UNIVERSITY OF DURHAM

THE SOILS AND AGRICULTURE OF THE AL AIN OASES, ABU DHABI

REPORT
TO THE DEPARTMENT OF AGRICULTURE
GOVERNMENT OF ABU DHABI

J. H. STEVENS

CENTRE FOR MIDDLE EASTERN AND ISLAMIC STUDIES

DEPARTMENT OF GEOGRAPHY
UNIVERSITY OF DURHAM

November, 1969

THE SOILS AND AGRICULTURE OF THE AL AIN OASES, ABU DHABI

Report to the Department of Agriculture, Government of Abu Dhabi.

by

J.H. STEVENS.

Department of Geography, University of Durham.

November 1969.

CONTENTS

MAPS

FIGURES

INTRODUCTION

This report embodies the results of five and a half weeks fieldwork in the Trucial States during July and August 1969. During this period, visits were made to 55 farms and date gardens in the Al Ain district and from these, information relating to irrigation techniques, fertilizer applications and general agricultural practice was obtained. Much of the material obtained is of a general nature and there is need for further research in many of the topics discussed. However, this is an attempt to collate material from a wide variety of sources so as to provide a basic statement on which further research can be centred. 14 soil profiles were also sampled to provide information on the effects of agriculture on soil characteristics and development.

In addition to the work at Al Ain, visits were made to Digdaga Agricultural Trials Station and to the new agricultural scheme at Tawi Mileiha. 8 farms were visited on the northern Jiri Plain in order to obtain comparative data.

The report is subdivided into three parts:-

Part I is concerned with the contemporary agriculture in the Al Ain district. Since the fieldwork took place in the summer, there was considerable emphasis on fodder and tree crops whilst information regarding winter vegetables was of a general nature. Little information was obtained about cereal cultivation.

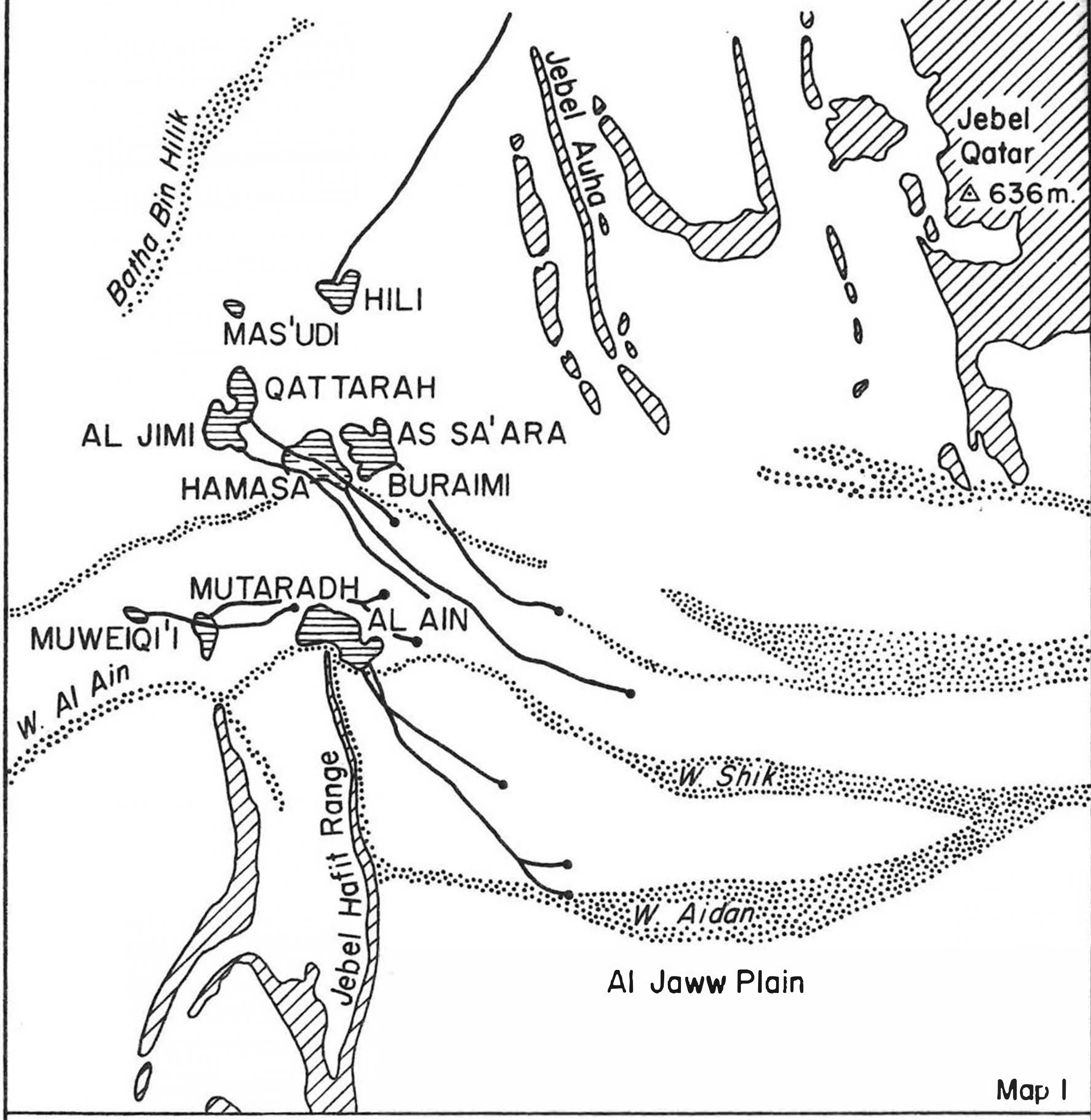
Part II deals with the effects of agriculture on soil characteristics and pedogenesis.

Part III presents the conclusions and some recommendations.

The work was carried out under a Travel Grant from the Middle East Centre, University of Durham for which I am extremely grateful. I am also greatly indebted to His Excellency Sheikh Tahnoun bin Mohammed, the Chairman of Agriculture, for permission to work with the Department of Agriculture and to Dr. Hassan Gharaybeh, Director of Agriculture, for the vast amount of help he provided. I am also grateful for all the help provided by the staff of the Department, but, in particular, by Abdullah Hamdan el Wahabi, the Extension Officer, without whom fieldwork would have been impossible. Additional information was provided by Dr. Khan, Director of Horticulture, by the staffs of Sir A. Gibb and Partners and Hunting Geology and Geophysics Limited, and by Ahmed Ariby, for which I am grateful.

During my visit to the northern Trucial States much help was given by the Trucial States Development Council, Mr. P. Jones of Sir W. Halcrow and Partners and Mr. R. Mackay, Director of Digdaga Agricultural Trials Station. My thanks are also due to Mr. & Mrs. J. Coles, Political Agency, Dubai and Mr. R. Mackay for their kind hospitality.

LOCATION OF THE AL AIN GROUP OF OASES



Jebels

Major Wadi Spreads

Oases

Lines of Aflaj

0 Kms 5

Based on Interim Report of Groundwater Survey (Sir W. Halcrow) and 1:100,000 Map Published By Director of Military Survey

Chapter 1

HISTORICAL DEVELOPMENT

The Al Jaww Plain is made up of gravel outwash material from the Oman Hills which, to the east of Al Ain, are composed of Oligocene and Cretaceous limestones as well as serpentinite. Gravel diminishes in size away from the hills and gives way to increasingly thicker deposits of fine sands and silts. The Buraimi group of oases are located on these fine sands, at the northern end of Jebel Hafit (1160 m) at an elevation of 270-290 m. The soils that have developed are of light texture with only weak structural development. Organic matter contents are low and the soils have a high permeability. The parent material is highly calcareous whilst in certain localities soluble salts are a hazard. In their natural state the soils are inherently low in fertility but with correct management can be made fertile. Topographically, the area is irregular due to a number of wadis that have been deflected to the north of Jebel Hafit whilst there are also frequent areas of dune sand.

With the exception of Mas̕udi, the Buraimi group of oases are long established centres of agriculture and for many centuries, Buraimi was the most important centre of Western Oman (Zwemer, 1902). The date gardens were irrigated by aflaj bringing water from the mountains to the east and also from the Al Jaww Plain - some of these aflaj have in recent years been renovated and they still supply the bulk of the water for irrigation of the date gardens (Map 1). However, dates were by no means the only crop cultivated during the early years of the twentieth century and Zwemer also records figs, mangoes, mulberry trees and pomegranates.

Lorimer (1915) estimated that there were about 60,000 date palms growing in the oases, mainly of the "Mibsali, Fardh and Khalis varieties". He further remarked that "they are not equal to their cogeners of Sharqiyah and Wadi Samail in the Oman Sultanate" and that, even then, insufficient were produced to satisfy local requirements.

In the early 1920's, the oases were supporting a population of about 5,000 and Mas'udi had recently been established (Cox 1925). In addition to the fruit crops noted by Zwemer, Cox also records grapes, melons and limes, whilst wheat, barley, jowari and "quantities of lucerne" were also cultivated.

Sir A. Gibb and Partners (1969) have estimated the size of the cultivated area as 482 hectares (this excludes modern large units away from the traditional area) of which the old established date gardens account for 281 hectares. A rapid expansion of the cultivated area is taking place and the new smallholdings grow lucerne and vegetables as well as tree crops. Apart from individual development, Sheikh Zaid and Sheikh Khaled have established large farms (over 40 hectares) away from the traditional cultivated area, whilst the Department of Agriculture has started a 76 hectare farm, two kms. east of Al Ain. The cultivated area of these large units is in excess of 300 hectares, though the total production from them is currently small since much of the area has only been tilled for a few months. Despite the increase in agricultural area, the amount of produce is insufficient to supply the population of about 13,000 (1968 census figures for the oases in Abu Dhabi territory). Farms thus may be divided into three categories (Map 2):-

1. Old established date gardens. These are small, less than 10 dunums in size, and rely almost exclusively on the cultivation of dates. In some cases, old dates have been partly cleared and replaced by citrus and pomegranates, whilst lubia is also cultivated under the palms. These units are mainly subsistence orientated and only produce, surplus to the owner's requirements, is marketed.

2. Smallholdings around the old date gardens which concentrate on the cultivation of fodder crops and vegetables, though some tree crops are also grown. The size of these units varies from less than 10 dunums

to over 80 dunums with an average size of about 22 dunums. Many of these farms are commercially orientated though some only provide for the owner's requirements. In April 1968 there were about 115 of these smallholdings being cultivated, whilst a number have come into production subsequently. Major areas of recent expansion are to the east of Qattarah, to the east of Hili, to the west and south of Mutaradh and Al Muweiqi'i, as well as to the south and east of Al Ain.

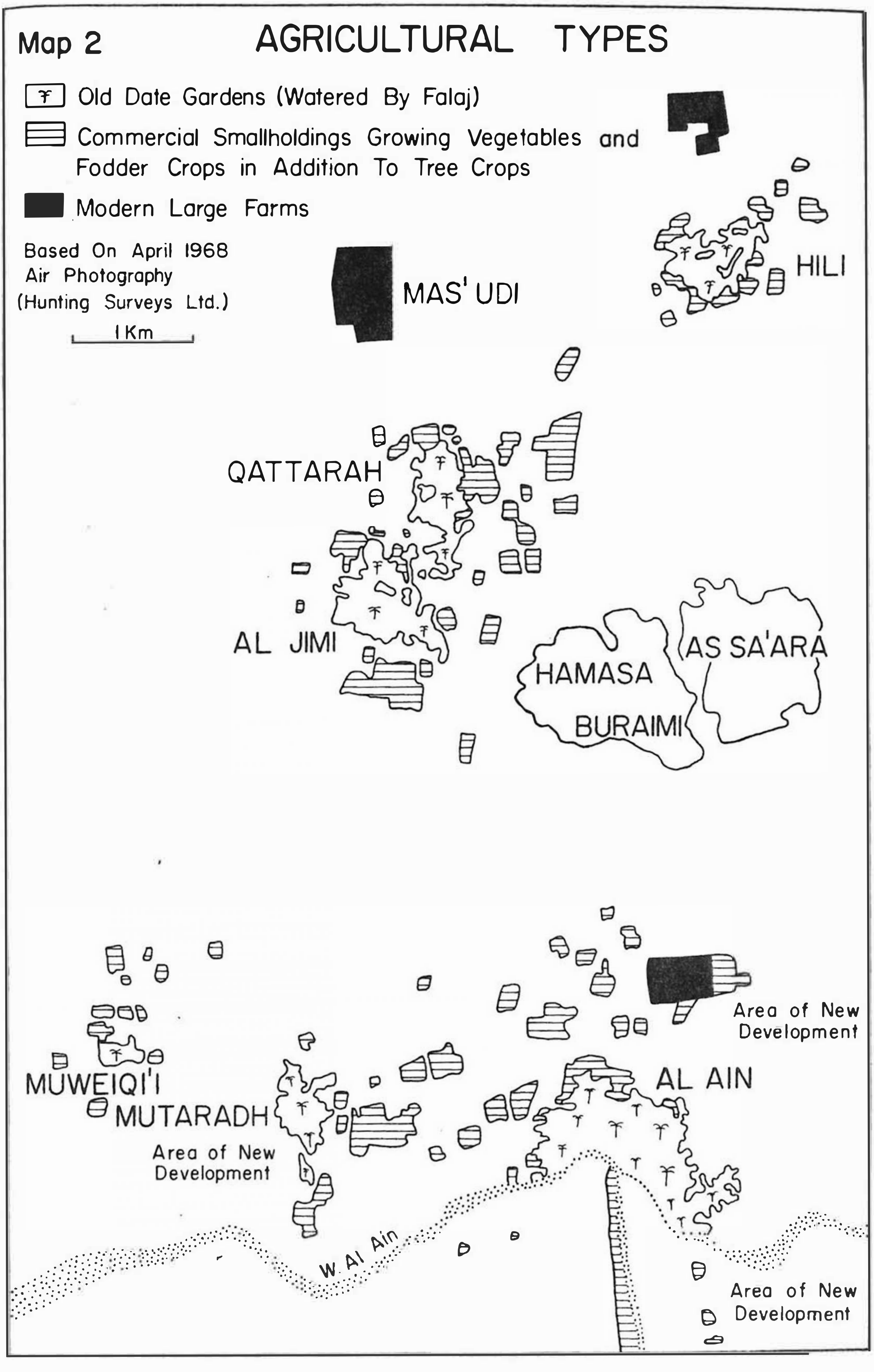
3. Modern large units owned by Sheikhs and the Department of Agriculture. These are over 100 dunums in size and may be as large as 1000 dunums. Such farms are situated away from the old oases - for instance Asharig is approximately 20 kms. west of Al Ain whilst Masyad is about 25 kms. to the south.

