Some problems of economic geography in Northern tripolitania: a study of agriculture and irrigation on the Jefara plain

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Some Problems of Economic Geography in Northern Tripolitania - A study of agriculture and irrigation on the Jefara Plain.

ABSTRACT

Libya has few resources and poverty is rife among its 1¼ million inhabitants. It is not surprising therefore that it has a permanent adverse trade balance and budget deficit, both being covered by foreign aid. Agriculture seems to offer the only prospect of overcoming these financial difficulties and at the same time raising the living standards of the population. The sandy plain round Tripoli is the most important agricultural area and here the conditions are most favourable for an extension of agriculture.

This plain known by the Libyans as the Jefara, is composed mainly of unconsolidated deposits of Tertiary, Pleistocene and Recent ages: these all dip gently northwards and sometimes contain reserves of underground water. They afford very sandy soils which are deficient in organic material, clay and plant nutrients. The climate is a very dry Mediterranean type and Saharan influences result in high temperatures and unreliable rainfall.

Prior to the 1939/45 war there were two basic types of agriculture: Arab and Italian. Arab subsistence agriculture was either irrigated cultivation in the small coastal oases or shifting cultivation of barley further inland. Italian Agriculture was largely concentrated on the growing of dryland tree crops, such as olives, vines and almonds, and usually

associated with winter cereals.

There has been a radical change in the agricultural pattern in recent years. This has been due largely to the increased importance of irrigation which is dependent on underground water. Groundnuts, tobacco, cereals and potatoes, olive and citrus trees, are all irrigated. The numbers of dryland tree crops, particularly almonds and vines, are declining.

The expansion of irrigation has increased the productivity of the plain and irrigation now forms an integral part of Jeferan agriculture. Future development should be a combination of dry and irrigated farming with both field and tree crops.

SOME PROBLEMS OF ECONOMIC GEOGRAPHY IN NORTHERN TRIPOLITANIA

A study of agriculture and irrigation on the Jefara Plain

by

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Thesis submitted for the Degree of Doctor of Philosophy in the University of Durham.

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ARRIDET ARIDEM

Let the dry land smile.

C O N T E N T S

PREFACE

I arrived in Durham in September 1956 with a view to visiting one of the Arab countries in the Middle East. Libya was chosen for three main reasons: firstly, as an under-developed country having recently gained its independence, it faced many problems because, with its sparse population and limited resources, it was finding considerable difficulty in maintaining its economy without foreign aid; secondly, there was a great need for basic research in many fields; and finally it was politically stable and was little affected by the Suez Crisis.

Many difficulties had to be overcome. At the outset the initial plan of work was very broad and a more defined topic for study had to be worked out as quickly as possible. It was found that only a limited quantity of general literature was available in the United Kingdom and even this was difficult to trace; in Libya, very little source material existed and most of the few statistics available were estimates and largely unreliable. In addition the language barrier proved a hindrance in establishing contacts and appraising local conditions. Thus a slow rate of progress was inevitable.

I made two visits to Libya. During my first stay in the country, which lasted from April 1957 to April 1958, I spent a certain time gaining general impressions by travelling in Tripolitania, Cyrenaica and Fezzan, and at the same time collecting literature and reports and compiling a bibliography. Later I confined myself to field work in various agricultural areas, collecting statistics and commercial information, reading relevant reports and consulting some of the many experts at work in the country. My second stay was for the month of August in 1958, when I distributed questionnaires to farmers.

I wish to thank the many people in Libya who have shown an active interest in my work, and I am particularly indebted to the following who gave me much valuable assistance:-

Government Experimental Farm Sidi Mesri	E.M.Siceley - former Director of Agriculture. Sadik Sghaier - Assistant Director of Agriculture. Khairi Sghaier Muftah Ettumi - Statistics Section. Jiumaa Jiaddui and other forestry officers. K.M.Guichard - Locust Control Officer.
F.A.O. Mission, Sidi Mesri	Mr. Van Der Ploeg - Head of Mission. Mr. Easton - Administration. Drs. Martin & Carraro - Plant Protection. S.G.Mazzocchi - Horticulture.
United Nations	H.E.Caustin - in 1957 Chief Economist now Head of the United Nations Mission. M. Corroy - Documents Officer.
Istituto Nazionale della Previdenza Sociale	Dott. Attilo Rompietti - Director.
State Tobacco Monopoly	G.A.F.Rands, Cultivation Manager.
Consorzio Agrario	R.B.Lamboglia - Crops. A.Amilcare - Pumps and Irrigation.
Development Council	N.Horsley and others.
U.S.O.M. Experts	E.Sirra - Extension Officer. D.Morrison - Extension Officer. D.J. Cederstrom and others.
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British Council — Mr. Jerrom & Mrs. D.L.Stephens.

