	1.0	0.1	10.1	9.9		0.12				
4.5	5.3	2.2	0.1	12.1	18.2		0.14				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	Gypsum m.e/100g
1.00	0.58	0.03	19.3	36.9	1.8		12.1		0.15
0.98	0.57	0.05	11.4	33.6	1.8		11.4		
1.14	0.66	0.04	16.5	28.5	1.3		19.3		
0.88	0.51	0.03	17.0	23.8	1.3		16.2		

LOCATION AL AIN (Jimi - Ibrahim Abboud) TITLE 15.

TOPOGRAPHY Level, cultivated plot

VEGETATION Cynodon dactylon locally infesting plot

CULTIVATION Date plot established for 16 years. Remnants of lubia (Dolichos lablab) crop in plot

SOIL GROUP Xerosol (cultivated variant)

SURFACE Thin crust

PROFILE DESCRIPTION

0-80 cms+ 10YR5/4 (yellowish brown); loamy sand - loamy fine sand; weak angular blocky structure; friable, breaking to single grains; slightly moist; abundant date, lubia roots with occasional patches of black decomposed organic matter; rare fine gravel increasing with depth. Below 80 cms roots rare and patches of black decomposed organic matter absent.

LABORATORY ANALYSES

Profile ...15.........   Location Al Ain - Jimi (Ibrahim Abboud)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-10	37.5	82.2	12.9	74.6	20.5	4.9		8.80
	38-43	28.5	86.9	7.0	74.9	19.0	6.1		8.40
	75-80	27.5	83.1	12.5	79.3	16.3	4.4		8.55

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
4.3	4.4	0.9	0.1	9.7	9.3		0.09				
4.6	4.9	1.1	0.1	10.7	10.3		0.11				
6.0	5.4	0.9	0.3	12.6	7.2		0.17				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs/100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	Gypsum me/100g
1.77	1.03	0.05	20.6	30.4	0.4		12.2		0.01
1.67	0.97	0.05	19.4	30.8	1.3		14.3		0.12
1.42	0.82	0.06	13.7	45.1	1.3		33.2		0.18

LOCATION	AL AIN (Jimi - Sultan bin Ahmed) TITLE 16.
TOPOGRAPHY	Slope 1°SW
VEGETATION	
CULTIVATION	Long-established traditional date garden. Plot had grown a crop of 'Dhufra' (vetch?)
SOIL GROUP	Date garden soil
SURFACE	

PROFILE DESCRIPTION

0-7 cms	10YR4/2-4/3 (dark greyish brown); sandy loam - loamy san moderate medium angular blocky structure with some singl grains; friable, breaking to small angular blocks and single grains; moist; frequent date palm roots and fine rootlets; frequent diffuse grey patches of decomposed organic matter; merging.
7-50 cms	10YR4/4 (dark yellowish brown); as above except frequenc of decomposed organic matter reduced.
50-112 cms	10YR5/3-5/4 (yellowish brown); silty clay loam; compact and massive with frequent fine pinholes; moist; frequent date palm roots; occasional grey channels (roots decomposed in situ); occasional small dull diffuse ochreous mottles; sharp change.
112 cms+	Gravel

LABORATORY ANALYSES

Profile 16 Location Al Ain (Jimi - Sultan bin Ahmed)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	0-5	42.5	77.3	12.0	55.2	34.1	10.7		8.80
	15-20	42.0	73.9	13.8	62.4	25.3	12.3		8.70
	40-45	33.5	87.1	5.5	72.4	20.4	7.4		8.80
	55-60	42.5	54.2	19.9	35.3	38.8	25.9		8.75
	75-80	41.0	38.0	34.2	25.4	46.8	27.8		8.85

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
5.9	4.7	1.0	0.2	11.8	8.5		0.14				
4.0	4.7	1.0	0.1	9.8	10.2		0.14				
3.9	4.4	0.9	0.2	9.4	9.6		0.26				
15.6	4.4	2.8	0.1	22.9	12.2		0.20				
18.4	5.3	3.8	0.2	27.7	13.8		0.32				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
3.06	1.77	0.11	16.1	21.6	1.8		23.4		
1.80	1.04	0.05	20.8	14.1	1.6		25.2		
1.43	0.83	0.05	16.6	15.0	1.3		15.2		
1.35	0.78	0.05	15.6	22.0	1.6		30.3		
2.09	1.21	0.07	17.3	15.8	1.4		43.4		

LOCATION	AL AIN (Al Ain - Manah Mohammed)	TITLE 17

TOPOGRAPHY Flat

VEGETATION

CULTIVATION Old-established, traditional, date garden. Some date palms partly cleared and burnt. Fodder crops (lubia) grown. Some traces of burning evident on the surface.

SOIL GROUP Date garden soil

SURFACE

PROFILE DESCRIPTION

0-26 cms	10YR4/2 (dark greyish brown); fine sandy loam; moderate and well developed medium angular blocks; friable, breaking to small angular blocks and some granules; moist; abundant roots; patches of grey 'ashy' material presumably derived from burning; merging.
26-100 cms+	10YR4/3 (dark brown); loamy fine sand; single grain structure; moist; frequent roots; rare limestone fragments

LABORATORY ANALYSES

Profile 17 Location Al Ain (Al Ain - Manah Mohammed)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-10	48.5	83.3	4.3	54.4	33.2	12.4		8.90
	38-43	49.0	79.5	9.6	62.1	27.0	10.9		8.85
	75-80	49.5	85.3	6.5	62.5	29.3	8.2		8.80

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
4.2	4.1	1.6	0.5	10.4	15.4		0.19				
5.1	4.2	1.5	0.2	11.0	13.6		0.34				
4.2	4.4	1.4	0.1	10.1	13.8		0.31				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
3.68	2.14	0.12	17.8	19.8	3.5		63.8		
3.41	1.98	0.08	24.8	19.4	2.6		28.4		
2.10	1.22	0.08	15.2	15.5	2.6		19.2		

LOCATION	AL AIN (Dept. of Agriculture Farm)	TITLE	18.

TOPOGRAPHY Slope 3°SW

VEGETATION

CULTIVATION First year of strawberry cultivation. Pit located near line of old aflaj, now blocked and fallen into disrepair.

SOIL GROUP Yermosol (solonchak)

SURFACE Ridged for strawberry irrigation. Occasional salt efforescences where soil had dried out.

PROFILE DESCRIPTION

0-18 cms	10YR5/3 (brown); silty clay loam; moderate medium angular blocks; driable, breaking to small angular blocks; moist; rare fine rootlets; occasional fine gravel; merging.
18-28 cms	10YR5/3 (brown); gravelly sandy loam; single grain structu moist; rare fine roots; sharp change.
28 cms+	Grey gravel with some sandy loam lenses; 'garlands' of carbonates on many of the gravels.

NOTES: Field conductivities

5 cms	40 mmhos/cm
15 cms	20.2 mmhos/cm
20 cms	12.4 mmhos/cm
30 cms	9.4 mmhos/cm
50 cms	0.9 mmhos/cm

No samples were obtained from this pit

LOCATION AL AIN (Al Ain - Rashid Obeid) TITLE 19.

TOPOGRAPHY Smallholding located among low (2m) sand dunes.
Slope 2^{O}N.

VEGETATION Scattered Acacia arabica. Ground vegetation cleared for cultivation.

CULTIVATION Land prepared for cultivation

SOIL GROUP Halosol (solonetz)

SURFACE Bare, loose, surface

PROFILE DESCRIPTION

0-17 cms 10YR5/4 (yellowish brown); loamy sand; weak, angular blocky structure; soft, breaking to single grains; dry, rare fine rootlets; occasional fine gravel; abundant weakly carbonate-cemented silt nodules (up to 40% of the profile face); clear change

17-45 cms 10YR5/3 (brown); fine sandy loam; single grain structure; dry; rare fine rootlets with thicker roots at base; rare silt nodules (5%); sharp change

45-110 cms+ 10YR5/3 (brown); silty clay loam; compact and massive; slightly moist; occasional carbonate filaments; occasional dull diffuse ochreous mottles.