The individual farmer's expenses are very low. Though a well and pump are installed free of charge, many of the farmers install a second pump "in case the first breaks down". The second pump is very rarely utilised. Seeds and fertilizers are provided free by the Department of Agriculture and from autumn 1969 25 kgs of superphosphate will be provided for each dunum under lucerne. If a farmer wishes to apply more he can ask for extra fertilizer. No water duty is charged and the only costs a farmer has to meet are costs of running the pump, the price of organic manure and labour costs.

There is a shortage of organic manure locally and farmers are travelling considerable distances to secure supplies. Local manure costs about B.D. 1* for 80-100 kgs depending on quality, whilst that obtained from Mahdah and other towns in Muscat is somewhat cheaper, though transport costs also have to be met. Some farmers are beginning to reduce the amount of organic manure that they apply and are using more mineral fertilizer. Quite apart from its nutrient value, organic manure is essential on the light soils since it aids structural formation and also moisture retention.

Many of the small commercial units are worked on a part-time basis or an overseer is employed to supervise the labour. Almost all labour is unskilled and lacking agricultural tradition or training. The standard of husbandry reflects the amount of interest and work put in by the owner and also the wage rates paid. Farms directly worked by the owner with or without hired labour are usually well managed - the highest standard of husbandry was observed on a farm worked by the owner using family labour and this was probably the most profitable farm visited. Whilst overseers might be paid up to B.D. 40 a month (all workers also have a bonus of free produce), some overseers were being paid as little as B.D. 18 monthly. Similarly, some labourers were earning as much as B.D. 30 a month though many earned as little as B.D. 12 monthly. On farms paying low wages, the standard of husbandry was usually of low quality.

* 100 Fils = 1 Rial (R) 10 Rials = 1 Bahrein Dinar (B.D.). B.D. 1.1 is approximately equivalent to £1 Sterling.



Map 2
AGRICULTURAL TYPES
Old Date Gardens (Watered By Falaj)
Commercial Smallholdings Growing Vegetables and Fodder Crops in Addition To Tree Crops
Modern Large Farms
Based On April 1968 Air Photography (Hunting Surveys Ltd.)
1 Km
MAS' UDI
HILI
QATTARAH
AL JIMI
HAMASA
BURAIMI
AS SA'ARA
MUWEIQI'I
MUTARADH
Area of New Development
AL AIN
Area of New Development
W. Al Ain
Area of New Development

Chapter 2

TREE CROPS

DATES

Dates are by far the most important crop grown, in terms of cultivated area, with 58 % (281 hectares) out of a total cultivated area of 482 hectares being given over to this crop. Analysis of aerial photographs suggests that, in the date gardens, 60-65,000 date palms are being cultivated, though many of these are old and producing fairly low yields. In addition, each of the smallholdings may grow up to 400 palms. There is an average density of 250-255 palms/hectare in the date gardens, and though, where young trees have replaced old palms, the spacing between individual palms may be 8-10 metres, in many cases it is 4 metres or less. In the new smallholdings, which are mainly devoted to fodder crops and vegetables, date palms line irrigation channels or they have been planted to provide protection for other crops.

Varieties More than 20 varieties of the date palm are commonly cultivated in the Al Ain district. Yellow dates, particularly of the nighal, fardh and bagal varieties are mainly grown for drying, there being a local preference for dried dates. They are, however, only of medium quality, especially the nighal variety, which is preferred for drying since it produces an early crop. The red dates (khinaizy, khisab and muselli) are of better quality and the muselli variety, in particular, is a heavy yielder as well as being regarded as the best for fresh eating.

Asharig farm, 20 kms west of Al Ain, is currently being established by Sheikh Zaid and here 2,200 dates, obtained from Egypt and Iraq, have been planted. Most palms are, however, obtained from Oman.

Irrigation Irrigation of the date gardens is mainly by falaj, though some owners are now installing pumps to supplement falaj irrigation (table 1). The concentration of pumps at Al Jimi and Qattarah results from

Table 1. Summary of wells in date gardens (based on Interim Report, Water Resources Survey, Sir A. Gibb and Partners).

	Area (hectares)	Wells with pump
Al Ain	102.6	10
Al Jimi	61.2	12
Hili	49.4	1
Qattarah	34.7	7
Mutaradh	23.8	2
Al Muweiqi'i	9.5	3

many of the owners there growing fodder crops (and vegetables) in addition to the dates. At Al Muweiqi'i the flow from the falaj has been insufficient to fully irrigate the date gardens.

In each of the oases, there is a cooperative agreement on the use of the falaj water and, in summer, there is considerable pressure on the water resources. In all the oases, apart from Mutaradh, irrigation in summer is at a three weekly interval, whilst in winter, when smaller quantitites are applied, the irrigation interval is reduced to 12-15 days. At Mutaradh, the corresponding intervals would appear to be 30 days and 20 days. Where pumps have been installed, there are either one or two supplementary irrigations between the main falaj irrigations. About 15-20 cms are applied during the summer irrigations reducing to about 10 cms in winter. This would suggest a water rate of about 2.9 metres p. annum.

Fertilizers No mineral fertilizers are applied to the date palms, though where there is a ground crop of lubia or lucerne, some benefit will be obtained from mineral fertilization of these crops. Almost all the owners, however, apply organic manure though at very variable rates - perhaps an average figure is that quoted by Sultan bin Ahmed at Al Jimi who applies about 15 tons/hectare/annum. The organic manure is spread over the plots and there is no placement. Very few owners use dried fish.

Yields It proved impossible to estimate the weight of the date crop harvested since very few dates find their way into the market. The crop is mainly grown for the owner's use. Only the surplus is sold and most of the dates in the market at Al Ain have come from Muscat territory. Comparative figures from Shimal, near Ras-al-Khaimah, would suggest that the maximum value of a date harvest would be about B.D. 400/hectare for good quality fruit (this figure was obtained for the date variety known as lu'lu').

CITRUS

Citrus fruits (lemons, limes and oranges) rank as the second most important tree crop, though in only a few holdings do citrus trees form a major component. In only 5 of the gardens and farms visited were over 100 citrus trees being cultivated (two of these farms belonged to Sheikh Zaid). Within the old established date gardens, a certain amount of clearance and replanting with citrus has taken place. Citrus trees appear to experience difficulty in becoming established and most young trees show signs of chlorosis, probably resulting from excess calcium in the soil inhibiting the uptake of other nutrients. The soils are highly calcareous whilst pH values are generally in excess of 8.0 (see Part II).

Irrigation This appeared to be very much at the owners whim. Young citrus at Asharig, on loamy sand, were being watered every second day in summer and every five days in winter. In contrast, 4 year old citrus at Al Jimi on slightly heavier soils were watered every 3 days and 7 days respectively, whilst on a fine sandy loam at Qattarah irrigation frequency was weekly throughout the year. Observation would suggest that, on the light soils in the oasis area, irrigation every 2/3 days in summer would produce the best results.

Fertilizers Though most farmers apply some sulphate of ammonia to citrus trees by placement, the Department of Agriculture farm and also those owned by Sheikh Zaid are applying compound fertilizer. 15-15-6-4 would appear to be the best strength and, on the light soils, small applications at fairly frequent intervals should give the best results. (At the first meeting on Soil Fertility and Fertilizer Use in the Near East and N. Africa (FAO 1960) the best general recommendation per bearing tree seemed to be: 5 kg ammonium sulphate, 1.5 kg superphosphate and 1 kg potassium sulphate, with slight modifications for local conditions).

Organic manures are also applied to citrus trees. Where only a few citrus are cultivated, the farmers generally spread the manure over the plot. However, apart from the large farms, one farmer at Al Ain (Abdul Rahim Mohammed) who concentrates on tree crops applied 24-96 kgs organic manure to each tree by placement during October and November each year. The amount applied depended upon size and type of tree. Some farmers who had only a few citrus trees applied dried fish by placement.

Quality Limes and lemons of fairly good quality are produced but oranges generally are of less than medium quality. The varieties grown are obtained from Muscat (lemon and lime) Iraq (oranges) and Egypt (citrus on Sheikh Zaid's farms). A farmer can obtain 60 fils/dozen for good quality oranges though less than half this figure for poor quality ones.

OTHER TREE CROPS

Though a wide range of tree crops are grown, few farmers concentrate on their cultivation. Apart from the Department of Agriculture farm, only the recently established farm of Sheikh Zaid at Asharig has any major concentration of tree crops. Here, in addition to 2,200 date palms and 500 citrus trees, 340 figs, 400 pomegranates, 300 apples and 300 guavas have been planted. A small holder, such as Abdul Rahim Mohammed, at Al Ain, grows 400 dates, 180 citrus, 20 pomegranates, 55 bananas and 60 vines on $32\frac{1}{2}$ dunum. Much of his income is, however, derived from 10-12 dunums of vegetables since many of his perennial tree crops are not yet fully bearing.

To obtain maximum profit from perennial tree crops, considerable expertise is required. This is often lacking as is evidenced by a farmer at Qattarah who is currently cultivating 31 bananas on 50 sq.

metres. He applies no mineral fertiliser whilst the application of organic manure is minimal. Furthermore irrigation is perfunctory.

Analysis of farms in Ras-al-Khaimah would suggest that, unless tree crops are cultivated on a major scale such as at Asharig, it is best to supplement one's income by growing vegetables. On a holding of 200 dunums in Ras-al-Khaimah approximately 80 dunums are given over to winter vegetables and 40 dunums to melons in the summer. Though dates, pomegranates, citrus and vines are grown, the return from these is still very low as many of the trees are young and are not yet producing. Nonetheless, this farm makes a profit of about B.D. 6,500 annually after deductions for water rates, seeds, fertilisers etc., all of which have to be provided by the farmer in Ras-al-Khaimah.

Chapter 3

FODDER CROPS

Large numbers of cattle and sheep are kept in the Al Ain district as well as a significant number of horses. The growing of fodder crops to support the stock has become traditional whilst there is also a steady sale to Bedu and Omanis. Three main fodder crops are grown - lucerne, lubia (Dolichos lablab) and masayblu, (possibly Panicum maximum). Small amounts of berseem and cereals are also grown.

LUCERNE

This is by far the most important of the fodder crops and takes up about 30% of the cultivated area on the smallholdings. Under good management, high yields can be obtained since up to 14 cuttings can be obtained annually. It is also an important crop on the large holdings belonging to the Sheikhs though it is mainly used for their own animals.

Management. The crop is grown in small basins, each about 30-40 sq. metres in area. Before planting, superphosphate and organic manures are applied to the plots but are not dug in. Consequently, when the crop begins to grow and irrigation commences, the manure is washed to the far end of the plot and crop growth is very uneven. Cutting takes place usually monthly throughout the year, though some farmers manage to cut every 25 days in the summer. Light dressings of superphosphate are applied after alternate cuts during the winter months by the better farmers. The lucerne is usually left in the ground for about 6 or 7 years but after about the 3rd or 4th year it begins to take on a very patchy appearance. One of the reasons for this is that the cutting is done by hand and usually the whole of the aerial portion of the plant is cut off, and damage is caused to the corn.

Irrigation. Usually, the crop is irrigated once every three days in summer and weekly during the winter months. However, at Hili good yields were obtained using a 5 day irrigation interval in summer, whilst at Al Ain more frequent irrigations are needed in both summer and winter to obtain good yields (table 2).

Table 2. The yield of lucerne related to irrigation interval and fertilizer treatment. (Owners of the farms are found in Appendix 4).

Farm	Yield (metric tons/dunum)	Irrigation Interval (days)		Organic Manure (metric tons/dunum)	Superphosphate (kgs/dunum)
		Summer	Winter		
H5	14.4	5	7	3.6	30
M2	14.4	3	7	3.6	25
Q5	13.9	3	7	N.D.	40
Q6	12.2	3	7	1.5	36
J2	11.5	3	7	0.75	50
Q2	11.5	5	7	2.2	30
M1	11.5	3	7	1.2	33
M3	11.5	3	7	6.0	6
A3	11.5	1	4	2.4	30
A5	11.5	2	5	2.9	55
H2	10.8	5	10	1.0	25
J11	10.3	4	7	3.6	50

The irrigation water is released into the basin from the main irrigation channels and the basin is flooded to a depth of about 8-10 cms. Frequently, the basin is uneven and the part furthest from the input may receive very little water. In contrast, the release of water into the basin causes scouring in the immediate vicinity of the inlet.

Flooding to a depth of 8 cms at irrigation intervals of 3 days in summer and 7 days in winter gives a water rate of about 7,000 cu m./dunum annually. In the water duty experiment at Digdaga (1964-1965), 4,460 cu m./dunum were applied in 10 months for the best yields, though these were less than half the best yields in the Al Ain district.

Fertilizers. Whilst every farmer applies some organic manure, there are still a considerable number who apply no superphosphate. Lucerne is a crop well-known to respond to applications of phosphatic fertilizer and it is to be Department policy to distribute superphosphate to all farmers growing lucerne at a rate of 25 kgs/dunum. The average application rate on the farms visited was 31.5 kgs/dunum, though some farmers applied over 50 kgs/dunum.

Very variable amounts of organic manure are applied whilst the manure itself is of very variable quality. The bulk of the organic manure is applied to the plot before the lucerne is sown and table 2 gives figures for the application of organic manure during the first year of cropping. Small amounts are added each succeeding year but much of the value of the organic fertilizer is lost since it is not dug into the ground.