Mitchell Cotts — Mr. Carabot.

Libraries — Ismail Ahmed Sueiah and others - Government Library.
Beshir Giawab - Agricultural Library, Sidi Mesri.
A.Budri - Antiquities Library.
Dott. T.Provasi - Director of Natural History Museum and Library.

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Farmers — Aiad Lafi and many others.

Questionnaire — Mohamed Bulugma.

Considerable help was given by the British Army, and I gratefully acknowledge the assistance in the form of transport, which was rendered by Brigadier G. Laing, District Commander. Major Shergold of the Service Hirings Department gave me invaluable advice during my early days in Tripoli. My thanks are also due to the Royal Air Force at Idris, which accommodated me during most of my stay. The Commanding Officer, Wing-Commander Stapleton and all the other officers were most helpful to an academic civilian in their midst. Flight-Lieutenant D.F. Townsend and Flying-Officer E. Wallis actively supported me in my travels in Libya.

In Durham I have to thank the three Libyan graduates, Hadi Bulugma, Mukhtar Buru, and Mahmud Khoja, who gave me patient advice on language and other problems. Finally I must record my appreciation of the work of Dr. J.I. Clarke has afforded me in his role as supervisor, and my gratitude to Professor W.B. Fisher, who gave me the opportunity of going to Libya.

LIST OF PLATES

LIST OF PLATES cont'd

List of Maps and Diagrams

List of Maps and Diagrams cont'd

List of Tables

List of Appendices

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PART ONE

Introduction

Libya, with a total area of 680,000 sq. miles, is wedged between the Maghreb in the west and Egypt in the east, and about 90% of its land forms part of the Sahara Desert. Its population, which according to the 1954 census was only 1,091,830, subsists on cereals, dates and animal products, and it has a per capita income reported to be barely one-fifth of that in Egypt (4). The people, who are largely Arabs and Berbers, are about 90% illiterate and are mainly limited in distribution to coastal areas in Tripolitania and Cyrenaica.

The country is accustomed to foreign domination. At the time of Christ the Romans ruled much of the land and even ventured south into the Fezzan; they established a thriving civilisation along the coast based on an agricultural economy in which cereals and olives were dominant. The country was overrun in later centuries by two successive waves of Arabs, about 700 and 1100 A.D., and both invasions particularly the latter, brought a decline in sedentary agriculture and an increase in pastoralism. The Turks arrived about 1600 and made Libya a part of their empire, but their control was very loose and the general stagnation of local agriculture was allowed to continue. The Italians, who arrived in 1912, expanded sedentary agriculture with a view to colonisation, but when they had to renounce sovereignty following their defeat in the 1939/45 War, their programme had not been completed. Eventually, as decreed by the United Nations, Libya emerged as an independent state on December 24th,1951, becoming a united kingdom of the three states Cyrenaica, Fezzan and Tripolitania, under the rule of Idris I, the Sanusi leader from Cyrenaica.

Cyrenaica, which is the largest province in size, has an area of 333,000 sq. miles. Its population of 291,328 which is predominantly tribal in structure and having a nomadic or semi-nomadic life, concentrates on raising livestock. Tripolitania, although smaller in area, has a larger population which is much more sophisticated and economically advanced. Fezzan which has only 55,000 people is mostly desert and the small population is generally concentrated in a few small depressed oases.

Agriculture is the basis of the Libyan economy and about 80% of the inhabitants are engaged in some type of farming, whether growing irrigated crops near the coast, tending olives in the hills or wandering miles over the desert in search of pasture for animals. The sedentary element of the population which numbers about 400,000 is economically much the most important.