LABORATORY ANALYSES

Profile 19 Location Al Ain (Al Ain-Rashid Obeid)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-10	48.5	74.9	16.6	63.2	28.3	8.5		8.9
	22-27	44.0	66.5	18.5	51.5	33.5	15.0		8.9
	48-53	56.0	65.0	19.6	35.3	49.3	15.4		8.65
	97-102	52.0	53.5	23.3	37.2	39.6	23.2		8.5

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
4.7	5.3	3.0	0.8	13.8	15.2		2.95	-	2.1	2.64	22.5
6.3	4.3	3.3	0.6	14.5	22.8		0.20	-	1.5	1.4	8.7
7.0	4.4	3.1	1.4	15.9	19.5		9.05	0.9	2.3	33.8	42.4
15.8	4.4	3.1	2.4	25.7	12.0		15.40	0.3	3.3	59.7	63.9

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
1.81	1.05	0.03	35.0	26.4	0.13		80.6		
1.35	0.78	0.04	19.5	17.6	0.18		63.2		
0.79	0.46	0.04	11.5	18.9	0.04		265.6		
1.72	1.00	0.09	11.1	25.1	0.04		200.0		

LOCATION AL AIN (Al Ain - Rashid Obeid) TITLE 20.

TOPOGRAPHY Smallholding located among low (2m) sand dunes. Slope $2^{o}N$

VEGETATION Bare

CULTIVATION Under irrigation channel (unlined)

SOIL GROUP Halosol (solonetz)

SURFACE

PROFILE DESCRIPTION

Essentially the same as profile 19 except

(i) 0-17 cms horizon contains dull diffuse olive yellow mottles (25%)

(ii) the 45 cms + horizon has traces of grey colouring

LABORATORY ANALYSES

Profile ....20........ Location ...Al Ain (Al Ain - Rashid Obeid)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-10	46.5	78.7	11.7	59.2	32.2	9.6		8.20
	22-27	43.5	64.7	19.2	46.1	37.3	16.6		8.95
	48-53	54.0	60.2	21.6	34.8	47.0	18.2		8.69
	97-102	49.5	47.0	33.1	32.7	47.4	19.9		8.75

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
5.1	4.1	3.3	0.9	13.4	24.6		1.75	-	1.1	1.2	12.3
5.7	5.1	2.5	0.4	13.7	12.7		0.35	0.5	0.9	0.2	7.5
8.0	5.8	2.2	2.1	18.1	12.2		2.44	0.6	0.8	4.3	18.7
11.2	4.4	3.0	1.3	19.9	15.4		5.40	0.8	1.1	8.4	42.7

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
1.81	1.05	0.04	26.2	32.2	0.13		79.6		
1.20	0.70	0.06	11.7	17.6	0.13		52.6		
0.81	0.47	0.03	15.3	20.7	0.18		168.0		
0.95	0.55	0.05	11.0	22.9	0.13		170.2		

LOCATION	AL AIN (Jebel Hafit)	TITLE 21.

TOPOGRAPHY Low ridge covered by loose angular chert fragments and aeolian sand. Slope 4°W.

VEGETATION Bare

CULTIVATION Uncultivated

SOIL GROUP Relic soil

SURFACE Loose chert fragments

PROFILE DESCRIPTION

0-3 cms	10YR5/3 (brown); loamy fine sand; single grain structure; dry; rare fine rootlets; frequent angular stones; sharp change.
3-12 cms	5YR4/4 (reddish brown); (sandy) clay loam; well developed medium angular blocks; firm, breaking to small blocks and crumbs; dry; very rare fine roots; sharp irregular boundary
12-22 cms	10YR7/4 (very pale brown); weathered limestone; carbonate skins below 18 cms; merging
22 cms+	Consolidated siliceous limestone.

LABORATORY ANALYSES

Profile 21 Location Al Ain (Jebel Hafit)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	0-3	53.5	71.9	10.7	55.7	26.9	17.4		7.60
	4-9	61.5	35.7	22.5	24.8	33.4	41.8		8.45
	13-18	87.0	n.d.	n.d.	n.d.	n.d.	n.d.		7.95

Cation exchange capacity m.e/100g Ca	Mg.	Na.	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
5.4	4.8	1.8	0.3	12.3	14.6		0.53	1.1	0.9	0.4	0.8
27.4	16.2	3.6	2.8	50.0	7.2		0.29	1.0	0.8	0.6	0.9
8.4	4.3	1.0	0.1	13.8	7.2		0.05	1.1	1.0	0.4	0.9

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
0.87	0.51	0.04	12.7	32.8	0.18		41.6		
0.36	0.21	0.02	10.5	48.4	0.40		58.2		
0.33	0.19	0.02	9.5	20.3	0.19		12.2		

LOCATION	TENDAHO (Barga)	TITLE	22.

TOPOGRAPHY	Located on natural level of Awash River
VEGETATION	Bare
CULTIVATION	Prepared for cotton cultivation
SOIL GROUP	Fluvisol
SURFACE	Uneven due to large subrounded clods. Crusts 2 mms thick.

PROFILE DESCRIPTION

0-20 cms	10YR3/3 (dark brown); silty loam - silty clay loam; weak large angular blocks; firm, breaking to small angular blocks; occasional fine roots; sharp change.
20-70 cms	10YR4/4 (dark yellowish brown); silty fine sandy loam; weak columnar structure though thin clay bands tend to be laminated; very slightly moist; occasional fine roots; occasional pinholes; rare ochreous mottles in clay bands; sharp change.
70 cms+	10YR2/2 (very dark brown); clay loam; compact and massive with some angular blocks at the top of the horizon; slightly moist; contains cracks including some infill from upper horizons; slickensides.

LABORATORY ANALYSES

Profile 22 Location Tendaho (Barga)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	3.0	32	39	12	59	29		7.60
	25-35	5.5	49	35	14	70	16		7.60
	45-55	6.0	26	51	5	72	23		7.60
	70-80	5.0	21	35	16	40	44		7.60

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
44.7	8.4	12.9	4.3	60.3	21.4		1.12	-	2.4	-	12.1
42.8	7.2	8.7	1.4	60.1	14.5		1.20	-	1.5	-	12.3
37.2	10.1	13.1	1.4	61.8	21.2		2.05	-	2.1	2.3	17.1
49.0	10.9	14.0	1.9	75.8	18.5		2.44	-	1.6	2.4	25.1

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.7	1.6	0.09	17.8		8.3		32.2		
1.6	0.9				n.d.		n.d.		
1.2	0.7				11.5		33.6		
1.2	0.7								

Profiles 22-34 Cation Exchange determinations carried out on ammonium acetate extractant.

LOCATION	TENDAHO (Dubti).	TITLE 23.

TOPOGRAPHY — Natural level of River Awash. Land subject to annual flooding.

VEGETATION — Callotropis procera, Euphorbia spp, Tamarindus spp, Salvadora persica, Cyperus rotundus. Grasses 5% cover, Bushes 15% cover.

CULTIVATION — Heavily grazed riverine woodland

SOIL GROUP — Fluvisol

SURFACE — Thin crust 0.5 mm in thickness

PROFILE DESCRIPTION

0-33 cms	10YR3/3 (dark brown); silty clay loam; weak/moderate medium angular blocks with some depositional platiness; firm, breaking to small angular blocks; dry to 12 cms but moist below; abundant fine roots and rootlets; rare dark patches of organic matter; sharp change.
33-63 cms	10YR3/3 (dark brown); sandy loam - loamy sand; mainly sin grain structure but some residual depositional platiness; slightly moist; frequent fine roots; occasional small earthy $CaCO_3$ accumulations; sharp changes.
63 cms+	10YR3/3 (dark brown); loamy fine sand - silt; compact wit residual depositional laminations; dry; occasional fine roots; rare earthy $CaCO_3$ accumulations.