Yields. In table 2, the yield column refers to fresh weight yields of 1-2 year old lucerne. Traditionally, the crop is left in the ground for 6-7 years but crops of this age yield less than 1.5 metric tons/dunum and very often as low as 0.5 metric tons/dunum. The average yield p. annum on the farms visited, for lucerne up to 3 years old, was 9.5 metric tons per dunum per annum. It would seem beneficial to plough the lucerne crop in after 3 years and plant vegetables for at least a year before reverting to lucerne again. From table 2, it would further seem that the best yields will be achieved with the application of 2.5 - 3.5 tons organic manure and about 30 kgs superphosphate per dunum annually.

One of the reasons why lucerne is kept for 7 years is that, financially, it is a profitable crop. In July, 8 kgs lucerne were fetching 2R in Al Ain market and an "average" farmer will thus obtain over B.D. 200 per dunum annually. This is based on yields of about 9.5 metric tons/dunum and constant prices). This figure will be considerably reduced if sold through a middleman but compares with a figure of B.D. 150 per dunum for vegetables, which require more labour.

LUBIA

Lubia is the second most important of the fodder crops grown in the Al Ain district. However, only small areas are grown on the smallholdings, the bulk being grown in the old established date gardens under the date palms. Consequently, little or no mineral fertilizer is applied.

Where this crop is grown on the smallholdings, yields of up to 8 metric tons/dunum can be obtained. Fertilizer and manurial practices are similar to lucerne but only 5 cuttings a year are possible. Market prices are lower than for lucerne but incomes of B.D. 100-150 per dunum should be possible. Lubia appears to be grown as a break crop.

MASAYBLU

Small areas of "Masayblu" (possibly *Panicum maximum*) are grown by the smallholders though less than 5% of the area is devoted to this crop. It is most popular in Al Ain/Daudi and Mutaradh oases where, on some farms, up to 20% of the area is under "Masayblu". Market prices for this crop are about 1R for 8 kgs, whilst only two cuttings appear to be possible.

CEREALS

Small areas of wheat and barley are grown on the larger farms for use as fodder. At Masyad, for instance, up to 20 hectares of wheat have been cultivated. Little organic manure is used though some sulphate of ammonia is applied before the crop is planted in late November or early December. During the early stages of growth, irrigation is at fortnightly intervals, though subsequently irrigation takes place every six days. Yields have averaged about 13 quintals/hectare but the frequency of irrigation has affected yields in that waterlogging has occurred where soil drainage has been impeded.

Chapter 4

VEGETABLES

Vegetable produce from the Al Ain district is insufficient to provide for the growing population. Apart from melons, the commercial cultivation of vegetables has been a comparatively recent trend stimulated, in part, by the establishment of construction camps for major development projects. Though the amount of produce is increasing annually, the only crops produced in surplus are melons, cabbages and tomatoes, and there is some export of these to Abu Dhabi. Other vegetables have, however to be imported, particularly from Ras-al-Khaimah.

In the winter months a wide range of crops is grown - cabbages, cauliflowers, tomatoes, carrots, beetroots, spinach and onions. Up to 20-25% of the cultivated area on the farms visited was devoted to the growing of winter vegetables but, in summer, less than half this area is devoted to vegetables, mainly melons and squash. This reduction in area devoted to vegetables is due to the large amounts of water required to irrigate very small areas brought about by high evapotranspiration rates (at Tawi Mileiha in a similar situation approximately 100 kms due north, evaporation from an open pan for the months May-October 1968 averaged 16.2 mms daily) and high seepage rates. In addition small patches of okra, aubergine and peppers are cultivated throughout the year.

A major problem is that the whole of a particular crop tends to ripen over a short period of time and gluts occur. Tomatoes are particularly prone to this, though some farmers are endeavouring to produce early or late crops when high prices can be obtained Early and late tomato crops will fetch 3-4R/kilo but during the glut prices fall to less than 50 fils/kilo.

Table 3. Vegetable prices per kilo in May and July 1969 at Al Ain Market. (May figures based on data supplied by Abdullah Hamdan el Wahabi)

	Early-May		Mid-July	
	Price received by farmer	Market Price	Market Price	Source
Aubergine	1R	1.75R	2R	local
Cabbage		2R		
Cucumber	2R	2.5R		
Melon, Sweet	1.25R		2R	local
Melon, Water	1R	1R	1R	local
Okra		4R	10R	local
Onions	1.25R	1.25R	1R	Bombay
Pepper	1.25R	4R	10R	local
Potatoes			1.5R	Iran
Spinach	2.5R	5R		
Tomatoes	1R	2.5R	4R	Iran

Production of vegetables requires a slightly larger labour force and considerably more expertise than lucerne cultivation. As a result few farmers currently rely entirely upon vegetable production as a commercial enterprise. One farmer, at Al Jimi, who concentrates on vegetable production made a profit of about B.D. 1200 during 1968, though he relied entirely on family labour. About 12 dunums of winter vegetables were grown, mainly cabbages and tomatoes, whilst two crops of water melons were obtained off about 8 dunums. 66% of his profit came from the winter vegetables. Profits of B.D. 1250-1500 per hectare should be possible with high standards of vegetable cultivation.

Irrigation. Melons and squashes are irrigated by the ridge and channel method whilst the remaining vegetables tend to be cultivated in shallow basins approximately 30-40 sq metres in size. Summer irrigation of both melons and crops such as okra, pepper and eggplant (aubergine) generally takes place with a two or three day interval between water applications, whilst the standard irrigation interval in winter is one week.

Fertilizers. Both organic manures and mineral fertilizers are applied to vegetable crops. Amounts of organic manures applied vary widely from farmer to farmer though an average figure is about 1 metric ton/dunum. Humus, imported from the Lebanon, is applied by some farmers and also on the Department of Agriculture farm. Application at a rate of about 1 metric ton/dunum, 10-15 days before planting, has proved advantageous.

Sulphate of ammonia is the common mineral fertilizer applied to vegetables. Farmers apply up to 33 kgs/dunum sulphate of ammonia but, in many cases, this is given as a single application. On the light soils that predominate in the Al Ain district, this amount applied in 3 doses at 10-15 day intervals during the first two months of crop growth should give better results than a single large application.

One farm was using ammonium nitrate on vegetables. 5-15 grms were applied to each plant by placement. The result of this treatment on water melons was a good growth of the leaf but only two marketable melons were obtained per plant.

The effect of organic manure + sulphate of ammonia and sulphate of ammonia only on water melons was clearly demonstrated at Masyad. The crop that had only sulphate of ammonia treatment was stunted and considerably behind that having both organic manure and sulphate of ammonia. On the plots having both manure and fertilizer, each plant was producing an average of 4 marketable melons of good quality whilst on the fertilizer only plot the plants had yet to bear any melons (late July) and it appeared that yields were going to be considerably reduced.

Insects. Irrigation in summer produces high humidities in the immediate vicinity of the crops and renders them susceptible to insect attack. Aphis tenuis not only attacks vegetables but also lucerne, though this can be controlled by spraying twice a day with Malathion. Attacks are, however, likely to recurr at fortnightly intervals. Summer crops of water melon are particularly susceptible to attack by the red spider mite especially where large areas are being cultivated. This pest can be controlled by Kilthain.

Whilst pest control is carried out by the Department of Agriculture, some farmers still prefer to carry out their own forms of control and pesticides such as Dieldrin, Agrocide and Submar (Indian) are not unknown.

Chapter 5

SOIL FORMATION

Soils are the result of the complex interaction of a number of factors - climate, parent material, vegetation and other biotic factors, topography, time, and man. In this study the effect of man, as exhibited by agriculture, is dealt with in more detail in Chapter 6. The major influence on pedogenesis in the Trucial States is the character of the parent material, since aridity limits vegetative growth whilst topographic variations on the Gravel Plains are slight and have only minimal effect on contemporary pedogenesis. On the other hand, the influence of past climatic change is clearly visible on both soil characteristics (Stevens, 1969) and on topography (Sir A. Gibb and Partners, 1969).

Climate. Climatic data are lacking at Al Ain, except for rainfall records since October 1965. These are shown in table 4 and it is clear that precipitation mainly occurs during the winter months, though small amounts occur during the summer.

More comprehensive data are available from Tawi Mileiha, where the Trucial States Development

Table 4. Rainfall at Jahili Fort. (figs. 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	

Council installed a meteorological station during summer 1967. These figures (table 5), though only of short term, provide some idea of the climatic characteristics at an inland locality in the Trucial States. Tawi Mileiha is located in a similar topographic location at the northern extremity of Jebel Faiya, about 100 kms due north of Al Ain. Differences between the two localities would appear to be

(1) Tawi Mileiha receives more rainfall than Al Ain

(2) Because of its more continental position, Al Ain is likely to experience greater temperature extremes than Tawi Mileiha.

The climatic data, although they cover only a very short period of time, illustrate a number of factors relevant to pedogenesis.

Table 5. Meteorological Data, Tawi Mileiha.

	Temperatures Mean Max (% C.)	Temperatures Mean Min (% C.)	Relative Humidity (Mean %)	Daily Wind Movement Mean (kms)	Pan Evaporation Daily Average (mms)	Rainfall mms.
			1967			
July	43.0	27.5	50	135.2	15.3	12.9
August	43.7	26.9	78	111.6	14.4	nil
September	42.0	23.7	76	114.4	12.5	21.1
October	38.2	18.8	72	95.0	11.6	nil
November	34.5	16.5	70	91.6	6.9	nil
December	24.9	10.2	72	87.3	4.5	15.5
			1968			
January	24.0	10.9	82	85.6	4.4	4.3
February	22.2	11.6	83	96.2	4.7	53.2*
March	30.3	14.6	76	98.8	8.7	nil
April	34.2	16.1	90	115.3	11.7	13.7
May	39.0	20.1	47	125.2	16.8	nil
June	42.6	22.4	42	123.2	20.8	nil
July	45.4	24.8	50	112.9	18.3	2.3
August	43.9	25.3	52	113.1	17.8	1.0
September	42.1	22.6	57	91.5	12.1	nil
October	37.8	17.5	58	87.1	11.1	nil
November	32.6	13.9	60	66.9	7.6	nil
December	27.9	13.1	67	69.8	5.6	29.7
			1969			
January	24.3	8.6	76	85.7	6.2	150.5
February	22.8	5.2	76	47.9	5.6	nil
March	34.5	9.6	60	115.1	10.2	nil
April	36.1	13.3	59	137.1	12.3	nil
May	41.1	16.1	76	142.5	15.6	nil

* Meteorological station was flooded out during February 1968. Rainfall and pan evaporation figures are less than actually occurred.

(1) High temperatures and scanty rainfall result in sparse vegetation. As a result, soil organic matter is low, though well humified.

(2) Lack of moisture and an extreme soil climate mean that chemical weathering and soil formation are very slow

(3) Percolation through the soil is limited by high evaporation rates. In no month, during the observation period at Tawi Mileiha, did precipitation exceed pan evaporation. After rainfall, the soil may be wetted to considerable depths and there may be some retention of soil moisture. For instance, rainfall at Al Ain on July 7th 1969 amounted to 6 mms and the soil was moistened to a depth of 20 cms. Three weeks later, the soil was still slightly moist between 13 and 18 cms.depth.

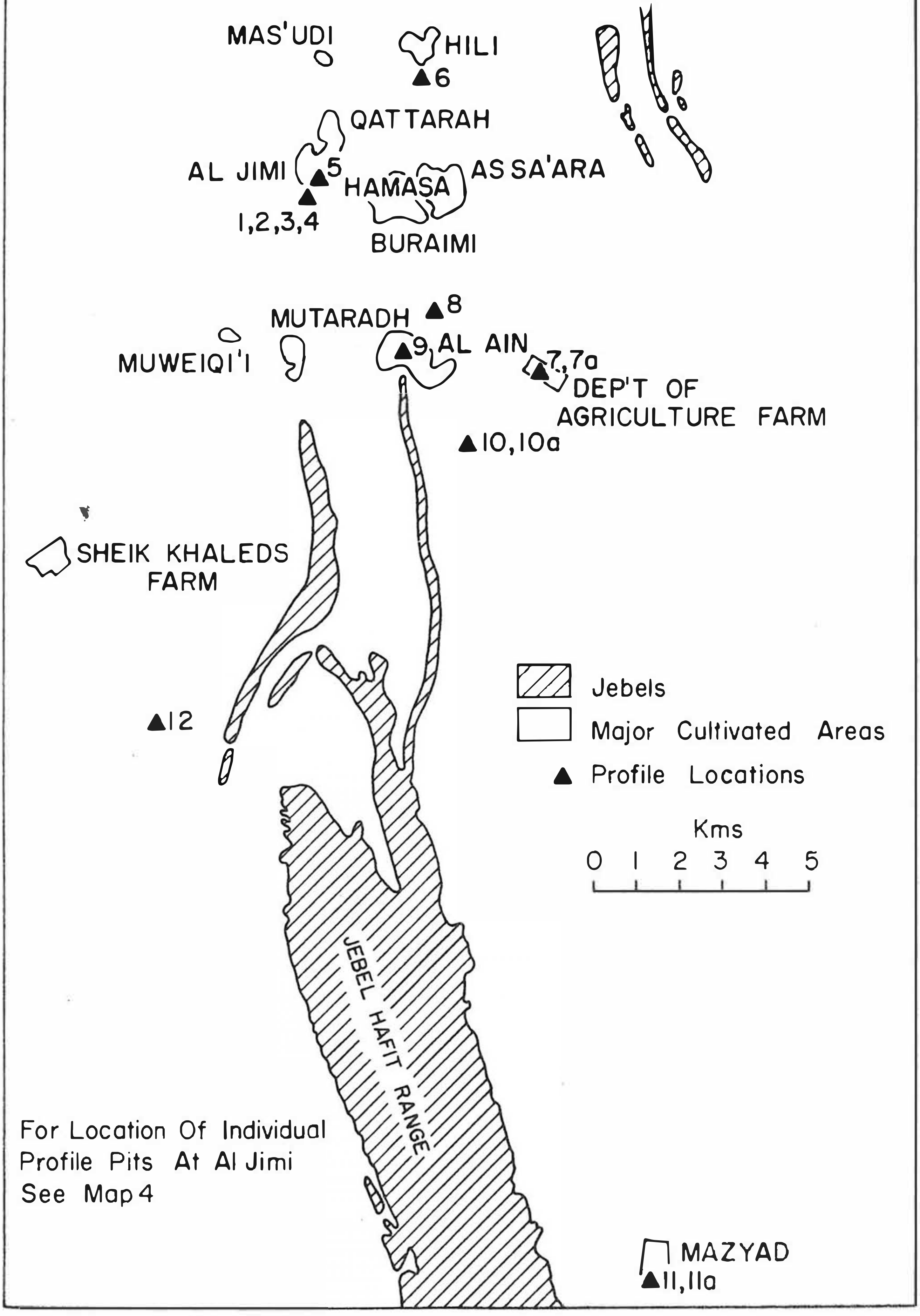
(4) Limited percolation results in some salts becoming soluble, with the resultant redistribution of carbonates and gypsum, whilst some transport of clay may also take place. In the Al Ain area, calxic, salic and gypsic horizons are more likely to be relic features from past climates, rather than the result of contemporary pedogenesis.