Immediately after the last war, scrap metal was the chief export but this has now been exhausted; the next most important export used to be esparto grass, which is needed for making high quality paper such as is used for bank notes, but this spontaneous crop was over-exploited and its collection is now rigidly controlled and the amount exported has been reduced to a more sensible level. All other important exports are derived from agriculture and since much of Libya is so arid their value is usually low and it is not surprising that there appears to be a permanent adverse trade balance. The following table summarises the balance of payments position between 1951 and 1955:- (7 p.21)

Table 0.1 Libya's balance of payments 1951-55 £L'000

	1951	1952	1953	1954	1955
Imports	11,842	11,566	11,294	11,286	14,282
Exports	3,090	4,363	3,322	3,479	4,340
Visible balance	-8,752	-7,203	-7,927	-7,807	-9,942
Net invisible income	4,110	5,820	5,305	2,974	4,239
Official economic aid	1,458	2,918	3,121	5,093	8,411
Surplus or deficit	-3,184	+1,535	+454	+260	+2,707

In every year imports exceed exports, but the deficit is made good by the net invisible income (the amount spent locally by British and American forces personnel) and official economic aid. If these two sources are taken into account there is usually a surplus in the balance of payments.

Internally Libya also experiences financial difficulties, because since the population is so poor and the taxes so few, there is usually a deficit in the Federal budget, as for instance in 1956/7 (1 p.110) when income was £L8,709,620 and expenditure £L9,174,620. In this year the deficit was covered by a reserve fund. It is important to remember that the visible deficit does not necessarily reveal the actual deficit for in 1956/7 the income side included a direct grant of £L3,000,000 paid by the British Government for direct budget support.

In addition to the trade and budget deficit, all economic development is financed by foreign money. In the period 1913/42 the Italian Government spent $159,000,000 on developing Libya and table 0.2 below indicates the amount of money made available to the Libyan Government for development in recent years:-

Table 0.2 Financial Resources available to Libya for Economic Development (11 p.14) in $'000

Source	1951/2	1952/3	1953/4	1954/5	1955/6	1956/7
U.S.A.	1,537	1,343	3,149	10,574	12,939	15,400
United Kingdom	1,200	1,621	2,800	2,800	2,800	2,800
Italy	196	532	0	28	28	28
France	364	476	280	210	420	658
Turkey	0	0	160	28	28	28
Egypt	0	0	480	868	868	868
United Nations	713	852	763	639	750	750
Total	4,010	4,824	7,632	15,148	17,832	20,532

Libya is a country of deficits and when it became independent many observers thought that its future as a sovereign state was very insecure. 'At the best it might become another Jordan and live out a shabby political future on foreign subsidies; at worst it would fall apart and the pieces be left for the neighbours to squabble about'.* Today Libya still maintains her political unity but she has not, however, achieved economic independence. Her strategic value in the eyes of the major powers in the Western Bloc has declined and already grants in aid are showing signs of shrinking, particularly from Britain. Most people in Libya look to oil for the country's salvation and several recent oil strikes have been encouraging and lead one to think that reserves must be considerable. At the moment, however, oil seems to be flowing freely from other areas in the Middle East and the companies appear to be holding Libyan oil in reserve for future development. Too often, however, there is the cry 'oil to the rescue' and the fact

* 'Libya - oil to the Rescue'. The Economist, January 2nd 1960, p.21.

that agriculture could be the foundation of a viable economy is forgotten.

The present high level of imports is due partly to the need to import certain food commodities, and partly to the need to satisfy the luxury demands of a large European element temporarily resident in Tripoli. If we disregard the imports for Europeans, then the adverse trade balance could be eliminated by an expansion of agriculture. In order to bring in additional foreign revenue the export of groundnuts should be expanded to 10,000 metric tons and citrus to 30,000 metric tons; in order to avoid the import of foodstuffs, the wheat area should be expanded to 35,000 ha., and a further 500 ha. added to the potato area, and in addition sugar beet should be grown so that the local consumption of sugar (about 2-3,000 metric tons) could be supplied by home production.