LABORATORY ANALYSES

Profile 23 Location Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	4.0	15	64	5	74	21		7.80
	23-33	5.0	45	21	20	46	34		7.90
	45-55	6.5	59	16	44	31	25		7.90
	65-75	9.0	80	15	29	66	5		8.20

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
29.5	15.7	1.2	2.8	49.2	2.4		0.70	-	2.0	2.6	4.3
29.6	10.8	0.9	2.4	43.7	2.1		0.64	-	1.3	0.6	4.1
25.8	8.2	1.0	2.5	37.5	2.7		0.88	-	1.7	1.1	4.1
22.1	8.7	0.8	1.5	33.1	2.4		0.46	-	1.5	1.3	2.3

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.6	1.5	0.1	15.0	320	7.3		15.5		
1.8	1.1			n.d.	n.d.		n.d.		
0.3	0.2			181	9.6		10.9		
0.5	0.3								

LOCATION TENDAHO (Dit Bahari Extension) TITLE 24.

TOPOGRAPHY Flat. Incipient erosion gullies in vicinity of profile pit. These result of natural cracks, widened firstly by animals and them by rain.

VEGETATION Heavily grazed tussock grassland - 80% cover. <u>Aristida sp</u>.

CULTIVATION

SOIL GROUP Vertisol

SURFACE Thin crust (1.5 mms) between tussocks. Irregular, due to tussocks.

PROFILE DESCRIPTION

0-14 cms	10YR3/2 (very dark greyish brown); silty clay loam - clay loam; well-developed large and medium angular blocks; hard; dry; frequent fine roots; merging.
14-120 cms+	10YR3/3 (dark brown); silty clay loam - clay loam; compact and massive but large angular blocks form due to cracking; dry; rare roots; rare small earthy carbonate accumulations below 70 cms; frequent cracks to 60 cms though some extend to 1.20m+; occasional slickensides.

LABORATORY ANALYSES

Profile ....24..... Location Dubti (Dit Bahari Extension)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	4-14	17.0	49	23	38	34	28		8.30
	25-35	19.5	58	9	38	29	33		8.10
	45-55	17.0	45	21	26	40	34		8.10
	65-75	16.5	48	23	38	33	29		8.20

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
44.0	6.7	7.1	1.8	59.6	11.9		0.98	-	2.5	1.7	12.1
38.7	5.7	5.8	1.4	51.6	11.3		0.77	-	2.3	2.1	10.5
45.3	4.8	5.8	1.1	57.0	10.2		0.92	-	2.0	2.1	12.5
30.9	8.3	4.3	2.7	46.2	9.3		0.90	-	2.0	2.5	12.9

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
9.1	5.3	0.45	11.8		10.1		28.7		
n.d.	n.d.				n.d		n.d.		
1.6	0.9				13.2		41.9		
n.d.	n.d.								

LOCATION TENDAHO (Dubti) TITLE 25

TOPOGRAPHY No appreciable slope

VEGETATION

CULTIVATION Bare. Irrigated prior to planting cotton. Under cotton for previous 3 years

SOIL GROUP Vertisol

SURFACE Crust 5 mms thick. Mosaic of medium size cracks extending to 15 cms depth.

PROFILE DESCRIPTION

0-15 cms	10YR4/2 (dark greyish brown); clay loam - silty clay loam; plastic but dries out to medium and large angular blocks; very moist; frequent root fragments; merging.
25-56 cms	10YR3/3 (dark brown); silty clay loam; weak medium angular blocks becoming massive; plastic; very moist; occasional small slickensides; occasional fine rootlets with concentration at top of horizon; clear change.
56 cms+	10YR3/2 (dark greyish brown) - 10YR3/3 (dark brown);clay l(compact and massive; moist; rare fine roots to 65 cms; depositional laminations; rare small white carbonate efforescences below 70 cms.

LABORATORY ANALYSES

Profile 25 Location Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	11.5	35	24	17	42	41		7.80
	25-35	10.2	17	19	9	27	64		7.40
	45-55	10.2	18	21	7	32	61		7.80
	65-75	8.2	29	25	8	46	46		7.45

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
72.5	14.5	6.7	4.8	98.5	6.8		0.11	2.6	2.4	0.4	2.7
56.5	14.2	7.9	4.2	82.8	9.5		1.48	0.6	2.3	0.4	12.5
65.5	11.4	9.8	4.2	90.9	10.8		0.56	-	2.0	-	2.9
66.5	11.7	10.5	3.6	82.3	11.4		4.35	2.0	1.1	-	42.5

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
3.6	2.1	0.10	21.0	536	5.3		26.2		
3.1	1.8			n.d.	5.5		23.6		
2.9	1.7			382	6.0		20.0		
1.4	0.8				9.0		16.8		

LOCATION	TENDAHO (Dubti)	TITLE	26.

TOPOGRAPHY

VEGETATION Echinocloa sp, Cyperus rotundus - 5% cover

CULTIVATION Awaiting planting for cotton. Previous cropping sequence; 5 years cotton, followed by 1 year rice.

SOIL GROUP Vertisol

SURFACE Crust 5 mms thick with fine cracks

PROFILE DESCRIPTION

0-40 cms	10YR4/2 (dark grey brown); silty clay loam; plastic but dries to strong medium and large angular blocks; moist; abundant roots and fine rootlets; abundant small diffuse 10YR4/1 (dark grey) stains (organic ?); waterlogged horizon from previous seasons rice crop; clear change.
40 cms+	10YR3/3 (dark brown); silty clay loam - clay loam; compact and massive with some residual depositional laminations; moist; rare fine roots; rare small earthy carbonate accumulations below 95 cms.

LABORATORY ANALYSES

Profile 26 Location Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	7.7	34	32	14	52	34		7.70
	25-35	8.2	17	21	9	29	62		7.80
	45-55	8.5	18	22	12	28	60		8.00
	65-75	9.7	22	26	11	37	52		7.95

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
70.5	12.7	5.0	4.1	91.3	5.5		0.93	1.1	4.4	-	2.2
69.0	12.2	5.9	4.4	91.5	6.4		1.35	-	2.0	-	12.1
67.0	11.2	6.4	3.7	88.3	7.2		0.47	-	1.8	-	1.3
64.5	7.3	5.8	3.4	81.0	7.2		0.43	-	0.4	-	1.3

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
4.0	2.3	0.11	20.9	450	5.6		27.8		
3.8	2.2			n.d.	6.2		23.3		
3.4	2.0			370	6.7		21.4		
2.8	1.6				8.0		20.4		

LOCATION TENDAHO (Dubti) TITLE 27

TOPOGRAPHY Depressional area close to exit of main drain of Dubti Plantation

VEGETATION

CULTIVATION Cotton 35 cms high at time of sampling. First year of cultivation

SOIL GROUP Vertisol

SURFACE Weak crust, 3 mms thick

PROFILE DESCRIPTION

0-80 cms	10YR2/2 (very dark brown); clay loam; moderate/well develop medium angular blocks with occasional residual laminations; plastic; moist; frequent fine rootlets; mottles below 30 cms along root channels; strong 10YR3/4 (dusky red), mottles along ped faces below 60 cms; sharp change.
80 cms+	10YR2/2 (very dark brown); silty clay loam; compact and massive; very moist especially below 120 cms; mottles finer and less distinct.

Notes: (i) Field lies below level of main drain and water has to be pumped off the field.
(ii) Augering continued to 2.5 metres but no evidence of water table

LABORATORY ANALYSES

Profile .....27........ Location Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	5.5	7	33	1	39	60		8.10
	25-35	8.0	11	16	7	20	73		8.35
	45-55	8.0	12	24	5	31	64		7.80
	65-75	9.0	45	15	30	30	40		8.00
	85-95	8.0	25	53	19	59	22		7.55

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
42.2	22.0	1.1	2.6	67.9	1.6		1.35	-	2.3	1.4	14.5
50.0	18.4	4.3	4.2	76.9	5.6		0.95	-	2.1	1.6	10.1
45.2	21.7	4.5	1.9	73.3	6.1		1.19	-	2.0	1.2	13.1
45.0	20.4	4.2	2.4	72.0	5.8		0.65	-	2.2	1.0	4.3
28.6	10.2	0.7	3.3	42.8	1.6		0.73	-	2.4	0.8	4.3

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.4	1.4	0.04	35.0	216	5.6		18.6		
2.2	1.2			n.d.	n.d.		n.d.		
2.1	1.2			143	6.2		15.5		
2.0	1.2								
0.6	0.4								

LOCATION TENDAHO (Dubti) TITLE 28.