(5) Sand and dust storms are frequent and these affect the surface soil horizon by both deflation and deposition. Where the former occurs, the surface is likely to be covered by gravel having desert varnish.

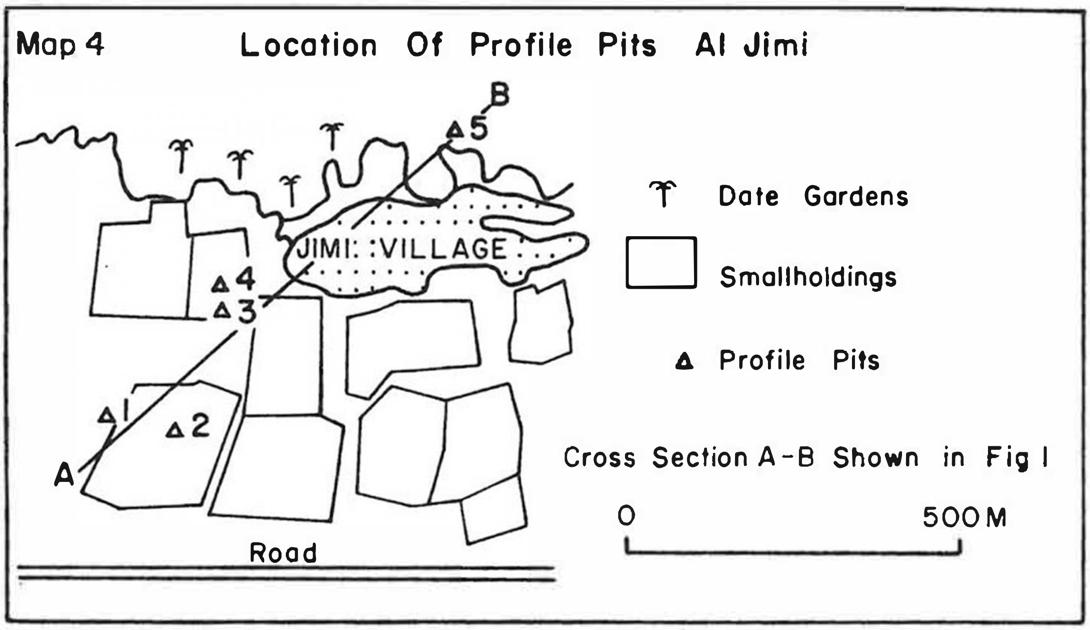
(6) The short sharp storms give rise to surface wash which also affects the surface horizons.

Parent Material. The parent material of the soils of the Al Ain area is characterised by its high calcareous content, a reflection of its origin in the Oman Hills and Jebel Hafit. The former, to the east of Al Ain,

LOCATION OF PROFILE PITS Map 3



For Location Of Individual Profile Pits At Al Jimi See Map 4


Map 4 Location Of Profile Pits At Jimi
B
5
4
3
1
2
A
JIMI VILLAGE
Date Gardens
Smallholdings
Profile Pits
Cross Section A-B Shown in Fig I
0
500M
Road

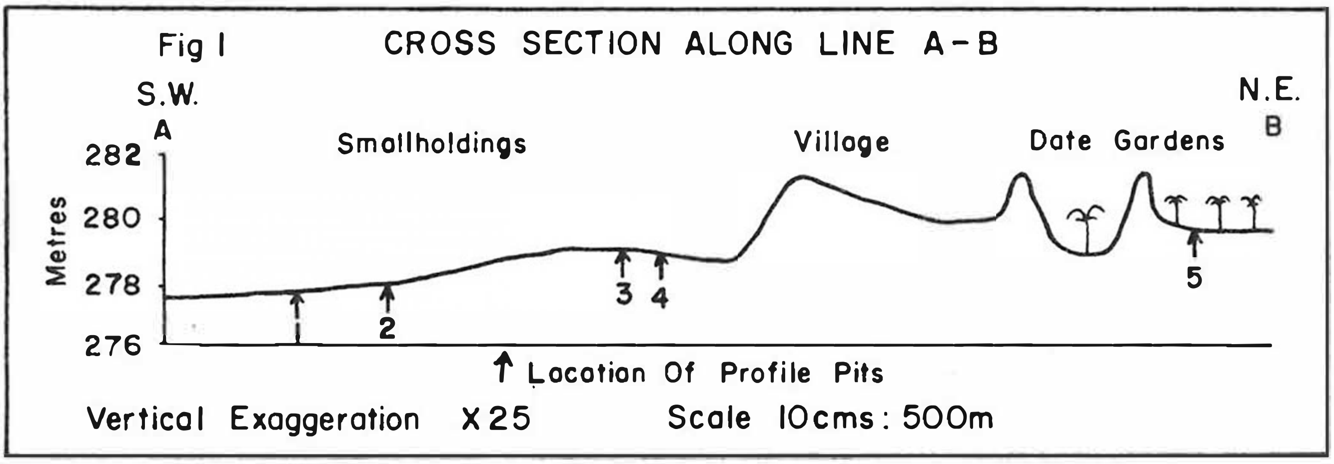


Fig I CROSS SECTION ALONG LINE A-B
S.W.
A
N.E.
B
Smallholdings
Village
Date Gardens
282
280
278
276
Metres
1
2
3 4
5
Location Of Profile Pits
Vertical Exaggeration X25
Scale 10cms: 500m

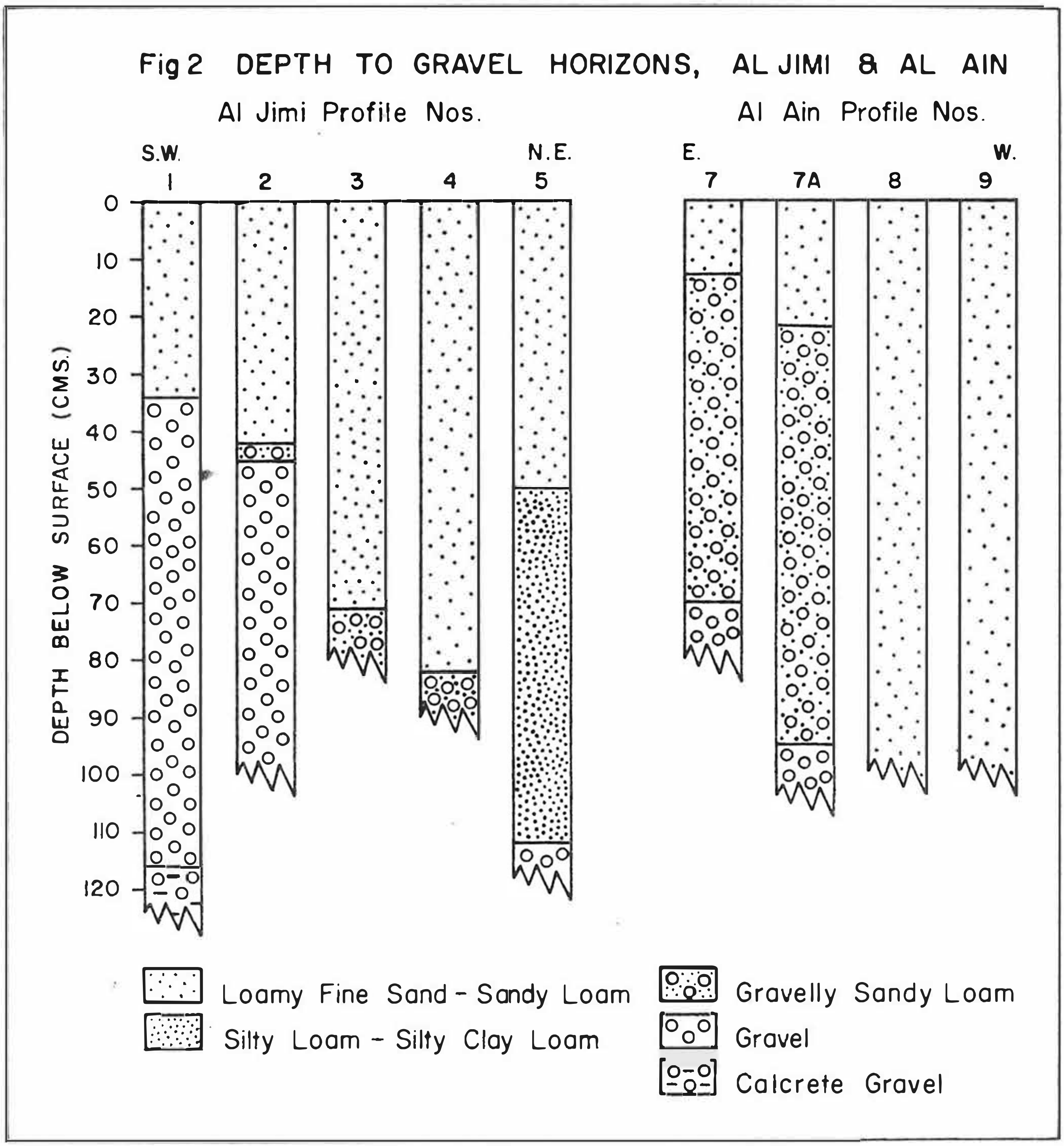


Fig 2 DEPTH TO GRAVEL HORIZONS, AL JIMI & AL AIN
Al Jimi Profile Nos.
Al Ain Profile Nos.
S.W.
N.E.
E.
W.
1
2
3
4
5
7
7A
8
9
DEPTH BELOW SURFACE (CMS.)
0
10
20
30
40
50
60
70
80
90
100
110
120
Loamy Fine Sand - Sandy Loam
Silty Loam - Silty Clay Loam
Gravelly Sandy Loam
Gravel
Calcrete Gravel

consist of a serpentinite core capped by Upper Cretaceous and Tertiary limestones, whilst Jebel Hafit is an anticline of Tertiary limestones and marls.

Erosion of the Oman Hills has resulted in the deposition of coarse rudaceous deposits as a gently sloping piedmont plain. Westward, away from the hills, gravel size diminishes and, in the Al Ain district, fine sands and silts have been deposited in what is regarded as a restricted natural basin area (Sir A. Gibb and Partners, 1969). This finer material overlies the gravel and is shown diagrammatically in fig. 2. At Al Ain, the depth to gravel increases westwards, from 70 cms on the Department of Agriculture Farm to well over 1 metre at Sheikh Khalifa's farm (profile 8). In contrast, in the north of the basin at Al Jimi, the depth to gravel increases in a north-easterly direction - in profile 1 the gravel horizon is within 32 cms of the surface whilst at profile 5, within the data gardens, it is present at a depth of 112 cms. A profile at Hili (profile 6) shows it to be at 284 cms.

The calcareous content of the parent material is by no means uniform, both within the area and within individual profiles. The gravel is mainly derived from the Oman Hills and is composed of a high percentage of serpentinite. Consequently the calcareous content is less than 35%, unless the gravels have been cemented by calcium carbonate, as in profile 1, where figures in excess of 40% carbonate are obtained. In the northern part of the area, the carbonate content of the overlying fines is considerably lower (33.5% - 42.5%) than sites that have a higher component of outwash material from Jebel Hafit where the marls tend to weather to the finer fractions. Profiles, 9, 10 and 10a are representative of sites affected by outwash from Jebel Hafit and carbonate figures vary from 43.5% to over 55%.

Vegetation. Owing to the aridity, vegetation is very sparse over the Al Jaww Plain. The gravels, of which the plain is composed, have a very low water holding capacity and it is only on the western parts of the plain that Acacia sp occur. Two reasons cause this concentration. Firstly, Jebel Hafit acts as a barrier to subsurface water flow and it may be possible that groundwater is slightly nearer the surface than further east on the plain. Secondly, the western parts of the Al Jaww Plain are covered by increasingly thicker deposits of fine sands and silts which are more retentive of moisture. Thick stands of Acacia sp also occur to the north west of Mas'udi and Hili.

Scattered trees of Prosopis spicigera are also to be found but their rarity may be the result of a long history of cutting for firewood and fencing.

Ground vegetation is very sparse and, on the plain, mainly consists of chenopods such as Salsola sp. In the oasis area, scattered clumps of Haloxylon salicornicum are present, which act as traps for aeolian material and consequently are to be found growing on small hummocks.

Topography. The oasis area is situated on the western extremity of a gently sloping piedmont plain with an active dune area immediately to the west. Dunes have encroached into the oasis area, and small active dunes separate the northern group of oases (Mas'udi, Hili, Al Jimi and Qattarah) from the southern group. Vegetation has acted as a stabiliser to aeolian movement and immediately south of Al Ain/Daudi oasis, the stands of Acacia have encouraged the formation of small dunes.

Contemporary wadi activity has also affected topography. Wadi Al Ain is confined between the southern group of date gardens and the northern spur of Jebel Hafit, incising quite a deep channel for itself. The wadi sides are steep and gullied, and on its southern side, there appears to have been some recent extension of the gullies. Between the northern and southern group of oases, as well as the dune belt previously mentioned, the shallow wadi that flows from Hamasa has deposited extensive areas of sterile gravel.