Three areas seem to offer scope for agricultural expansion: the Jefara Plain round Tripoli with possibilities for both dry and irrigated farming; the Eastern Tripolitanian Jebel especially east of Gharian where dryland tree crops cultivation could be further developed; and the Jebel Akhdar in Cyrenaica where dryland field and tree crop cultivations could be expanded and improved on the Barce Plain.

Tripolitanian agricultural products, over 50% of which come from the Jefara Plain, dominate the present export trade of Libya and it is worthwhile to study the balance of trade in recent years, divorced from grants in aid and net invisible incomes and the like.

Table 0.3 Libyan imports and exports £L'000

	1955	1956	1957
Total value of civil imports	14,548	16,601	28,076
Total value of exports	4,595	4,154	5,415
Total value of domestic exports	(4,805)	3,805	4,752
Total value of re-exports	210	349	663
Trade deficit	9,743	12,447	22,661

These figures show that imports are increasing at a faster rate than exports and as the trade gap steadily widens so Tripolitania's share of the export trade increases from about 64% in the period 1947-50 to 74% in 1957. The added predominance of Tripolitania is due to the decline of scrap metal exports from Cyrenaica and the increased exports of groundnuts from Tripolitania. In 1957, three items from Tripolitania - olive oil, groundnuts and castor seed - made up almost 50% of Libya's total exports, compared with only 31% in 1955. It is therefore evident that as Tripolitania's share of total exports increases so Jefaran products attain greater significance. The main Libyan crops and allied products exported from Tripolitania in 1957 were as follows:-

Table 0.4 Exports of Agricultural crops and products from Tripolitania in 1957

Olive Oil*	£L1,170,628	Almonds-	£L64,516
Groundnuts'	847,228	Citrus'	59,995
Castor Seed-	215,303	Tobacco'	29,474
Sansa oil*	146,407	Vegetables e, Maize' and Tomatoes'	12,667
Potatoes e	76,648		

Total £L2,627,585

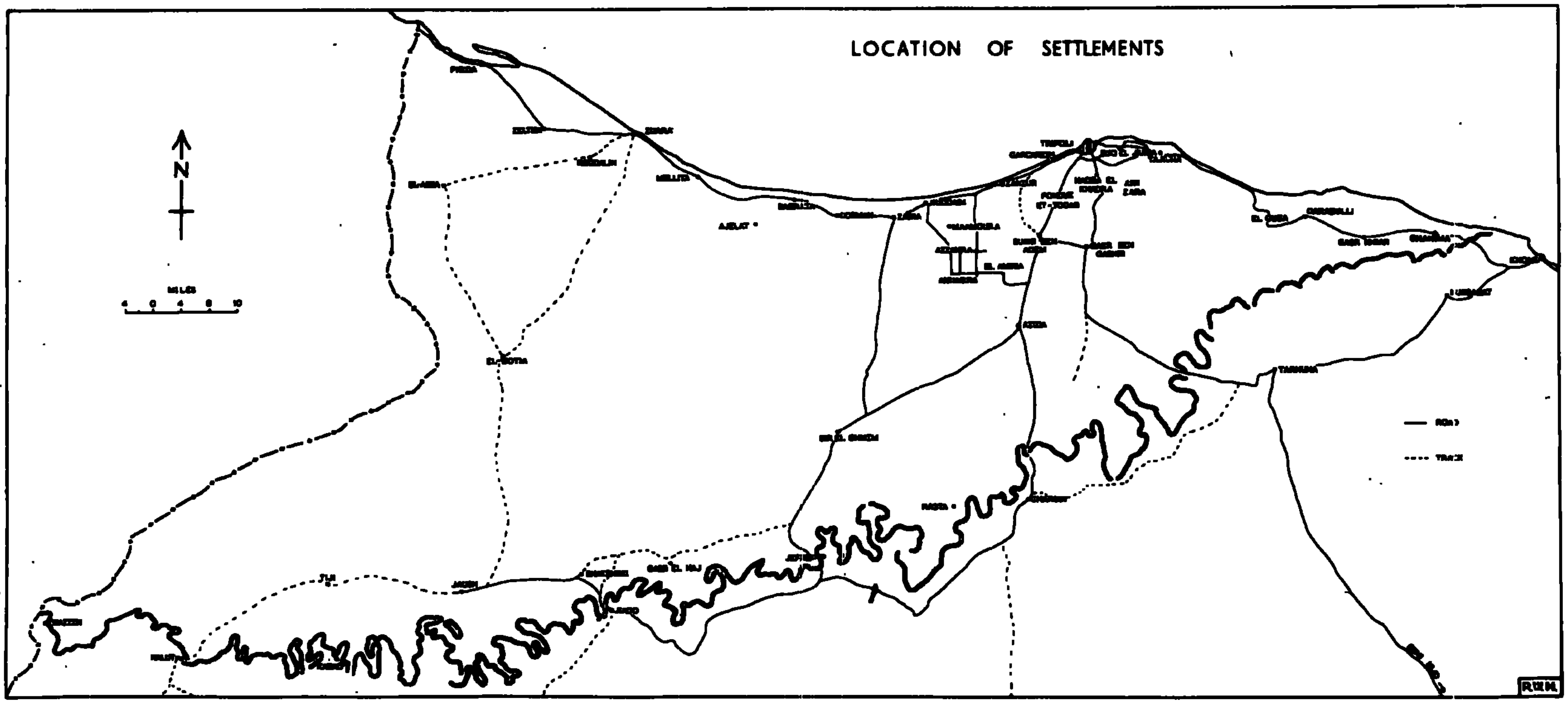
* Partly irrigated crop, i.e. some trees.
' Fully irrigated crop
e Supplementary irrigated crop.
- Dryland crop.