TOPOGRAPHY

VEGETATION *Sesbania sp*, *Echinocloa colonum*. 1% cover

CULTIVATION Irrigated prior to planting. Cotton for previous four ye

SOIL GROUP Vertisol

SURFACE Crust 2 mms thick. Cracks extend to 4 cms.

PROFILE DESCRIPTION

0-34 cms	10YR4/2 (dark greyish brown) - 10YR3/2 (very dark greyish brown); silty clay loam; plastic, but dries out to strong medium angular blocks; very moist; occasional fine roots; clear change.
34-63 cms	10YR3/2 (very dark greyish brown); silty clay loam - clay loam; compact and massive with some residual deposit laminations; very moist; rare fine roots; rare small earthy carbonates; merging.
63 cms+	10YR3/2 (very dark greyish brown); clay loam; more compac than previous horizon; moist; rare fine roots; frequent slickensides and clay skins; rare small earthy carbonate accumulations.

NOTE: Cultivated horizon extends to 21 cms.

LABORATORY ANALYSES

Profile ....28........ Location ...Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand%	International Silt %	U.S.D.A. Sand%	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	16.5	23	22	16	29	55		7.60
	23-33	16.0	24	19	17	26	57		7.25
	45-55	15.0	17	19	9	27	64		7.80
	65-75	15.0	19	17	11	25	64		7.60

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
35.0	20.1	8.4	2.0	65.5	12.8		0.53				
34.6	15.2	7.3	1.5	58.6	12.6		0.61				
47.0	17.3	10.6	1.9	75.8	13.8		0.94				
43.7	17.1	9.9	1.8	72.5	13.7		2.41				

Organic Matter Total %	Organic C%	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.6	1.5	0.08	18.7	275	9.4		17.3		
0.6	0.3			n.d.	10.6		14.8		
1.0	0.6			193	11.6		12.4		
0.8	0.5								

LOCATION	TENDAHO (Dubti)	TITLE	29.

TOPOGRAPHY

VEGETATION

CULTIVATION — Cotton crop in each of 6 previous years. Cotton crop planted 4 days prior to sampling.

SOIL GROUP — Fluvisol

SURFACE — Crust 4 mms thick. Occasional medium sized angular clods on the surface

PROFILE DESCRIPTION

0-58 cms	10YR3/2 (very dark greyish brown) - 10YR3/3 (dark brown); silty clay loam; plastic, but forms well developed small/ medium angular blocks on drying; very moist; occasional roots; occasional dull diffuse grey patches (? organic matter) in top 22 cms; clear change.
58 cms+	10YR3/2 (very dark greyish brown); silty clay loam; compac and massive; moist; rare fine rootlets; occasional pinhole

NOTE: Cultivated horizon extends to 22 cms.

LABORATORY ANALYSES

Profile ....29........ Location ....Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	5.5	46	31	22	55	23		7.60
	25-35	7.0	49	27	25	51	24		7.90
	45-55	8.0	38	24	17	45	38		7.50
	65-75	9.0	36	21	23	34	43		7.60

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
15.0	10.0	2.1	1.9	29.0	7.2		0.93				
23.2	7.2	2.9	1.8	35.1	8.3		1.08				
25.5	12.2	7.8	1.5	47.0	16.6		0.48				
26.0	17.1	6.8	1.6	51.5	13.2		1.45				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
2.8	1.6	0.07	22.9	287	7.0		11.7		
1.6	0.9			n.d.	7.7		14.4		
1.4	0.8			109	8.4		17.8		
0.9	0.5								

LOCATION	TENDAHO (Dubti)	TITLE 30.

TOPOGRAPHY

VEGETATION

CULTIVATION 4 years cotton, 1 year rice, 1 year maize. Cotton 15 cms high

SOIL GROUP Fluvisol

SURFACE Weakly developed crust, 1 mm thick. Maize stalks on surfa

PROFILE DESCRIPTION

0-36 cms.	10YR3/3 (dark brown); silty loam; weak medium angular bloc with residual depositional laminations; plastic; moist; frequent fine roots and maize stalks; merging.
36-69 cms	10YR3/2 (very dark greyish brown); loamy sand - loamy fine sand; bedded, with some ochreous stains; moist; occasional fine rootlets; carbonate filaments occur irregularly in some beds; clear change.
69 cms+	10YR2/2 (very dark brown); silty clay loam; compact and massive; moist; rare fine roots; frequent clayskins; occasional dull diffuse ochreous mottles with some grey gleying.

LABORATORY ANALYSES

Profile 30 Location Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	1.5	60	24	35	49	16		7.80
	25-35	3.0	52	30	34	48	18		7.50
	45-55	6.0	49	46	15	80	5		7.70
	70-80	7.5	57	13	45	25	30		7.45

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
21.2	13.2	3.7	1.8	39.9	9.3		0.59				
18.8	11.0	3.4	1.3	24.5	9.9		0.69				
15.1	9.3	3.2	0.9	28.5	11.2		0.67				
15.4	16.3	3.6	2.2	37.5	9.6		0.95				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.4	1.2	0.05	24.0	322	8.5		14.2		
0.9	0.5			n.d.	n.d.		n.d.		
1.1	0.6			293	10.9		11.0		
0.3	0.2								

LOCATION	TENDAHO (Dubti)	TITLE 31.

TOPOGRAPHY

VEGETATION

CULTIVATION — Cotton grown for previous two years. At time of sampling was 20 cms high but showing signs of chlorosis.

SOIL GROUP — Halosol/Xerosol

SURFACE — Well developed crust, 4 mms thick

PROFILE DESCRIPTION

0-25 cms	10YR3/3 (dark brown); sandy loam - sandy clay loam; weak medium angular blocky structure; firm, breaking to small angular blocks and single grains; moist; frequent fine roots; clear change.
25-60 cms	Bedded 10YR3/3 (dark brown), 3/2 (very dark greyish brown) and 2/2 (very dark brown); sandy clay loam and sandy loams compact and massive; moist; rare fine roots; frequent eartl carbonate accumulations below 45 cms; clear change.
60 cms+	10YR3/3 (dark brown); silty fine sandy loam - sandy loam; compact and massive; moist; rare fine roots; frequent earthy carbonate accumulations.

LABORATORY ANALYSES

Profile ..31..........   Location .Tendaho (Dubti)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	4.0	74	7	43	38	19		7.85
	45-45	5.5	55	32	16	71	13		8.10

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
25.2	8.2	3.9	1.6	38.9	10.0		0.70				
16.8	6.2	8.7	1.2	32.9	26.3		1.39				

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
1.4	0.8	0.04	20.0	32.2	5.6		16.1		
1.2	0.7			28.2	9.3		11.6		

LOCATION Al Hasa (Office) TITLE 32

TOPOGRAPHY On crest of stabilised sand dune

VEGETATION *Tamarix aphylla* plantation established for 8 years. No ground vegetation in vicinity of pit.

CULTIVATION

SOIL GROUP Anthropogenic polymorphic soil.

SURFACE Covered by litter

PROFILE DESCRIPTION

1.25-0.5 cms	undecomposed *Tamarix* litter (needles and seed pods); dry; clear change.
0.5-0 cms	10YR2/1 (black); decomposing litter; needles humified towa base of horizon but seed pods retained form; fungal activi in evidence; moist; clear change.
0-15 cms	2.5Y5/0 (grey), sandy loam; weak angular blocks and single- grains; friable, breaking to single grains; slightly moist; abundant fine roots; sharp irregular change.
15 cms +	10YR6/4 (light yellowish brown); sand; single grain structure; very slightly moist, occasional roots.