Time. On account of the arid or semi-arid conditions that have prevailed over the Trucial States since the termination of the last pluvial period, soil development has been severely restricted. Many of the features found in the soils are relic features, dating from previous climatic periods, which the contemporary climatic conditions have been unable to alter. The soils of the Trucial States thus reflect stages in pedogenesis, rather

rather than continuous soil formation since the deposition of parent material. In a recent paper (Stevens, 1969), the author has attempted to reconstruct the effect of Quaternary events on soil formation and postulates the following sequence

(1) Deposition of outwash alluvial fans from the erosion of the Oman Hills

(2) Evaporation at, or near, the surface of a high water table resulting in the formation of gypsum crusts. Examples of these are to be found on the Gharif Plain in the vicinity of Tawi Mileiha.

(3) Erosion of the fans. Remnants of the original outwash alluvial fans are to be found on the Al Jaww Plain to the east of Masyad.

(4) A period of aeolian activity with partial infilling of the erosion gullies in the old fans.

(5) A further period of limited erosion and further infilling of the gullies by material derived from the surfaces of the remnants of the fans. It may be that the fine material overlying the gravels in the Al Ain area was deposited during this period.

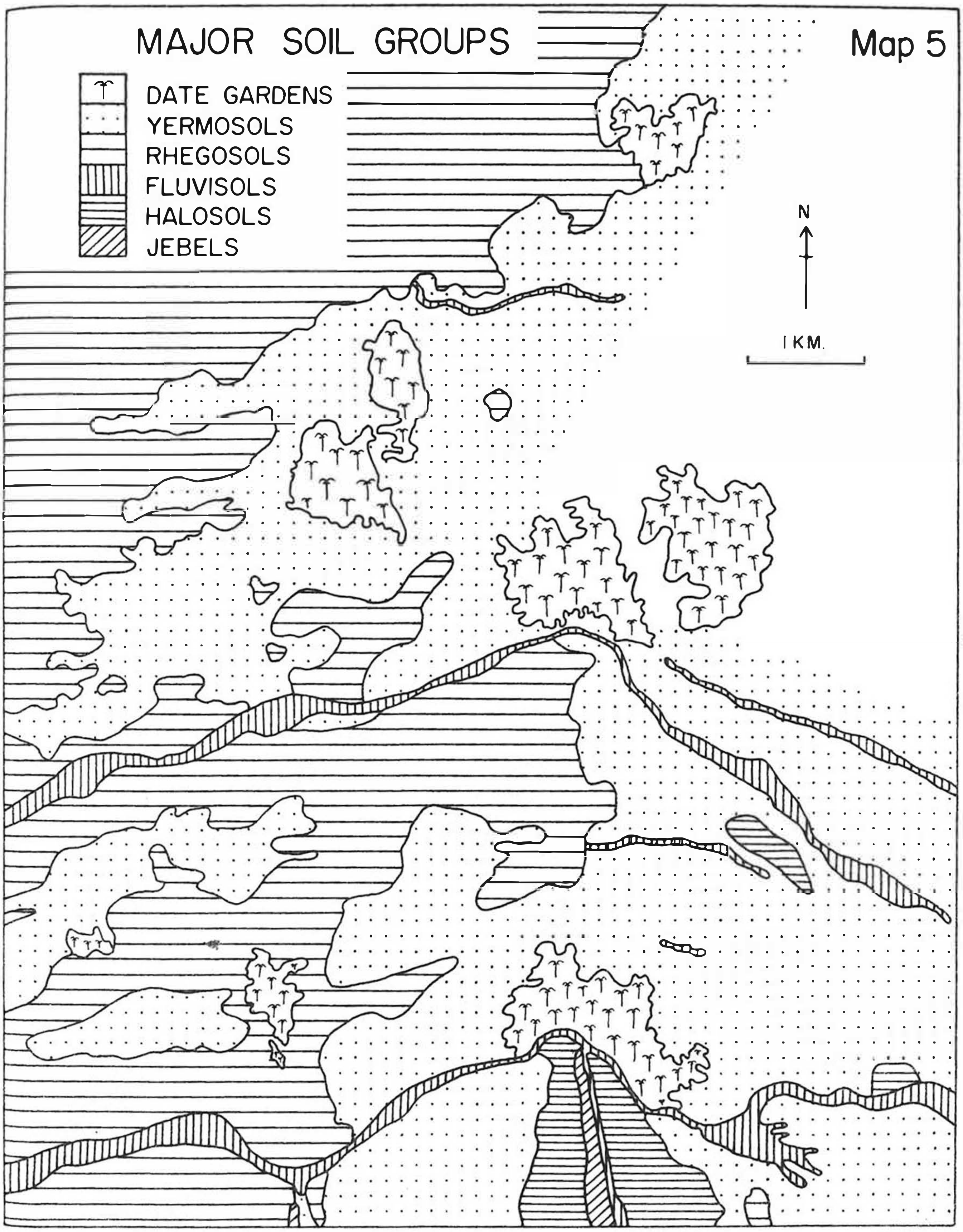
(6) Aeolian activity with limited sheet flow.

Soil Classification. The major soil type occurring in the Al Ain district is the Yermosol (F.A.O. 1968) and its distribution is shown in Map 5. A major characteristic of this soil is that it possesses weakly developed pallid A horizon. This is an A horizon in which the weighted average organic matter content in the surface 40 cms is less than 1% (0.58% organic carbon) if the weighted average sand:clay ratio is 1 or less, or 0.28% organic matter (0.16% organic carbon) if the ratio is 13 or more. Alternatively, the colour values or chroma of the top 18 cms are more than 4 when moist. Yermosols also show a conductivity of the saturation extract of 2 mmhos or more per cm at 25°C, or an increase with depth of the Na + K saturation. Calxic or gypsic horizons may also be present.

Whilst such a description is true of the uncultivated soils (for instance profile 6 at Hili), the profiles dug within the cultivated area show organic matter figures considerably in excess of the above limits. Cultivation has altered these Yermosols into what should be strictly described as Xerosols.

On some of the heavier textured parent materials, Halosols have developed. These are soils which have high concentrations of soluble salts and the amount of exchangeable sodium may also be high. Such soils have a very limited distribution in the immediate vicinity of Al Ain.

Areas of both Fluvisols and Rhegosols are to be found in the vicinity of the oases. The former are soils that have developed on alluvial material but show very limited pedogenic development. These soils are confined to areas affected by contemporary wadis and hence are mainly composed of coarse sterile gravels. Rhegosols are also soils that have weak or no pedogenic development being found on the aeolian sands.



MAJOR SOIL GROUPS
Map 5
DATE GARDENS
YERMOSOLS
RHEGOSOLS
FLUVISOLS
HALOSOLS
JEBELS
N
1 KM.

Chapter 6

THE EFFECT OF CULTIVATION ON SOIL CHARACTERISTICS

In contrast to the soil survey carried out for the Water Resources Survey (Sir A. Gibb and Partners, 1969), the current study was confined to the cultivated areas and was designed as an investigation into the effects of different agricultural practices on soil formation and characteristics. Virgin soils were examined within the Al Ain area to provide references from which conclusions could be drawn concerning the effects of agriculture on soil development. However, care must be exercised in distinguishing anthropogenic changes from those due to variations, over very short distances, which are the result of the mode of deposition of the parent material. The locations of profile sites are shown on Maps 3 and 4.

PROFILE SITE CHARACTERISTICS

The Northern Oases. The locations of profiles 1-5 are shown on Map 4 and on fig. 1.

(1) Profile 1. An uncultivated profile located outside a smallholding. The natural vegetation consisted of scattered bushes of Haloxylon salicornicum.

(2) Profile 2. This profile was located in the smallholding, adjacent to profile 1, which concentrates on vegetable production. The site was in a fallow plot which had been used to grow cabbages during the early months of 1969. Manurial treatment for this crop included applications of sulphate of ammonia at a rate of 33 kgs/dunum and organic manure at 0.75 metric tons/dunum. Irrigation took place at weekly intervals during the winter.

(3) Profiles 3 and 4 were located in a 16 year old holding. Profile 3 was sited in a crop of lucerne, 6 years old, in which young citrus were planted four years ago. The citrus trees were spaced approximately 4-5 metres apart. Superphosphate had only been applied since 1968 at a rate of 55 kgs/dunum, whilst irrigation took place every three days in summer and weekly in winter.

Profile 4 was located in the part of the garden that had been growing dates since its development 16 years ago. Most of the area devoted to date palms also grew an undercrop of lubia, though at the profile site only the remnants of such a crop were visible.

(4) Profile 5 was located amongst the old established date gardens at Al Jimi. These gardens are surrounded by high mounds (up to 5 m.) of silts and fine sands (fig. 1). Some of these mounds may be the remnants of an old eroded surface (Sir A. Gibb and Partners, 1969) whilst others may be the result of levelling the land in the past. The date gardens are irrigated at three weekly intervals in summer and every 12 days in winter. No mineral fertilizers are applied, though the owner uses 240 kgs. of organic manure per basin annually. These basins are about 150 sq. metres in size and have been so arranged that the existing date palms grow on the bunds separating the plots. Lubia is the most common crop, though no crop had been cultivated recently in the basin where profile 5 was sampled.

(5) Profile 6 was located south east of Hili in an area where considerable agricultural development is taking place. A well being dug for a new smallholding provided an opportunity to take deep samples (2.6 metres below surface) as well as exhibiting soil characteristics in an area where irrigation water is saline. Scattered trees (Acacia arabica) are present in the locality.

The Southern Oases.

(1) Profile 7. Department of Agriculture farm. The profile was located in a plot that had been prepared for a late crop of water melons.

(2) Profile 8. The site of this profile was on the interfluve between Wadi Al Ain and the small wadi north of Al Ain village. Lucerne had been grown on the site of the profile for the previous seven years (since the establishment of the farm) but had been ploughed in shortly before this study took place.

(3) Profile 9 was located in the middle of Al Ain date gardens. This date garden had been partly cleared and was growing crops of lucerne and lubia. Evidence of burning was visible both on the ground and in the soil profile which was sited amongst the lubia crop. No mineral fertilizers had been applied, but organic manure, at a rate of 1 metric ton/dunum, had been spread over the plot. Watering of fodder crops took place at three day intervals in summer and weekly during the winter, since the owner possessed a pump to supplement falaj supplies.

(4) Profiles 10a and 10b are representative of the soils on which the new smallholdings are being established to the south of Al Ain. The two profiles were sampled within four metres of each other - one was on virgin land though in close proximity to a tree (Acacia arabica), whilst the other profile sampled was immediately adjacent to an irrigation channel that had been used continuously since the establishment of the smallholding, a year previously. Both irrigation water (E.C. of about 5 mmhos/cm at 25°C.) and soils are saline in this area, whilst the latter, in addition, tend to have heavy textured subsurface horizons.

Masyad. Two soil profiles (11a and 11b) were sampled. Both were located on water melon plots, though different manurial treatments were applied. In the first instance the plot had been treated with both sulphate of ammonia and organic manure, whilst the second plot had had no application of organic manure.

Ain Busukhana. One profile, which appeared to be a residual soil developed on a conglomerate of hard siliceous limestone was sampled.

SOIL PHYSICAL CHARACTERISTICS

Agricultural development has mainly taken place on soils classified as Yermosols (Map 5). These soils have better inherent physical characteristics than the Rhegosols or Fluvisols, whilst agriculture is less hazardous than on the Halosols. Both Rhegosols and Fluviosols have extremely weak structural development (very often this is single grain) whilst textures are very coarse. Rhegosols are, however, being used for forestry at Al Ain. In contrast, the Yermosols have a variable proportion of "fines" (the silt + clay fraction) whilst weak medium and large subangular blocky structure predominates in the surface horizons.

Texture. The soils of the Al Ain district are characterised by the variability in texture of their parent material. Some surface horizons have a coarse gravel texture (Fluviosols), whilst others have a silty clay loam texture, though most of the surface horizons of the Yermosols are of sandy loam or loamy sand texture. The soils generally have a high percolation capacity, though at lower levels in the profile, horizons of caliche (calcium carbonate cementation) or of a heavy texture may cause some impedance. One of the problems arising from this high percolation capacity is that large quantities of water are required for irrigation purposes, and this is further accentuated if irrigation channels are unlined. For instance, at the Department of Agriculture farm, it took 5 hrs to transmit water for 450 metres along an unlined channel, pumping at a rate of $3\frac{1}{2}$ galls/second.

The textural characteristics of the surface horizons, and also at 35-45 cms depth, for the soil profiles in the sequences at Al Jimi and Al Ain are shown in table 6. A feature is the increase in the 0.05 - 0.02 mm fraction in the surface horizons, and to a lesser extent in the subsurface horizons, of profiles 5 and 9. Both of these profiles are located in the old established date gardens and it seems likely that the sites of these were chosen so as to take advantage of better soils where the slightly heavier texture aids moisture retention. However, irrigation over many centuries will produce a very different soil climate under the date palms to that experienced by the uncultivated soils. Greater moisture in the date gardens will increase both physical and chemical weathering and consequently some of this increase in the 0.05 -0.02 mm fraction may be attributed to the weathering of part of the coarser fraction induced by the anthropogenic factor.

Structure. Uncultivated Yermosols are characterised by weak structural development, but the effects of agriculture can be noticeable after even relatively short periods. Of the crops grown, lucerne appears to be the most beneficial in aiding structure formation. Profile 8 clearly exhibited the effect of seven years of lucerne - the top 24 cms possessed a moderate/well developed small and medium angular blocky structure whilst adjacent soils, which had not been cultivated with lucerne, exhibited single grain structure or, at best, weakly developed medium angular blocky structure.