The export of olive oil was abnormally high in this year and in 1955 and 1956 groundnuts were the leading export. The production of all crops in table 0.4, except tobacco, could be expanded.

The Jefara Plain, which is shown in black in the frontispiece, is the leading economic region in Libya and it offers the best prospects for the expansion of commercial farming. Here there are resources, which with careful development, will outlast the period of foreign aid and even a possible oil boom. In studying this area an attempt has been made to discover the potential of the natural resources and also to establish the types of agriculture to be found; each crop has been studied, and cropping trends have been analysed to try and show how, in response to physical and economic factors, many farmers are finding it more profitable to grow irrigated crops. There has been a phenomenal increase in the world production of agricultural crops in the first half of this century as a result of the widespread introduction of fertilizers, and the second half of the century is likely to witness a similar trend but this time the result of an expansion of irrigation. It will be interesting to assess the importance of irrigation on the Jefara Plain. The information presented in this study will help in deciding the type of future development that is required, whether the emphasis should be on dry or irrigated cultivation or a combination of the two, and whether field crops or tree crops should be developed for supplying home demands and export requirements.

The thesis is presented into two parts. Part One contains the texts, maps and diagrams and photographs; Part Two the references and appendices. The actual text is divided into sections: Section I describes the area, its land-use and farm types; Section II studies the physical resources; Section III is devoted entirely to the study of water use, since water is such an important factor; Sections IV and V deal with the crops - how they grow, where they grow, yields, production trends and popularity; and Section VI, which is only one chapter, briefly summarises a few of the more important points made in the text, and then draws some conclusions. Part Two contains a list of references and numerous appendices. References are given by chapter and are numbered, the numbers being bracketed in the text. Some sources of information are given as footnotes and occasionally they may be coded such as B/96. In this example reference to page 96 of 'A Bibliography of Libya' by R.W. Hill, Research Papers Series no. 1, 1959, Department of Geography, Durham Colleges in the University of Durham, will give the required information. The appendices are rather long because they include 40 farm studies and a considerable amount of statistical material which is referred to in the text.

A map is included (fig. 1) which shows the location of the major place names; other localities and places of lesser importance are generally to be found on the G.S.G.S. 1:200,000 War Office Map, sheet 1 Zuara and sheet 2 Tripoli.


LOCATION OF SETTLEMENTS
N

SECTION I

THE JEFARA REGION

CHAPTER 1

Morphology: a descriptive and genetic study.