LABORATORY ANALYSES

Profile .....32........ Location ..Al..Hasa (Office)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	20.0	80.8	8.4	71.2	18.0	10.8		7.45
	25-35	9.8	94.2	3.2	92.6	4.8	2.6		8.40

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
3.4	1.1	1.1	1.7	9.3	11.8		1.14	-	2.7	2.7	8.0
1.2	1.0	0.5	0.3	3.0	16.7		0.06	-	1.0	0.4	2.8

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.9	1.6	0.04	38.0	41.0	3.3				
0.4	0.2			33.0	2.7				

LOCATION	AL HASA (Shaibani)	TITLE	33.

TOPOGRAPHY Smoothed sand dune

VEGETATION Tamarix aphylla established for 1 year

CULTIVATION

SOIL GROUP Anthropogenic polymorphic soil

SURFACE Crusted saline topsoil

PROFILE DESCRIPTION

0-15 cms	2.5Y5/0 (grey); sandy loam - loamy sand; weak moderate angular blocky structure; friable, breaking to single grains; moist; frequent fine roots; clear change.
15 cms+	10YR6/4 (light yellowish brown); sand; single grain structure; moist; rare roots; occasional dull diffuse rusty and ochreous stains.

LABORATORY ANALYSES

Profile ..33.......... Location ......Al Hasa (Shaibani)

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	5-15	24.2	76.1	13.1	67.1	22.1	10.8		7.75
	25-35	13.5	97.6	1.0	97.2	1.4	1.4		7.80
	60-70	12.7	98.6	1.4	99.0	1.0	-		8.50

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
8.8	1.8	2.9	1.7	15.2	19.1		10.40	-	1.5	32.3	73.8
1.6	0.5	0.7	0.6	3.4	20.6		1.66	-	0.2	6.7	13.4
1.6	0.5	0.7	0.3	3.1			0.11	-	0.2	0.5	3.2

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Phosphates Available	Potash mgs/100gm Total	Potash Available	Boron (ppm)	
2.2	1.3	0.04	32.5	62.0	3.9				
0.7	0.4								
0.3	0.2								

LOCATION AL HASA TITLE 34.

TOPOGRAPHY Flat - levelled dune

VEGETATION *Tamarix aphylla* woodland established for 3 years

CULTIVATION

SOIL GROUP Anthropogenic polymorphic soil

SURFACE Salt crusts with irregular covering of litter

PROFILE DESCRIPTION

0.5–0 cms	Irregular litter layer
0–14 cms	10YR4/2 (dark grey brown); sandy loam; weak small and medium angular blocks and single grains, friable, breaking to single grains; moist; frequent fine roots; clear change
14 cms+	10YR6/4 (light yellowish brown); sand; single grain structure; moist; rare roots.

LABORATORY ANALYSES

Profile ...34.........   Location ...Al Hasa.........

Sample	Depth Cm.	Total Carbonate %	International Sand %	International Silt %	U.S.D.A. Sand %	U.S.D.A. Silt %	Clay %	Saturation %	pH
	3-13	26.5	80.6	9.0	63.2	26.4	10.4		7.45

Cation exchange capacity m.e/100g Ca	Mg	Na	K	Total	E.S.P.	S.A.R.	Conductivity mmhos/cm	Soluble Anions m.e/litre CO_3	HCO_3	CL	SO_4
7.1	0.9	1.9	1.3	11.2	17.0		17.50	-	1.8	18.4	156.3

Organic Matter Total %	Organic C %	Total Nitrogen %	C:N	Phosphates mgs 100gm Total	Available	Potash mgs/100gm Total	Available	Boron (ppm)	
1.6	0.9	0.04	22.5	37.5	3.0				

APPENDIX II

BASIC DATA FOR 62 PROFILES USED IN CLUSTER ANALYSIS

Tables II_B - II_H form a single data matrix from which the similarity indices were calculated. They are given separately, in this appendix for ease of presentation. The upper line for each characteristic represents the actual value, the lower line the value on a 0-100 scale from which the similarity index was derived.

Table II_A Soil characteristics used in ordination

In this table, the suffix $_c$ denotes a value relating to the cultivated, or surface, horizon of the soil, the suffix $_s$ denotes a value relating to the subsoil or horizon immediately underlying the surface horizon.

Characteristic 1. thickness of the cultivated horizon or surface horizon of uncultivated soils.

2. pH_c
3. $pH_c:pH_s$
4. % $CaCO_{3_c}$
5. % $CaCO_{3_c}$:% $CaCO_{3_s}$
6. % $Clay_c$
7. % $clay_c$: $clay_s$
8. % silt and clay (USDA limits)$_x$
9. % (silt and clay)$_c$: % (silt and clay)$_s$
10. $E.C._c$
11. $E.C._c$: $E.C._s$
12. $C.E.C._c$
13. Exchangeable calcium $percentage_c$
14. $E.S.P._c$
15. $E.S.P._c$: $E.S.P._s$
16. % organic $carbon_c$
17. % total $nitrogen_c$
18. C:N $ratio_c$
19. available $phosphate_c$

Characteristic	AD5	AD9	TSS28	TSS60	TSS25	AD4	Soil Profile
	16	17	3		4	15	Profile number in thesis
	1	2	3	4	5	6	Matrix number
1	7	26	30	20	40	80	
	0.0	23.4	28.4	16.1	40.7	90.2	
2	8.8	8.9	8.5	8.7	8.6	8.8	
	94.4	100	83.3	88.8	83.3	94.4	
3	1.01	1.01	1.01	1.01	1.00	1.05	
	70.0	70.0	70.0	76.0	65.0	95.0	
4	42.5	43.5	58.0	19.5	54.0	37.5	
	56.4	65.0	78.5	23.6	72.8	49.2	
5	1.01	0.99	1.02	1.56	0.92	1.32	
	23.0	22.0	23.5	50.1	18.5	38.5	
6	10.7	12.4	17.2	6.8	19.2	4.9	
	12.0	15.0	23.6	5.0	27.1	1.6	
7	0.87	0.82	0.75	1.31	1.30	0.80	
	7.0	6.4	5.7	11.7	11.6	6.2	
8	44.8	45.6	56.2	24.3	55.4	25.4	
	31.7	32.7	46.1	5.9	45.1	7.3	
9	1.21	1.20	0.96	1.22	1.18	1.01	
	5.9	5.8	3.8	6.0	5.6	4.2	
10	0.14	0.19	1.13	0.33	0.85	0.09	
	0.4	0.5	4.0	1.1	3.0	0.2	
11	1.00	0.56	0.87	2.06	2.24	0.82	
	3.4	1.8	2.9	7.3	7.4	2.8	
12	11.8	10.4	25.8	7.5	20.8	9.7	
	5.9	4.3	21.7	1.2	15.7	3.5	
13	50.0	40.4	68.0	56.0	77.8	44.4	
	45.3	26.9	80.0	57.1	99.4	34.3	
14	8.5	15.4	17.1	16.0	11.5	9.3	
	32.1	64.2	72.0	67.0	46.0	35.8	
15	0.83	1.13	1.47	0.73	1.13	0.90	
	16.5	29.9	47.3	12.0	29.9	19.6	
16	1.77	2.14	1.17	1.21	0.74	1.03	
	81.2	100	51.0	53.0	29.3	43.9	
17	0.11	0.12	0.06	0.07	0.04	0.04	
	90.0	100	40.0	50.0	20.0	30.0	
18	16.1	17.8	19.5	17.3	18.5	20.6	
	36.1	40.0	45.0	38.5	42.1	48.2	
19	1.8	3.5	0.8	2.1	0.2	0.4	
	7.2	14.4	3.0	8.4	0.4	1.3	