Uncultivated soils are generally low in both organic and inorganic colloids. The soils that have been cultivated for long periods of time (the date gardens) have higher organic matter contents (. 3%) than other

Table 6. Soil Textural Characteristics

AL JIMI

	Profile 2				Profile 3				Profile 4				Profile 5			
	S	CSi	Si	C	S	CSi	Si	C	S	CSi	Si	C	S	CSi	Si	C
0 - 10 cms	74.1	13.9	6.5	5.5	78.0	9.5	7.2	5.3	74.6	7.6	12.9	4.9	55.2	22.1	12.0	10.7
35 - 45 cms	66.7	11.2	18.2	4.9	80.1	7.1	4.7	8.1	74.9	12.0	7.0	6.1	72.4	14.7	5.5	7.4

AL AIN

	Profile 7				Profile 8				Profile 9			
	S	CSi	Si	C	S	CSi	Si	C	S	CSi	Si	C
0 - 10 cms	70.0	9.8	11.4	8.8	72.9	12.7	1.8	12.6	54.4	28.9	4.3	12.4
35 - 45 cms	71.4	8.9	13.6	6.1	N.D.				62.1	17.4	9.6	10.9

S	- Sand	2.0 - 0.05 mms
CSi	- Coarse silt	0.05 - 0.02 mms
Si	- Silt	0.02 - 0.002 mms
C	- Clay	< 0.002 mms.

soils and also exhibit moderate medium angular blocks. Stability of the structures in the date gardens is much greater than, for example, the example quoted for profile 8, though the structural stability of this soil is greater than in the uncultivated soil.

One of the problems associated with soils that are inherently low in colloids is that structure is extremely difficult to maintain. The problem is accentuated if little or no organic matter is added to the soil, whilst weakly developed structures are likely to break down under incorrect management.

SOIL CHEMICAL CHARACTERISTICS

Calcium carbonate content and soil pH values. As has been seen, the soils of the Al Ain district have high calcium carbonate contents (25 - 55 %) and, with the exception of profile 12, which was located away from the oases area, pH values for a soil saturation paste are between 8.0 and 9.0. Calcium carbonate accumulations are to be found at depth in most profiles, generally occurring as 'beads' on the gravel - only rarely were discrete secondary calcium carbonate accumulations visible in the upper horizons of profiles. However, in the uncultivated profile at Hili (profile 6), there were abundant light grey silt accumulations, about 2 cms in diameter, which were weakly cemented by calcium carbonate and which probably owed their origin to the erosion of an old higher surface. Caliche horizons occur at depth in some localities e.g. profile 1.

Conductivities. Within the cultivated areas, conductivities of saturated soil pastes are sufficiently low so as not to restrict agriculture. The highest conductivities recorded in surface samples were for uncultivated soils (pits 6 and 10), whilst the application of sufficient irrigation water removes soluble salts (table 7). Profiles 10 and 10a are located in the area mapped as Halosols where the irrigation water is also saline (conductivity of about 5.0 mmhos). The surface 45 cms are very permeable and, even though permeability

Table 7. Soil Conductivities (expressed in mmhos/cm at 25°C.)

Depth	Profile 10 (unirrigated)		Profile 10a (irrigated)	
	Conductivity	E.S.P.	Conductivity	E.S.P.
5 - 10cms	2.94	32.2	1.75	23.4
22 - 27cms	0.20	18.2	0.35	12.3
48 - 53cms	9.05	12.8	2.44	22.4
97 - 102cms	15.45	35.7	5.40	20.2

is reduced below this depth, the application of sufficient irrigation water has washed many of the soluble salts out of the rooting depth. The irrigation of such soils as profile 6 at Hili will also wash out the soluble salts, and cultivation should not be seriously impaired.

Cation Exchange Capacity (C.E.C.) The cation exchange capacities of the soil samples vary between 6.9 and 28.8 m.e./100 grms soil. The highest values are recorded for samples having the heaviest texture, though soils having a high organic matter content also tend to possess high C.E.Cs. whilst the sandy soils have low cation exchange capacities.

The dominant exchangeable cations are Ca^{++} and Mg^{++}. Whilst the amount of exchangeable magnesium remains fairly constant, between 4.0 and 5.5 m.e./100 grms soil, the amount of exchangeable calcium is very variable (< 2.0 m.e./100 grms to over 15 m.e./100 grms). Exchangeable sodium makes up less than 20% of the exchangeable cations in the topsoil samples except in the area south of Al Ain, east of Jebel Hafit, where up to 35% of the exchange complex is composed of sodium cations. The uncultivated profile at Hili also has a high proportion of exchangeable sodium (27.7%) but from table 7 it would appear that undesirable exchangeable sodium percentages can be reduced by leaching. Exchangeable potassium remains uniformly low and only rarely exceeds 1 m.e./100 grms soil. Where figures in excess of 1 m.e./

Table 8. Organic Matter data for representative profiles (C and N are expressed as %).

Depth (cms)	Profile 2 Vegetables			Profile 3 4 yr. old citrus and lucerne			Profile 4 16 yr. old dates			Profile 5 Old date garden			Profile 6 Uncultivated			Profile 8 7 yr. old lucerne		
	C	N	C:N	C	N	C:N	C	N	C:N	C	N	C:N	C	N	C:N	C	N	C:N
5-10	1.32	0.04	33.0	0.58	0.03	19.3	1.03	0.04	25.7	1.77	0.04	44.2	0.57	0.03	19.0	1.18	0.04	29.5
15-20										1.04	0.04	26.0						
25-30	1.23	0.05	24.7															
30-35																0.55	0.04	13.7
35-40	0.61	0.04	15.2															
38-43				0.57	0.04	14.2	0.97	0.02	48.5				0.55	0.03	18.3			
40-45										0.83	0.05	16.6						
50-55	0.62	0.04	15.5													0.78	0.05	15.6
55-60										0.78	0.04	19.5						
63-68				0.66	0.04	16.5												
68-73													0.58	0.03	19.3			
75-80							0.82	0.02	41.0	1.21	0.04	30.2						
95-100	0.61	0.04	15.2	0.51	0.03	17.0										0.51	0.04	12.7

100 grms soil are recorded there is a high content of the fine fractions.

Organic Matter. Man has, through agricultural practices, greatly added to the organic matter content of the soil. Natural soils in the Al Ain district have low organic matter contents which tend to be evenly dispersed throughout the profile (for example, profile 6, table 8). The cultivation of different crops has added varying quantities of organic matter to the soil. By far the highest contents of organic carbon in the soil are to be found in the old established date gardens. In the surface horizons, the organic carbon content exceeds 1.75% (3% organic matter) whilst subsurface samples show varying accumulations due to the root systems of the date palms. In contrast, the young citrus plantation has organic carbon contents very similar to the uncultivated soil. Both the vegetable and the lucerne plots show accumulation of organic carbon within the rooting depths of the crops, but below the rooting depth, there is no build up.

One of the features of these soils is that the nitrogen values are very low and that there is very little difference between cultivated and uncultivated soils. C:N ratios are wide, particularly in the topsoils of cultivated soils, though with the exception of soils under date palms, the ratio narrows to 12-15 at depth. The old established date gardens appear to have slightly higher nitrogen contents than the profiles under other crops - in addition to the profiles quoted in fig. 8, the profile sampled in Al Ain date gardens had the following organic carbon and nitrogen contents:-

5-10 cms	2.14% organic carbon	0.06% nitrogen
38-43 cms	1.98%	0.04%
75-80 cms	1.22%	0.04%

Vegetable and fruit crops respond to nitrogen, and sulphate of ammonia is commonly applied. However, from these preliminary investigations, it would appear that the growing of lucerne results in little appreciable difference to the nitrogen content of the soil.

Potassium. Whilst exchangeable potassium in the cation exchange capacity is low, the amount of available potassium in the soil is fairly high. Available potassium values range from 8 mgs/100 grms soil to over 260 mgs/100 grms. In the Al Jimi district the available potassium values appear to increase with depth down the profile but elsewhere no clear pattern emerges, though there is a general link with the soil textural characteristics. Where textures are heavy (i.e. where there is a high proportion of fine material), available potassium values are generally high whilst lower values occur where coarse textures prevail.

Phosphate. Total phosphate values range from 14-48 mgs/100 grms soil but the amount that is in an available form to plants is extremely low. In no instance does the amount of available phosphate exceed 0.4 mgs/100 grms soil whilst generally it is less than 0.2 mgs/100 grms soil. This lack of phosphate solubility results from the high proportion of complex calcium compounds, and unless superphosphate is applied to crops such as lucerne, yields are considerably affected.

PART III CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The April 1968 census revealed a population of 21,000 for Abu Dhabi island and 13,000 for Al Ain district. Since then, the dual carriageway tarmac road linking Al Ain and Abu Dhabi island has been completed and some crops which are produced in surplus at Al Ain are also marked at Abu Dhabi. Sir A. Gibb and Partners have projected a population of 25,000-30,000 in the Al Ain district by 1975 (partly resulting from the development of Zaid new town) and of 60,000-70,000 on Abu Dhabi island. Market prospects brought about by the increased population would thus justify the expansion of indigenous agriculture since, even now, most of fruits and vegetables consumed in Abu Dhabi are imported.

Expansion of the cultivated area is dependent upon the availability of areas of good soil allied with an adequate supply of suitable irrigation water. Sir A. Gibb and Partners (1969) estimate that 6,500 hectares of land around Al Ain warrant further investigation for agricultural development. While there is likely to be little competition for land, the rapid increase in population will produce severe competition for water and the Water Resources Survey are not optimistic over water prospects in the Al Ain district.

Whilst the development of commercial agriculture has been a comparatively recent phenomenon, little deterioration has been caused to the soils by the more traditional methods of agriculture. Many of the commercial smallholdings should be capable of considerable increases in yields with correct management techniques. Some increase in yields, for instance, should be immediately noticeable from the recently introduced policy of fertilizer distribution by the Department of Agriculture, since a number of farmers have never applied mineral fertilizers. In the final analysis, however, the total agricultural output from the Al Ain district is going to be restricted by the availability of water for irrigation purposes

The recommendations, therefore, fall into two categories. There are those which will, in themselves, lead to increased productivity from the existing cultivated areas and, secondly, there are recommendations which will lead to a more rational use of water and thus allow further lands to be brought into cultivation.

"A rational system of agriculture cannot be formed without the application of scientific principles, for such a system must be based on the exact acquaintance with the means of nutrition of vegetables, and with the influence of soils and the action of manure upon them" (Justus von Liebig in the nineteenth century). In the short period of its existence, the Department of Agriculture has gone a long way towards collecting basic information as well as establishing such facilities as pest control and extension services. The role of the latter cannot be overemphasised for the attitude of the individual is of paramount importance in the successful introduction of new techniques, and it is the job of the Extension Officer not only to advise on new methods but also to ensure that any new developments are seen by the farmers to be beneficial; crop demonstrations are particularly important in putting ideas over.

RECOMMENDATIONS

These recommendations are based upon field investigations concerned with the management of the physical resource base, whilst the socio-economic systems involved were not specifically studied in detail. Their justification lies in the critical and over-riding importance of certain aspects of the physical environment of Al Ain. In the formulation of these recommendations, however, experience of analogous socio-economic situations and local observation of the situation at Al Ain has been utilised.

Date Gardens These are the traditional units of cultivation and many of the problems result from the age and condition of the palm trees, their close spacing, and the lack, or limited nature, of manurial and fertilizer treatment.

1. A policy of clearance of old, diseased and unproductive trees should be instituted, whilst replacements should be planted at greater distances apart (10 metres or more). Replacement palms should be of high yielding varieties. It might also be advantageous to introduce citrus and other fruit trees into the date gardens to increase the owner's income.

• 2. With greater spacing between the date palms, an increased use could be made of the gardens for the growing of ground crops. Lubia and lucerne (already grown in some gardens) as well as some vegetables, provided that there was sufficient distance between the palms, would be suitable.

3. Irrigation is mainly by falaj and is based on communal rights; it would not be advantageous to alter the latter. Some economies in water utilisation could be made:-

(a) Lining of main distribution channels within the date gardens. This has already been carried out in some gardens, but the practice should be extended.

(b) Irrigation water is currently applied by flooding and there is considerable loss of water. Economies could be made by channelling the water direct to the date palms whilst only basins that are being actually cropped need to be irrigated by flood methods.

4. Fertilizer applications. Farmers outside the date gardens who specialise in perennial tree crops apply fertilizers by placement but experimentation will be necessary to determine the value of such applications.

Commercial smallholdings

A. Citrus. Many of the citrus trees, particularly the young trees, are exhibiting a yellowing of the leaves which may result from a lime induced chlorosis causing iron deficiencies. Such chlorosis is increased in severity by excess moisture and by high or low soil temperatures (Bear, 1965). Experiments should be carried out to determine optimum irrigation rates and intervals, particularly for young trees. Experimentation should also be carried out into the varieties grown and into correct fertilizer applications.

B. Lucerne and other fodder crops.

1. One of the major factors affecting lucerne yields is the method of harvesting the crop. The general practice is to cut off the aerial portions so close to the soil as to damage the crown. The remedy is to cut at least 3 cms from the ground.

2. Improved lucerne and fodded crop yields can be obtained by better fertilizer techniques. These include

(a) Experimentation as to the optimum amounts of superphosphate to be applied. The distribution of superphosphate at a rate of 25 kgs/dunum will certainly improve the yields of some farmers but the data, presented in table 2, would suggest that the optimum level might be in excess of 30 kgs/dunum.

(b) Time of application is important. Many farmers do not apply fertilizer until after the crop has started to grow and it is also applied in bulk. Heavy applications are also given in the summer which results in a heavy demand for water. Since the available phosphate is rapidly fixed in these high lime content soils,light applications at fairly frequent intervals would appear desirable, particularly during the early period of growth.

(c) The application of organic manure is to be encouraged. Not only does it release nutrients in an available form for the crops, but it also aids moisture retention. Currently organic manure is applied only to the surface of plots and subsequent irrigation washes it to the end of the plot furthest from the water inlet. By ploughing in organic manures the beneficial effects would be greatly enhanced whilst they would be more effective over the whole plot.

3. Irrigation.

(a) On many of the smallholdings visited, the main irrigation channels were unlined and since the majority of these units have been established on soils of light texture, permeability losses in transmission are high.