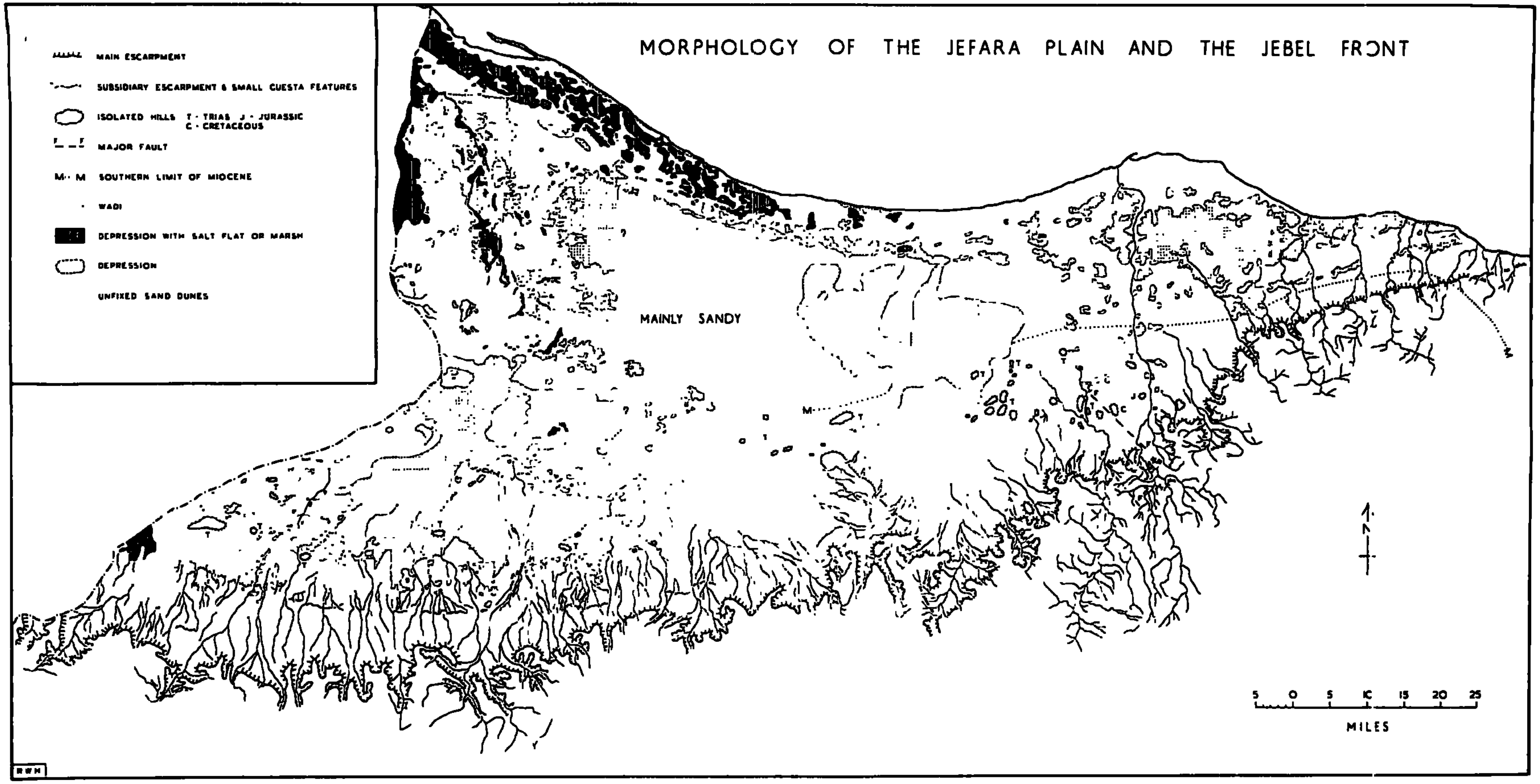
A. Introduction.

A brief explanatory study of the morphology of the Jefara Plain is fundamental to a study of agriculture. It is necessary to know the nature of the terrain, the type of soil parent-material, and the underlying structure of the rocks. The agricultural geographer is keenly interested in slope and aspect, the nature of the soil, and the availability of water resources, and it is with this in mind that chapter 1 has been written. It is sub-divided as follows:-

Description of major morphological features: Evaluation of structural and lithological geology in order to explain present large-scale relief features and general structure: Consideration of palaeogeography of Tertiary and Quaternary times: Division of the area into morphological units: significant conclusions.