Notes 1. AD - Al Ain, TSS - Ras-al-Khaimah

2. AD4 has only been under dates for 16 years.

Table II_8 Characteristics of soils of traditional date gardens

Soil Profile	AD2	AD11	AD11a	TSS24	TSS29	TSS39	TSS54	TSS71	AD3	AD8
Profile number in thesis	13			7	2	5	8		14	
Matrix number	7	8	9	10	11	12	13	14	15	16
Characteristic										
1	33	29	29	26	24	31	35	25	71	24
	32.1	27.2	27.2	23.4	21.0	29.7	34.6	22.2	79.1	21.0
2	8.7	8.65	8.6	8.8	8.8	8.5	8.45	8.55	8.75	8.9
	88.8	86.1	83.3	94.4	94.4	77.7	72.1	80.51	91.6	100
3	0.97	1.02	0.99	1.01	1.03	1.03	0.96	0.96	1.01	1.04
	50.0	75.5	60.0	70.0	80.0	80.0	45.0	45.0	70.0	85.0
4	34.0	54.0	52.5	45.5	73.0	48.0	33.0	24.0	38.0	44.5
	44.2	72.8	70.7	60.7	100	64.2	42.8	30.0	50.0	59.3
5	0.94	1.28	1.18	0.98	0.96	1.00	1.05	0.68	1.10	1.01
	19.5	36.5	31.5	21.5	20.5	22.5	25.0	7.5	27.5	23.0
6	5.5	21.0	16.0	16.0	7.8	14.3	12.2	10.7	5.3	12.6
	2.7	20.3	21.4	21.4	6.8	18.4	14.4	12.0	2.3	15.4
7	1.12	1.71	1.45	1.03	4.34	0.7	1.27	0.96	0.66	0.93
	9.6	16.0	13.2	8.7	44.2	5.1	11.3	7.9	4.7	7.6
8	25.9	64.4	61.9	73.0	25.8	88.1	59.7	29.4	22.0	27.1
	7.9	56.3	53.2	67.3	7.8	86.2	49.1	12.4	3.1	9.4
9	0.76	1.20	1.13	0.98	5.62	1.02	1.25	0.90	0.99	0.95
	2.0	5.8	5.2	3.9	43.6	4.3	6.3	3.2	4.0	3.7
10	0.21	0.34	0.20	1.16	0.17	0.14	0.37	0.84	0.07	0.24
	0.6	1.1	0.6	4.1	0.5	0.4	1.2	3.0	0.1	0.7
11	1.40	1.13	2.0	0.48	1.0	0.94	1.03	1.56	0.5	1.41
	4.9	3.9	7.1	1.5	3.4	3.2	3.4	5.5	1.6	4.9
12	13.9	21.1	20.5	16.1	12.1	25.0	9.8	10.7	6.9	12.0
	8.2	16.0	15.4	10.5	6.2	20.1	3.6	4.6	0.5	6.2
13	43.2	43.3	51.0	61.5	76.1	69.6	69.5	67.3	62.3	45.0
	32.4	32.6	47.3	67.7	96.2	83.4	83.2	79.0	69.3	35.5
14	17.3	11.8	15.2	14.3	13.2	14.4	15.3	20.5	13.1	8.3
	72.9	47.4	63.2	59.0	53.9	59.5	63.7	87.8	53.4	31.2
15	2.70	1.28	1.36	0.50	0.82	0.78	1.01	0.69	0.72	1.06
	100	36.7	40.2	1.8	16.2	14.0	246	10.3	12.0	26.8
16	1.32	0.55	0.86	0.66	0.54	0.51	0.78	0.82	0.58	1.18
	58.6	19.7	35.4	25.3	19.2	17.7	31.3	33.3	21.2	51.5
17	0.05	0.04	0.06	0.04	0.04	0.04	0.05	0.05	0.03	0.06
	30.0	20.0	40.0	20.0	20.0	20.0	30.0	30.0	10.0	40.0
18	26.4	13.8	14.3	16.5	13.5	12.8	15.6	16.4	19.3	19.7
	74.5	27.9	29.7	36.1	27.3	25.8	33.5	35.8	44.4	45.6
19	3.1	2.6	2.2	0.5	2.3	1.4	0.4	0.3	1.8	1.3
	12.7	10.5	8.8	1.7	9.3	5.5	1.3	0.8	7.2	5.1

Notes: (i) AD - Al Ain, TSS - Ras-al-Khaimah
(ii) AD3, AD8 - soil profiles under fodder crops (lucerne).

Table II_C Characteristics of soils under vegetable and fodder crops

	D1	D9	D10	D13	D14	D30	D32	Soil profile
	25				28			Profile number in thesis
	17	18	19	20	21	22	23	Matrix number
Characteristic								
1	15 9.9	27 24.7	24 21.0	25 22.2	21 17.3	22 18.5	20 16.1	
2	7.81 38.9	7.4 16.7	8.0 50.0	7.9 44.5	7.6 27.8	7.7 33.4	8.0 50.0	
3	1.04 85.0	0.97 50.0	1.04 85.0	1.00 65.0	1.05 90.0	0.96 45.0	1.03 80.0	
4	11.5 12.2	13.5 15.0	13.0 14.3	9.5 9.3	16.5 19.3	4.5 2.1	3.0 0.0	
5	1.13 29.0	1.35 40.0	1.30 37.5	1.27 36.0	1.03 24.0	1.00 22.5	0.67 6.5	
6	41.0 66.1	38.0 60.8	44.0 71.4	34.0 53.5	55.0 91.1	32.0 50.0	45.0 73.2	
7	0.64 4.5	0.97 8.0	0.86 6.9	0.74 5.6	0.96 7.9	0.63 4.4	0.98 8.1	
8	83.0 79.9	80.0 76.1	74.0 68.5	85.0 82.4	84.0 81.1	86.0 83.7	73.0 67.3	
9	0.91 3.3	1.07 4.7	0.82 2.6	0.92 3.4	1.01 4.2	0.93 3.5	0.96 3.8	
10	0.11 0.3	0.75 2.6	0.95 3.3	0.98 3.4	0.53 1.8	0.86 3.0	0.68 2.3	
11	0.07 0.0	1.06 3.6	0.26 0.7	1.04 3.5	0.87 2.9	0.78 2.6	0.87 2.9	
12	98.5 100.0	53.7 51.5	52.2 49.8	71.0 70.0	65.5 64.3	56.5 54.5	65.7 64.5	
13	73.6 91.3	67.1 78.6	64.6 73.6	60.6 65.9	63.4 51.8	61.7 68.1	64.0 72.4	
14	6.8 24.2	3.9 10.7	9.0 34.4	5.8 19.6	12.8 47.5	13.5 55.3	10.8 42.8	
15	0.72 11.6	0.54 3.6	0.62 7.1	0.88 18.7	1.02 25.0	0.99 23.7	0.95 21.9	
16	2.1 97.8	1.4 62.6	1.4 62.6	1.2 52.5	1.5 67.6	1.8 82.7	1.6 72.6	
17	0.1 80.0	0.08 60.0	0.08 60.0	0.07 50.0	0.08 60.0	0.08 60.0	0.08 60.0	
18	21.0 49.4	17.5 39.1	17.5 39.1	17.1 37.9	18.7 42.7	22.5 54.0	20.0 46.6	
19	5.3 22.1	13.8 57.7	9.5 39.7	9.3 38.8	9.4 39.3	12.6 52.7	7.6 31.7	

Table II_D Characteristics of heavy textured soils under cotton cultivation, Dubti Plantation, Tendaho.