(b) Lucerne and other fodder crops are cultivated in basins. Many of these are uneven causing an irregular distribution of water. Furthermore, considerable scouring takes place in the vicinity of the inlets because the main distribution channels are at a much higher level than the basins. Both these problems can be overcome by greater care in the establishment of the irrigation schemes.

(c) Experimentation should take place into the frequency and amount of water applied. It would seem that the quantity of water applied by some smallholders is excessive.

(d) Every effort should be made to encourage evening irrigation. Irrigation during the heat of the day is an all too common practice.

4. Lucerne is allowed to grow for up to seven years in a particular plot before being ploughed in. Maximum benefit would be conferred on the soil if the crop was ploughed in at the end of the third year before the economic return is heavily reduced due to the damage caused to the crown by cutting. The introduction of vegetables for a year before replanting with lucerne would seem economically advantageous.

5. Lucerne at Al Ain does not seem to improve the nitrogen status of the soil to any appreciable degree and experiments should be carried out into the reasons for this. It may be that this is an isolated feature at the sites where the samples were obtained, the heavy rains in July 1969 may have washed much of the nitrogen out of the soil, or that denitrification is extremely rapid after the crop has been ploughed in (e.g. profile 8). Lucerne seeds may also require innoculation.

C. Vegetable crops. Many of the recommendations already made (e.g. lining of main irrigation channels, frequency of irrigation and water rates) also apply to the cultivation of vegetable crops but there are also additional features.

1. Problems of seasonal surplus must be overcome by planting early and late varieties of crops to spread the period of production. The different varieties should be tested for their performance under the physical conditions prevailing at Al Ain.

2. Fertilizer and manurial trials should be initiated to provide data concerning optimum applications for the different vegetable crops and to find the fertilizers most suited to local conditions.

3. Artificial fertilizers are not a substitute for organic manures and the trend towards the use of mineral fertilizers only should be reversed. The organic manures have considerable influence on such features as soil stability, aggregate formation and moisture retention that their use should be positively encouraged. However, it appears that a shortage of local organic manures may be developing, and to partly alleviate this problem, the ploughing in of lucerne after three years is to be encouraged.

4. Crops such as water melons are often irrigated by furrow. More use might be made of this type of irrigation whilst the planting of tree crops along main water courses will ensure a more economical use of water as well as providing windbreaks.

5. Some farms currently utilise the Department of Agriculture tractors for ploughing their smallholdings. The introduction of light garden tractors as recommended by Sir A. Gibb and Partners (1969) would be beneficial, though care must be taken to avoid accelerating the loss of the fine fraction of the soil by wind erosion.

Individual farmers are being encouraged to use all the facilities provided by the Department of Agriculture such as mechanised ploughing and crop spraying. This trend is very heartening and, as experience at Digdaga Agricultural Trials Station would suggest, the establishment of the Department Farm should stimulate further interest in agriculture and a desire for agricultural education in the area. For agricultural development to be effective, the principles must be ecologically sound, and also understood by the farmers. In a recent arid lands conference held at Tueson in June 1969 (reported by H.E. Dregne in Water and Resources), W. Thorne declared that irrigated arid lands have unique advantages where combined with mechanised, science-based farming and that these advantages have been exploited only recently. At Al Ain, the Department of Agriculture have made a commendable start in acquiring the essential data that must be the basis for scientific agriculture whilst the beneficial influence of the Department is already being felt at all levels of agricultural production. Further developments by the Department would be very rewarding.

J.H. STEVENS
Department of Geography.
University of Durham.

November 1969.

APPENDIX 1

BIBLIOGRAPHY

Bear, F.E., 1965, Chemistry of the Soil. Reinhold. New York.

Cox, P., 1925, Some Excursions in Oman. Geographical Journal. Vol. LXVI, 3 pp 193-227

F.A.O., 1960, Report of 1st Meeting Soil Fertility and Fertilizer Use in the Near East and North Africa.

F.A.O., 1968, Definitions of Soil Units for the Soil Map of the World. World Soil Resources Report 33. F.A.O./UNESCO.

Gibb, Sir A. and Partners, 1969, Water Resources Survey, Interim Report. Govt. of Abu Dhabi.

Halcrow, Sir W. and Partners, 1969, Report on the Water Resources of the Trucial States. Trucial States Council.

Lorimer, J.G. 1915, Gazetteer of the Persian Gulf, Oman and Central Arabia. Vol. I. Historical. Calcutta.

Stevens, J.H., 1969, Quaternary Events and their Effect on Soil Development in an Arid Environment - The Trucial States. Quaternaria. X pp 73-81.

Thorne, W., (reported by Dregne, H.) 1969, International Arid Lands Conference. Nature and Resources. V, 3 pp 7-12. (UNESCO).

Zwemer, S.M., 1902, Three Journeys in Northern Oman. Geographical Journal. Vol. XIX, 1. pp 54-64.

APPENDIX 2

METHODS OF ANALYSIS

Analyses were carried out on samples that had been air dried, crushed gently and had passed through a 2 mm mesh sieve.

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

Particle size analyses. The soil samples were initially treated with an excess of acid to completely remove the soluble carbonates. After shaking overnight, the separates were determined by measuring the density of the suspension with a Bouyoucos hydrometer.

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

Conductivity. Determination by a conductivity bridge on a saturated paste.

Cation exchange data. The high carbonate contents of the soil precluded the use of ammonium acetate for extraction of exchangeable calcium and magnesium. It was, however, used for exchangeable sodium and potassium and the extract analysed on a flame photometer. For the determination of exchangeable calcium and magnesium, a barium chloride-triethanolamine solution was used for extraction and analysis carried out using 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 indicator.

Nitrogen. Determination was by a semi-micro Kjeldahl method as modified by Markham.

Total Phosphate. Total phosphate content was determined using Lorch's developer.

Available Phosphate and Potash. These were determined colorimetrically on a flow-through spectra after extraction by 2.5% acetic acid.

APPENDIX 3

PROFILE DESCRIPTIONS AND ANALYSES

PROFILE 1. AL JIMI

Uncultivated. Scattered bushes of Haloxylon salicornicum. Occasional low dunes (< 1 m). Slope 2°S.

0 - 34 cms	10YR5/4(Munsell notation, moist soil, yellowish brown); fine sandy loam; weak medium angular blocks; frequent fine roots; frequent small gravel; rare small carbonate concretions; local slight compaction; sharp change.
34 - 119 cms	Colour as above; sandy loam gravel with silt adhering to gravel; rare fine rootlets; some carbonate beading on gravel; carbonate accumulations increasing with depth with some cementation at top of horizon; sharp change.
119 cms +	Calcrete gravel horizon; cementation strongest at top.

PROFILE 2. AL JIMI

Smallholding that had grown cabbages the previous winter. Slope 2°S. Loose gravel skiff on surface.

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

PROFILE 3. AL JIMI

Smallholding. 4 year old citrus planted amongst 6 year old lucerne. Slope 1°S.

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

Sample Depth (cms)	Moisture (%)	Conductivity (mmhos)	pH	Carbonates (%)	Mechanical Analysis				Cation Exchange m.e./100 grms					E.S.P.	Phosphate mgs/100 grms		Available Potash mgs/100 grms	Organic Carbon (%)	Nitrogen (%)	C:N ratio
					2.0 - 0.05 mms	0.05 - 0.02	0.02 - 0.002	< 0.002	Ca	Mg	Na	K	Total		Total	Available				
PROFILE 1. AL JIMI																				
25-30	1.6	0.11	8.4	38.0	78.2	10.6	2.4	8.8	4.8	4.8	0.9	0.3	10.8	8.3	22.0	0.22	40.2	0.92	0.03	30.7
50-55	2.5	0.15	8.75	29.5	69.4	19.2	4.1	7.3	6.0	4.5	1.1	0.3	11.9	9.2	32.6	0.18	37.1	0.43	0.05	8.6
95-100	2.7	0.23	8.7	29.0	75.3	9.6	4.9	10.2	5.6	4.8	1.0	0.3	11.7	8.5	25.1	0.18	21.4	0.44	0.05	8.8
127-132	2.0	0.41	8.8	43.5	72.4	10.7	2.6	14.3	5.4	4.8	1.3	0.1	11.6	11.2	25.5	0.22	16.3	1.09	0.03	36.3
PROFILE 2. AL JIMI																				
5-10	1.1	0.21	8.7	34.0	74.1	13.9	6.5	5.5	6.0	5.4	2.4	0.1	13.9	17.3	24.2	0.31	8.2	1.32	0.04	33.0
25-30	1.4	0.14	8.95	37.5	76.7	13.8	3.1	6.4	6.3	5.5	2.5	0.1	14.4	17.3	27.8	0.31	9.4	1.23	0.05	24.6
35-40	3.3	0.15	8.95	36.0	66.7	11.2	18.2	4.9	6.4	5.2	0.8	0.1	12.5	6.4	26.4	0.22	12.3	0.61	0.04	15.2
50-55	5.3	0.13	8.9	25.0	62.8	22.6	9.7	4.9	4.3	4.9	1.1	0.1	10.4	10.6	23.8	0.09	23.1	0.62	0.04	15.5
95-100	7.3	0.22	8.85	27.5	83.7	6.2	5.2	4.9	2.5	4.3	0.8	0.4	8.0	10.0	32.6	0.13	52.4	0.61	0.04	15.2
PROFILE 3. AL JIMI																				
5-10	1.0	0.07	8.75	38.0	78.0	9.5	7.2	5.3	1.6	4.3	0.9	0.1	6.9	13.1	36.9	0.18	12.1	0.58	0.03	19.3
38-43	1.3	0.12	8.4	34.5	80.1	7.1	4.7	8.1	3.2	3.0	0.9	0.1	7.2	12.5	33.6	0.18	11.4	0.57	0.05	11.4
63-68	1.0	0.12	8.65	34.0	83.9	4.7	4.0	7.4	3.6	5.4	1.0	0.1	10.1	9.9	28.5	0.13	19.3	0.66	0.04	16.5
95-100	4.1	0.14	8.7	34.0	77.7	8.4	4.5	9.4	4.5	5.3	2.2	0.1	12.1	18.2	23.8	0.13	16.2	0.51	0.03	17.0

PROFILE 4. AL JIMI.

16 year old date garden with remnants of lubia crop in sample plot. No slope.

0 - 80 cms +	10YR5/4 (yellowish brown); loamy sand-loamy fine sand; weak angular blocky structure; abundant date roots and occasional patches of black decomposed organic matter; rare fine gravel increasing towards base of profile; slightly moist.

PROFILE 5. AL JIMI.

Old established date garden. Pit located in plot growing 'Dhufra'. Slope 1° SW.

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

PROFILE 6. HILI.

Uncultivated. Scattered Prosopis spicigera and Haloxylon salicornicum.

0 - 33 cms	10YR6/4-5/4 (light yellowish brown); fine sandy loam-loamy fine sand; weak angular blocky structure with single grains; frequent/abundant light grey silt accumulations weakly cemented by carbonates; frequent fine gravel; sharp change.
33 - 56 cms	10YR7/4 (very pale brown) with 7.5YR tinge; silty clay loam; compact and massive when dry with occasional fine pinholes; weak carbonate cementation; merging.
56 - 105 cms	10YR 5/4 (yellowish brown); silty fine sandy loam; compact when dry breaking to angular blocks, frequent carbonate filaments with rare concretions towards the base of the horizon; frequent fine gravel; merging.
105 - 204 cms	10YR6/3 (pale brown); loamy fine sand - fine sandy loam with silt bands; compact with some weak columnar structure; frequent carbonate filaments to 150 cms; two caliche layers, each 30 cms thick at 105 cms and 160 cms; sharp change.
204 - 284 cms	5YR6/2 (pinkish grey); fine sandy loam; compact; remnants of abundant fine roots; strongly mottled (green and red colours); sharp change.
284 cms +	Gravel.

Sample Depth (cms)	Moisture (%)	Conductivity (mmhos)	pH	Carbonates (%)	Mechanical Analysis 2.0 - 0.05 mms	0.05 - 0.02	0.02 - 0.002	< 0.002	Cation Exchange m.e./100 grms Ca	Mg	Na	K	Total	E.S.P.	Phosphate mgs/100 grms Total	Available	Available Potash mgs/100 grms	Organic Carbon (%)	Nitrogen (%)	C:N ratio
PROFILE 4. AL JIMI																				
5-10	0.9	0.09	8.8	37.5	74.6	7.6	12.9	4.9	4.3	4.4	0.9	0.1	9.7	9.3	30.4	0.04	12.2	1.03	0.04	25.7
38-43	2.7	0.11	8.4	28.5	74.9	12.0	7.0	6.1	4.6	4.9	1.1	0.1	10.7	10.3	30.8	0.13	14.3	0.97	0.02	48.5
75-80	2.0	0.17	8.55	27.5	79.3	3.8	12.5	4.4	6.0	5.4	0.9	0.3	12.6	7.2	45.1	0.13	33.2	0.82	0.02	41.0
PROFILE 5. AL JIMI																				
0-5	3.0	0.14	8.9	42.5	55.2	22.1	12.0	10.7	5.9	4.7	1.0	0.2	11.8	8.5	21.6	0.18	23.4	1.77	0.04	44.2
15-20	6.3	0.14	8.7	42.0	62.4	11.5	13.8	12.3	4.0	4.7	1.0	0.1	9.8	10.2	14.1	0.16	25.2	1.04	0.04	26.0
40-45	8.8	0.26	8.8	33.5	72.4	14.7	5.5	7.4	3.9	4.4	0.9	0.2	9.4	9.6	15.0	0.13	15.2	0.83	0.05	16.6
55-60	4.7	0.20	8.75	42.5	35.3	18.9	19.9	25.9	5.6	4.4	0.8	0.1	10.9	7.4	22.0	0.16	30.3	0.78	0.04	19.5
75-80	7.0	0.32	8.85	41.0	25.4	12.6	34.2	27.8	8.4	5.3	0.8	0.2	14.7	5.4	15.8	0.14	43.4	1.21	0.04	30.2
PROFILE 6. HILI																				
5-10	1.3	2.67	8.1	48.0	52.4	15.3	26.0	6.3	3.0	4.5	3.1	0.6	11.2	27.7	25.1	0.18	85.6	0.57	0.03	19.0
38-43	2.7	0.32	8.05	46.0	19.8	27.4	24.4	28.4	5.6	4.7	3.2	0.7	14.2	22.6	31.5	0.16	94.8	0.55	0.03	18.3
68-73	1.0	0.20	8.3	47.0	59.6	15.0	4.6	20.8	5.1	4.6	3.0	0.6	13.3	22.6	23.9	0.18	76.6	0.58	0.04	14.5
108-113	0.9	0.18	8.4	43.5	62.7	21.9	6.8	8.6	5.2	4.9	3.1	0.5	13.7	22.0	17.7	0.16	68.2	0.32	0.04	8.0
255-260	3.8	0.32	8.0	35.0	69.5	13.4	7.0	7.0	5.5	4.8	1.3	0.1	11.7	11.1	19.8	0.13	67.0	0.81	0.02	40.5

PROFILE 7. DEPT. OF AGRICULTURE FARM, AL AIN.