B. Description of major morphological features.

The Jefara is a well-marked morphological unit both in Libya and in Tunisia, and Brichant (6 p.5) refers to it as constituting 'a geographical entity on either side of the frontier'. In general, the Tripolitania Jefara gives the impression of being a flat sandy plain, bounded to the south by an abrupt wall of limestone, and with a gentle gradient seawards of 3:1,000. In plan it has a triangular shape, with an apex towards Khoms in the east, a base of some 150 kilometres along the Tunisian border in the west,


MORPHOLOGY OF THE JEFARA PLAIN AND THE JEBEL FRONT
MAIN ESCARPMENT
SUBSIDIARY ESCARPMENT & SMALL CUESTA FEATURES
ISOLATED HILLS T - TRIAS J - JURASSIC C - CRETACEOUS
MAJOR FAULT
M·· M SOUTHERN LIMIT OF MIOCENE
WADI
DEPRESSION WITH SALT FLAT OR MARSH
DEPRESSION
UNFIXED SAND DUNES
MAINLY SANDY
5 0 5 10 15 20 25
MILES
RWH

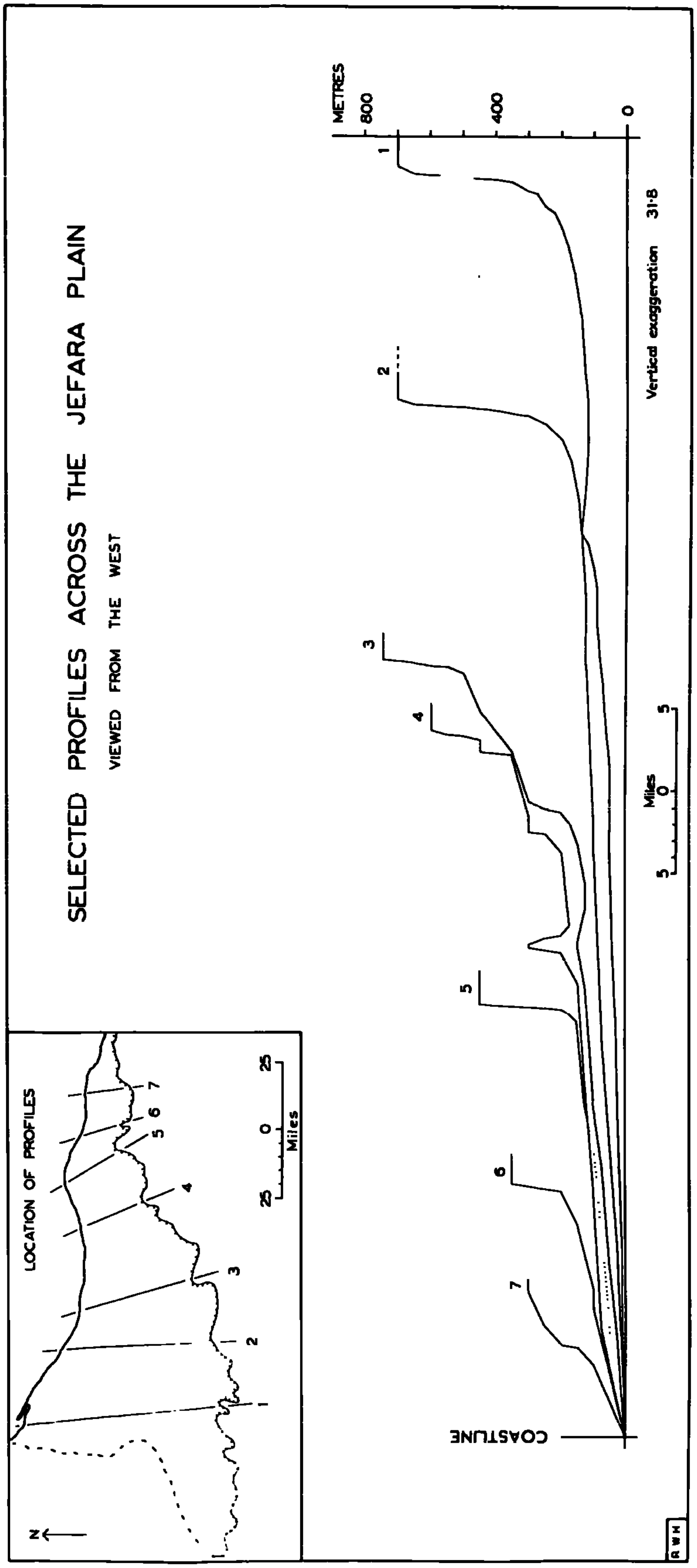
and the two sides along the coast in the north and the escarpment in the south respectively (see fig. 2). It has a total area approaching 20,000 sq. kilometres.