Soil Profile	D4	D5	D6	D8	D11	D12	D15	D17	D18	D20	D23	D24	D25
Profile number in thesis									29				
Matrix number	24	25	26	27	28	29	30	31	32	33	34	35	36
Characteristic													
1	22 18.5	25 22.2	26 23.4	22 18.5	25 22.2	24 21.0	20 16.1	26 23.4	22 18.5	24 21.0	24 21.0	30 28.4	22 18.5
2	7.8 38.9	7.7 33.4	7.65 30.6	7.75 36.2	7.8 38.9	7.8 38.9	7.45 19.4	7.6 27.8	7.6 27.8	7.95 47.4	7.8 38.9	7.6 27.8	7.7 33.4
3	0.96 45.0	0.99 60.0	0.95 40.0	0.98 55.0	1.00 65.0	0.97 50.0	0.94 35.0	1.03 80.0	0.96 45.0	1.02 75.0	1.00 65.0	0.96 45.0	1.03 80.0
4	7.0 5.7	16.5 19.3	13.5 15.0	9.0 8.6	14.0 15.7	8.5 7.9	9.5 9.3	5.5 3.6	5.5 3.6	7.5 6.4	5.5 3.6	5.0 2.9	5.0 2.9
5	1.08 26.5	1.32 38.5	1.59 52.0	1.13 29.0	1.22 33.5	1.70 57.5	0.91 18.0	0.52 0.0	0.79 12.0	1.21 33.0	0.92 18.5	0.63 5.5	0.83 14.5
6	25.0 37.5	15.0 19.7	21.0 30.3	22.0 32.1	31.0 48.2	27.0 41.1	26.0 39.3	26.0 39.3	23.0 33.9	25.0 37.5	31.0 48.2	24.0 35.7	29.0 44.6
7	2.50 24.4	0.83 6.5	0.68 4.9	0.69 5.0	0.94 7.7	0.84 6.6	1.74 16.3	1.04 8.8	0.96 7.9	1.92 18.2	1.11 9.5	1.33 11.8	1.16 10.1
8	69.0 62.2	81.0 77.4	73.0 67.3	90.0 88.6	75.0 69.8	81.0 77.4	76.0 71.0	67.0 59.7	78.0 73.5	68.0 60.9	60.0 50.9	55.0 44.5	76.0 71.0
9	1.02 4.3	0.99 3.9	0.91 3.3	1.06 4.6	0.89 3.2	0.99 3.9	0.93 3.5	0.84 2.7	1.04 4.4	0.88 3.1	0.83 2.6	0.90 3.2	1.14 5.3
10	0.71 2.4	0.89 3.1	1.06 3.9	2.50 9.1	0.93 3.4	0.95 3.3	0.88 3.0	1.75 6.2	0.93 3.3	1.00 3.5	1.11 3.9	1.55 5.5	1.22 4.5
11	1.57 5.6	1.27 4.4	1.33 4.6	3.76 13.6	1.65 5.8	1.34 4.7	2.02 7.2	4.86 17.6	0.86 2.8	1.14 3.9	1.11 3.8	1.21 4.2	1.30 4.6
12	45.6 42.6	37.7 34.0	57.4 55.4	25.6 20.9	45.9 42.9	68.9 68.1	62.0 60.4	53.4 51.1	29.0 24.5	57.8 55.9	51.1 48.6	32.0 27.8	45.3 42.3
13	73.8 91.7	53.1 51.2	70.0 84.4	55.4 55.9	60.4 65.5	48.6 42.6	60.4 65.5	56.2 57.5	51.7 48.7	62.9 70.5	62.3 69.3	56.2 57.5	51.7 48.6
14	4.2 12.2	5.3 17.2	3.7 9.8	6.6 23.3	5.2 16.7	14.6 60.4	4.4 13.1	6.5 22.8	7.2 26.0	8.6 32.6	6.0 20.5	13.1 53.4	6.6 23.3
15	1.02 25.0	0.95 21.9	0.88 18.7	1.31 37.5	0.46 0.0	1.16 31.3	0.51 2.2	0.90 19.6	0.87 17.6	1.31 38.0	1.22 33.9	0.81 15.7	0.93 21.0
16	1.60 72.6	0.90 37.4	1.20 52.5	0.90 37.4	0.30 7.1	1.40 62.6	0.90 37.4	0.70 27.3	1.60 72.6	0.60 22.2	1.30 57.6	0.70 27.3	1.40 62.6
17	0.07 50.0	0.05 30.0	0.07 50.0	0.08 60.0	0.07 50.0	0.06 40.0	0.08 60.0	0.07 50.0	0.07 50.0	0.08 60.0	0.06 40.0	0.04 20.0	0.08 60.0
18	22.9 55.2	18.0 40.6	17.1 37.9	11.2 20.5	4.3 0.0	23.3 56.3	11.2 20.5	10.0 16.9	22.9 55.2	7.5 9.5	21.7 51.5	17.5 39.1	17.5 39.1
19	6.7 27.9	7.0 29.1	7.3 30.3	22.8 95.7	6.1 25.5	7.4 30.7	7.1 29.5	7.8 32.6	7.0 29.1	10.3 43.1	6.4 26.4	5.1 21.1	9.4 39.3

Table II_E Characteristics of soils of medium texture under cotton cultivation, Dubti Plantation, Tendaho

Characteristic	D7	D16	D19	D27	Soil Profile
					Profile number in thesis
	37	38	39	40	Matrix number
1	23	18	24	26	
	19.7	13.6	21.0	23.4	
2	7.8	7.6	7.7	7.8	
	38.9	27.8	33.4	38.9	
3	1.03	0.99	0.99	0.97	
	80.0	60.0	60.0	50.0	
4	7.5	8.0	4.5	4.0	
	6.4	7.1	2.1	1.4	
5	1.0	1.14	0.75	1.33	
	22.5	29.5	11.0	39.0	
6	14.0	20.0	21.0	4.0	
	17.9	28.6	30.3	0.0	
7	1.55	3.33	1.75	0.36	
	14.3	33.4	16.4	1.5	
8	42.0	67.0	70.0	90.0	
	28.1	59.7	63.4	88.6	
9	1.27	0.93	0.97	1.22	
	6.4	3.5	3.8	6.0	
10	0.45	0.73	3.21	0.83	
	1.5	2.5	11.2	2.9	
11	2.50	1.55	0.99	1.21	
	8.9	5.4	3.3	4.2	
12	36.4	30.8	27.6	28.3	
	32.6	26.5	23.1	23.8	
13	73.9	39.6	72.4	41.6	
	91.6	25.0	88.9	28.9	
14	9.1	11.7	12.0	8.8	
	34.9	46.9	48.5	33.5	
15	1.09	1.04	1.02	1.02	
	28.1	25.9	25.0	25.0	
16	0.80	1.30	1.10	1.30	
	32.3	57.6	47.5	57.6	
17	0.06	0.08	0.08	0.06	
	40.0	60.0	60.0	40.0	
18	13.3	16.2	13.7	21.7	
	25.4	35.2	27.6	51.5	
19	23.8	10.0	9.2	9.2	
	100.0	42.2	38.3	38.3	

Table II_F Characteristics of light textured soils under cotton cultivation, Dubti Plantation, Tendaho.