Plot prepared for water melon cultivation. Slope 3°SW. Loose surface.

0 - 13 cms	10YR5/3 (brown); loamy sand - sandy loam; weak angular blocky structure; very rare fine rootlets; occasional fine gravel; moist; merging.
13 - 70 cms	10YR5/3 (brown); gravelly loamy fine sand; single grain structure though slightly compacted below 35 cms; rare fine rootlets; occasional carbonate filaments with rare beading on the gravels; sharp change.
70 cms +	Grey gravel with carbonate beading.

PROFILE 8. AL AIN.

Plot cultivated with lucerne for seven years - ploughed in two weeks previously. Slope 3°S. Pit located near interfluve. Fine crust on surface.

0 - 24 cms	10YR4/3-4/3 (dark yellowish brown); loamy sand - sandy loam; moderate/strong small and medium angular blocks; abundant fine roots; rare fine gravel; clear change.
24 cms +	as above but loamy sands; single grain structure; frequent/rare fine roots; rare fine limestone fragments and carbonate accumulations; rare fine gravel.

PROFILE 9. AL AIN.

Old established date garden partly cleared and planted with fodder crops. Profile site located in lubia plot. Traces of burning on surface.

0 - 26 cms	10YR4/2 (dark greyish brown); fine sandy loam; moderate/well developed medium angular blocks; abundant roots; patches of grey ashy material (from burning ?); moist; merging.
26 cms +	10YR4/3 (dark brown); loamy fine sand; single grain structure; frequent roots; rare limestone fragments; moist.

Sample Depth (cms)	Moisture (%)	Conductivity (mmhos)	pH	Carbonates (%)	Mechanical Analysis 2.0 - 0.05 mms	0.05 - 0.02	0.02 - 0.002	< 0.002	Cation Exchange m.e./100 grms Ca	Mg	Na	K	Total	E.S.P.	Phosphate mgs/100 grms Total	Available	Available Potash mgs/100 grms	Organic Carbon (%)	Nitrogen (%)	C:N ratio
PROFILE 7. DEPT. OF AGRICULTURE FARM, AL AIN.																				
5-10	5.2	0.17	8.6	33.5	70.0	9.8	11.4	8.8	9.1	3.3	0.9	0.3	13.6	6.6	31.7	0.18	30.4	0.97	0.04	24.2
23-28	1.6	0.15	8.8	29.0	70.0	7.8	13.4	8.8	9.5	4.8	2.4	0.2	16.9	14.2	26.0	0.18	33.0	0.43	0.04	10.7
45-50	0.4	0.87	8.25	37.5	71.4	8.9	13.6	6.1	10.9	4.7	3.1	0.3	19.0	16.4	15.9	0.09	43.6	0.70	0.02	35.0
PROFILE 8. AL AIN.																				
5-10	1.4	0.24	8.9	44.5	72.9	12.7	1.8	12.6	5.4	5.5	1.0	0.1	12.0	8.3	15.5	0.13	25.0	1.18	0.04	29.5
30-35	2.0	0.17	8.6	44.0	74.4	8.9	3.1	13.6	5.5	5.0	0.9	0.1	11.5	7.8	19.6	0.13	18.2	0.55	0.04	13.7
50-55	2.1	0.16	8.7	40.5	80.9	2.4	5.9	10.8	5.0	4.9	0.9	0.1	10.9	8.3	24.2	0.13	16.2	0.78	0.05	15.6
95-100	3.1	0.23	8.75	42.5	75.4	9.3	5.9	9.2	2.8	5.0	1.2	0.1	9.1	13.2	24.2	0.13	11.2	0.51	0.04	12.7
PROFILE 9. AL AIN.																				
5-10	4.7	0.19	8.9	48.5	54.4	28.9	4.3	12.4	4.2	4.1	1.6	0.5	10.4	15.4	19.8	0.35	63.8	2.14	0.06	35.7
38-43	5.1	0.34	8.85	49.0	62.1	17.4	9.6	10.9	5.1	4.2	1.5	0.2	11.0	13.6	19.4	0.26	28.4	1.98	0.05	39.6
75-80	4.1	0.31	8.8	49.5	62.5	22.8	6.5	8.2	4.2	4.4	1.4	0.1	10.1	13.8	15.5	0.26	19.2	1.22	0.04	30.5

PROFILES 10 and 10a. AL AIN.

New garden (established for 1 year) sited amongst low dunes. Slope 2°N. Scattered Acacia arabica. Profile 10 uncultivated, Profile 10a irrigated for one year.

Profile 10.

0 - 17 cms	10YR5/4 (yellowish brown); loamy sand; weak angular blocky structure; rare fine rootlets; occasional fine gravel; abundant weakly carbonate-cemented silt nodules (40%); clear change.
17 - 45 cms	10YR5/3 (brown); fine sandy loam; single grain structure; 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; rare pinholes; occasional carbonate filaments; occasional dull diffuse ochreous mottles; slightly moist.

Profile 10a. as above except top 17 cms moderately mottled (25%) - dull diffuse olive yellow, and silty clay loam horizon has traces of grey colouring.

PROFILES 11 and 11a. MASYAD.

Water melon plot. 11 had mineral fertilizer and organic manure applied, 11a only had application of mineral fertilizer (sulphate of ammonia).

Profile 11.

0 - 29 cms	10YR5/4 (yellowish brown); fine sandy loam; weak small angular blocks and single grains; frequent fine rootlets; rare fine gravel; slightly moist; merging.
29 cms +	10YR4/3 (brown) with 7.5YR tinge; fine sandy loam; compact and massive with slight carbonate cementation; rare fine roots, rare fine gravel with rare angular stones up to 2.5 cms in length; occasional carbonate filaments; slightly moist.

Profile 11a. Identical except that compact horizon is not so well developed.

Sample Depth (cms)	Moisture (%)	Conductivity (mmhos)	pH	Carbonates (%)	Mechanical Analysis				Cation Exchange m.e./100 grms					E.S.P.	Phosphate mgs/100 grms		Available Potash mgs/100 grms	Organic Carbon (%)	Nitrogen (%)	C:N ratio
					2.0 - 0.05 mms	0.05 - 0.02	0.02 - 0.002	< 0.002	Ca	Mg	Na	K	Total		Total	Available				
PROFILES 10 and 10a. AL AIN.																				
									10											
5-10	2.0	2.95	8.4	48.5	63.2	11.7	16.6	8.5	4.7	5.3	3.0	0.8	13.8	15.2	26.4	0.13	80.6	1.05	0.03	35.0
22-27	5.3	0.20	8.9	44.0	51.5	15.0	18.5	15.0	6.3	4.3	3.3	0.6	14.5	22.8	17.6	0.18	63.2	0.78	0.04	19.5
48-53	2.2	9.05	8.65	56.0	35.3	29.7	19.6	15.4	14.1	8.8	3.1	2.8	28.8	10.8	18.9	0.04	265.6	0.46	0.04	11.5
97-102	11.8	15.40	8.5	52.0	37.2	16.3	23.3	23.2	15.6	4.4	3.1	2.4	25.7	12.0	25.1	0.04	200.0	1.00	0.03	33.3
									10a											
5-10	7.3	1.75	8.9	46.5	59.2	20.5	11.7	9.6	5.1	4.1	3.3	0.9	13.4	24.6	32.2	0.13	79.6	1.05	0.04	26.2
22-27	5.0	0.35	8.95	43.5	48.1	16.1	19.2	16.6	5.7	5.1	2.5	0.4	13.7	12.7	17.6	0.13	52.6	0.70	0.06	11.7
48-53	7.5	2.44	8.7	54.0	34.8	25.4	21.6	25.4	8.0	5.8	2.2	2.1	18.1	12.2	20.7	0.18	168.0	0.47	0.03	15.3
97-102	15.9	5.40	8.75	49.5	32.7	14.3	33.1	19.9	8.2	4.4	3.0	1.3	16.9	17.7	22.9	0.13	170.2	0.55	0.05	11.0
PROFILES 11 and 11a. MASYAD.																				
									11											
5-10	1.2	0.34	8.65	54.0	35.6	23.2	20.2	21.0	4.8	4.7	1.3	0.3	11.1	11.8	18.4	0.26	45.8	0.55	0.04	18.7
33-38	1.6	0.30	8.45	42.5	46.5	30.7	10.5	12.3	4.7	4.7	1.0	0.3	10.7	9.2	25.1	0.18	39.8	1.08	0.05	21.6
70-75	4.8	0.18	8.45	45.0	45.3	3.3	34.3	17.1	8.3	4.8	1.6	0.3	15.0	10.7	20.7	0.18	45.8	0.86	0.05	17.2
									11a											
5-10	1.3	0.20	8.60	52.5	38.1	24.1	21.8	16.0	2.3	4.3	1.6	0.3	8.5	18.8	22.4	0.22	50.0	0.86	0.04	21.5
33-38	0.5	0.10	8.70	44.5	45.9	37.1	6.0	11.0	4.9	4.4	1.2	0.2	10.7	11.2	31.7	0.22	32.6	0.39	0.03	13.0
70-75	2.4	0.17	8.50	46.5	45.4	6.0	35.3	13.3	8.3	4.5	1.4	0.3	14.5	9.6	24.6	0.13	43.6	0.67	0.04	16.7

PROFILE 12. AIN BUSUKANA.

Uncultivated. Located on low ridge covered by loose angular chert fragments and aeolian sand. Area (0.75 hectare) bounded on north by low sand dunes and small wadi to the south. No vegetation. Slope 4°W.

0 - 3 cms	10YR5/3 (brown); loamy fine sand; single grain structure; rare fine rootlets; frequent angular stones; sharp change.
3 - 12 cms	5YR4/4 (reddish brown); (sandy) clay loam; well developed medium angular blocks breaking to small blocks and crumbs; very rare fine roots; frequent fine cracks containing material from surface horizon; sharp irregular boundary.
12 cms +	10YR7/4 (very pale brown) weathered limestone merging into consolidated limestone at 22 cms; crystal (calcite ?) skins at 18 cms.

Sample Depth (cms)	Moisture (%)	Conductivity (mmhos)	pH	Carbonates (%)	Mechanical Analysis				Cation Exchange m.e./100 grms					E.S.P.	Phosphate mgs/100 grms		Available Potash mgs/100 grms	Organic Carbon (%)	Nitrogen (%)	C:N ratio
					2.0 - 0.05 mms	0.05 - 0.02	0.02 - 0.002	< 0.002	Ca	Mg	Na	K	Total		Total	Available				
PROFILE 12. AIN BUSUKANA.																				
0 - 3	0.6	0.53	7.6	53.5	55.7	16.2	10.7	17.4	5.4	4.8	1.8	0.3	12.3	14.6	32.8	0.18	41.6	0.51	0.04	12.7
4 - 9	2.2	0.29	8.45	61.5	24.8	10.9	22.5	41.8	9.2	4.3	1.2	0.5	15.2	7.9	48.4	0.40	58.2	0.21	0.02	10.5
13 - 14	2.0	0.05	7.95	87.0	N.D	N.D	N.D	N.D	8.4	4.3	1.0	0.1	13.8	7.2	20.3	0.19	12.2	0.19	0.02	9.5

APPENDIX 4

OWNERS OF SMALLHOLDINGS

HILI

H1 Rashid Ali Rahmeh
H2 Mohammed Ali
H3 Said Mubarraq
H4 Ahmed Salem
H5 Saleh Khalfan
H6 Ali Ruashid
H7 Unknown
H8 Maiouf Mohammed
H9 Ali Omir

AL JIMI

J1/J10 Ibrahim Abboud
J2 Saif Allah Mahdi
J3 Dr Tabit
J4 Ahmed Abdullah Barak
J5 Darwish Mohammed
J6 Ahmed Rashid
J7 Khalifa Ahmed Suweidy
J8 Ali Rashid
J9 Yahia Hassan
J11 Mohammed Hamid Barak
J12 Sultan bin Ahmed

AL AIN

A1 Saif Mubarraq
A2 Ali Saleh
A3 Rashid Obeid
A4 Hamis Salem
A5 Khalfan Said
A6 Abdul Rahim Mohammed
A7 Ahmed Jumma
A8 Sheikh Khalifa
A9 Sheikh Khalifa
A10 Said bin Abdullah
A11 Unknown
A12 Unknown

QATTARAH

Q1 Sheikh Khaled
Q2 Addouda Maktum
Q3 Khalfan Matter
Q4 Mohammed Nasser
Q5 Rashid Said
Q6 Hamid Khamis
Q7 Unknown
Q8 Khalfan Hasin

MUWEIQI'I

M1 Mohammed Awaian
M2 Sheikha Mariam Hamdan
M3 Suweidan Harib
M4 Omair Muthid
M5 Sheikha Salaama bin Zaid

MUTARADH

Mu 1 Said bin Badi
Mu 2 Mohammed bin Badi
Mu 3 Said bin Mubarrak
Mu 4 Ahmed bin Sarour