Characteristic	A	B	D	E	F	G	H	Soil Profile
	32						33	Profile number in thesis
	41	42	43	44	45	46	47	Matrix number
1	15	10	16	16	18	17	15	
	9.9	3.7	11.1	11.1	13.6	12.3	9.9	
2	7.45	7.2	8.2	7.5	7.6	7.7	7.75	
	19.4	5.6	61.2	22.2	27.8	33.4	36.2	
3	0.87	0.93	0.95	0.93	0.94	0.99	0.99	
	0.0	30.0	40.0	30.0	35.0	60.0	60.0	
4	20.0	20.7	32.3	25.0	24.7	22.3	24.2	
	24.3	25.3	41.8	31.4	29.6	27.6	30.3	
5	2.20	1.80	2.55	1.88	1.86	1.56	1.79	
	82.5	62.5	100.0	66.5	65.5	50.5	62.0	
6	10.8	12.8	8.6	8.5	8.8	8.6	10.8	
	12.1	15.7	8.2	8.0	8.6	8.2	12.1	
7	4.12	7.10	9.55	3.41	6.29	4.30	7.72	
	41.8	73.7	100.0	34.2	65.1	43.8	80.8	
8	28.8	32.8	25.6	26.8	27.0	25.0	32.9	
	11.6	16.6	7.5	9.1	9.3	6.8	16.7	
9	3.86	5.47	12.20	2.91	5.40	4.54	11.75	
	28.6	42.4	100.0	20.5	41.7	34.4	95.8	
10	1.14	27.40	4.65	19.40	0.99	0.25	10.40	
	4.0	100.0	16.8	70.6	3.5	0.8	37.0	
11	19.0	2.37	27.3	5.46	2.02	1.32	6.28	
	69.5	8.4	100.0	19.9	7.1	4.7	22.7	
12	9.3	14.4	10.5	18.2	12.3	11.9	15.2	
	3.2	8.7	4.4	12.8	6.4	6.0	9.7	
13	58.1	59.1	56.2	60.4	72.4	67.3	57.9	
	61.0	63.1	57.5	65.6	89.9	79.0	58.7	
14	11.8	21.5	20.9	23.1	17.1	15.9	19.1	
	47.4	92.5	89.8	100.0	72.0	65.7	86.1	
15	0.71	0.95	0.81	0.75	0.91	1.06	0.93	
	11.1	21.9	15.7	13.0	20.1	26.8	21.0	
16	1.60	1.20	1.70	1.80	1.80	0.90	1.30	
	72.6	52.5	77.7	82.7	82.7	37.4	57.6	
17	0.04	0.04	0.06	0.06	0.05	0.04	0.04	
	20.0	20.0	40.0	40.0	30.0	20.0	20.0	
18	38.0	28.5	27.0	32.2	36.7	25.0	32.5	
	100.0	71.8	67.3	82.3	95.8	61.4	82.6	
19	3.3	4.3	2.5	3.8	4.7	4.2	3.9	
	13.2	17.7	9.8	15.6	19.4	17.2	16.0	

Table II_G Characteristics of Anthropogenic soils under Tamarix woodland, Al Hasa

Soil Profile	AD1	AD6	AD7	TSS25	TSS27	TSS35	TSS38	TSS55	TSS58	TSS59	TSS60	D3	D21	D22	D28
Profile number in thes	12			6									23	27	
Matrix number	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
Characteristic															
1	34	33	13	88	23	30	23	21	36	25	23	35	33	80	36
	33.3	32.1	7.4	100.0	19.7	28.4	19.7	17.3	35.8	22.2	19.7	34.6	32.1	90.1	35.8
2	8.4	8.1	8.6	8.55	8.6	8.6	7.9	8.6	8.6	8.7	8.8	7.1	7.8	8.1	7.75
	72.1	55.6	83.3	80.4	83.3	83.3	44.5	83.3	83.3	88.8	94.4	0.0	38.9	55.6	36.2
3	0.94	1.01	0.98	0.98	0.98	0.99	0.97	0.98	0.99	0.99	1.02	0.92	0.98	1.07	1.01
	35.0	70.0	55.0	55.0	55.0	60.0	50.0	55.0	60.0	60.0	75.0	25.0	55.0	100.0	70.0
4	38.0	48.0	33.5	46.5	40.0	44.0	35.5	32.0	32.5	34.0	33.0	7.2	4.0	8.0	4.0
	50.0	64.2	43.6	62.1	52.8	58.6	46.4	41.4	42.1	44.2	42.8	6.0	1.4	7.1	0.7
5	1.34	1.04	1.16	0.91	1.03	1.01	1.00	0.93	0.97	0.98	1.03	1.00	0.62	1.00	0.73
	39.5	24.5	30.5	18.0	24.0	23.0	22.5	19.0	21.0	21.5	24.0	22.5	4.5	22.5	10.0
6	7.7	6.3	8.8	15.3	13.3	14.8	20.2	9.5	13.3	13.7	7.2	8.0	21.0	60.0	16.0
	6.6	4.1	7.9	20.2	16.6	18.9	28.9	9.8	16.6	17.4	5.7	7.1	30.3	100.0	21.4
7	1.05	0.22	1.00	0.89	0.69	1.06	0.81	0.89	1.23	1.16	0.41	0.36	0.84	2.73	0.89
	8.9	0.0	8.4	7.2	5.0	9.0	6.3	7.2	10.8	10.1	2.0	1.5	6.4	26.9	7.2
8	19.6	47.6	30.0	36.3	34.2	35.0	35.0	29.2	31.6	32.4	26.4	69.0	95.0	99.0	76.0
	0.0	35.2	13.1	22.0	18.4	19.4	19.4	12.1	15.1	16.1	8.5	62.2	94.9	100.0	71.1
9	0.64	0.59	1.00	0.88	0.80	0.97	0.68	0.94	1.10	1.13	0.52	0.82	1.70	1.22	0.85
	1.0	0.6	4.1	3.1	2.4	3.8	1.3	3.5	5.0	5.2	0.0	2.6	10.6	6.0	2.8
10	0.11	0.67	0.17	0.21	0.15	0.17	0.04	0.12	0.22	0.16	0.14	0.55	0.70	1.65	1.25
	0.3	2.5	0.5	0.6	0.4	0.5	0.0	0.3	0.6	0.4	0.4	2.0	2.6	4.9	4.6
11	0.73	8.34	1.13	0.72	0.94	1.31	2.0	1.09	1.19	0.89	0.78	0.60	0.80	1.85	1.26
	2.4	30.4	3.9	2.3	3.2	4.6	7.0	3.7	4.1	3.2	2.6	1.9	2.7	6.8	4.4
12	10.8	11.2	13.6	13.7	10.5	9.6	10.2	6.4	11.6	9.5	7.2	41.6	49.2	67.9	29.9
	4.8	5.2	7.8	7.9	4.4	3.4	4.2	0.0	5.6	3.4	0.9	38.3	46.5	66.8	25.8
13	44.4	26.8	66.9	61.3	59.1	55.8	74.5	59.4	48.3	65.5	65.2	78.0	60.0	61.9	47.8
	34.3	0.0	78.3	67.4	63.1	56.6	92.8	63.7	42.0	75.8	75.2	100.0	64.9	68.6	40.9
14	8.3	10.2	6.6	5.1	8.6	8.4	5.9	12.5	6.0	9.5	9.8	4.6	2.4	1.6	15.4
	31.1	40.1	23.3	16.3	32.6	31.6	20.0	50.7	20.5	36.8	38.2	14.0	3.7	0.0	64.2
15	0.90	1.23	0.47	1.09	1.23	0.90	1.59	0.94	1.07	1.64	1.10	1.53	0.89	1.0	0.94
	19.6	34.3	0.4	28.1	34.3	19.7	50.4	21.5	27.2	52.6	28.6	48.8	19.2	24.1	21.5
16	0.92	0.57	0.47	0.16	0.24	0.55	0.39	0.62	0.94	0.86	0.42	1.10	1.50	1.40	1.1
	37.4	20.7	15.7	0.0	4.0	19.7	11.6	23.2	39.4	35.4	13.1	47.5	67.6	62.6	47.5
17	0.09	0.05	0.04	0.02	0.03	0.05	0.05	0.05	0.06	0.06	0.04	0.06	0.10	0.04	0.07
	70.0	30.0	20.0	0.00	10.0	30.0	30.0	30.0	40.0	40.0	20.0	40.0	80.0	20.0	50.0
18	10.5	11.4	11.8	8.0	8.0	11.0	7.8	12.4	15.7	14.3	10.5	18.3	15.0	35.0	15.7
	18.4	21.1	22.3	11.0	11.0	19.9	10.4	24.1	33.8	29.7	18.4	41.5	31.8	90.9	33.8
19	2.0	1.8	1.8	0.4	0.2	1.1	1.0	0.3	2.1	0.2	0.1	5.8	7.3	5.6	8.6
	8.1	7.2	7.2	1.3	0.4	4.3	3.9	0.8	8.5	0.4	0.0	24.3	30.3	23.2	35.9

Table II_H Characteristics of uncultivated soils at Al Ain (AD) Ras-al-Khaimah (TSS) and Tendaho (D)