1. <u>The escarpment</u>. From Khoms, a crenulate escarpment about 400 kilometres long stretches westwards to the Tunisian border; this is the eastern half of a crescent-shaped feature which continues into Tunisia as far as Gabes. The Jefara Plain rises gently southwards and attains an average height of 250-300 metres at the base of the Jebel. The foot of the escarpment, however, is not constant in height throughout its length and there is a general decline eastwards. This is evident from studying fig. 3.

   Although the escarpment is an impressive feature which rises abruptly from the Inner Jefara, it is not continuous, and only in the east is it straight. It is breached, gullied and ravined by innumerable wadis, resulting in a very scalloped appearance with numerous projecting spurs. The amplitude of relief of this cliff-like feature is usually about 300-450 metres, being greater in the central and western sections. The height of the top of the escarpment varies; it reaches a maximum of over 800 metres above sea-level between Gharian and Yefren, falling to 300 metres in the east and 600 metres in the west.

2. <u>Pre-Jebelic Hills</u>. There are certain relief forms which interrupt 'les plaines à peine ondulees de la monotone et plate Djeffara' (16, p.9). Zaccagna (34) calls them the Pre-Jebelic Hills.

Figure 3.


SELECTED PROFILES ACROSS THE JEFARA PLAIN
VIEWED FROM THE WEST
METRES
800
400
0
1
2
3
4
5
6
7
Vertical exaggeration 31·8
Miles
5
0
5
COASTLINE
LOCATION OF PROFILES
N
Miles
25
0
25
RWH

A study of the selected profiles (fig. 3) shows that the plain narrows and steepens to the east until it is finally obliterated by the front of the cuesta. Profiles 3 & 4 indicate a break in the scarp's symmetry, this being ~~done~~ due to a secondary bench in the Gharian area and to the El Menshar Hills between Yefren and Bir el Ghnem. Profile 4 has an isolated residual, a relic of the scarp's former position, while profile 1 has a small break towards the Jebel which would appear to be related to the subsidiary features just mentioned.

These secondary features are clearly indicated on the morphological map (fig. 2). In the south-western part of the Jefara there is a series of small cuestas which start at Ras el Manfes and Gasr Tekut and then pass eastwards into a low discontinuous bench approximately along the line of settlements – Tiji, Jaush, Shakshiuk and Gasr el Haj. Near Gasr Tekut in the west, the minor cuestas are 20-30 metres high and up to 16 kilometres from the escarpment, but in the east the bench is almost indiscernible since it has nearly disappeared beneath the main escarpment at Shakshiuk. However, another 20 kilometres to the east the bench appears again, but this time it is larger and takes the form of gently rounded hills, known as El Menshar by the Libyans (S.S.E. of M in fig. 2). Moving still further east this relief form recedes southwards and finally merges with the escarpment, although at Gharian it reappears again as a minor break in the scarp face.

Besides these extensions and irregularities of the main cuesta there are many small isolated hills in what can be called the Inner Jefara zone. These are 200-250 metres and occasionally 300 metres above sea-level and often have shrines or tombs on their summits. For the moment it is sufficient to point out that the hills are composed of consolidated rock.

3. Inner Jefara. Amid the Pre-Jebelic Hills is an area of basins and flats largely covered by alluvial material deposited by the wadis as they leave the Jebel.

4. Dune Jefara. Dunes cover the larger part of the Jefara Plain (see fig. 2). When flying over it, the sandy nature of the land is readily seen, and this inherent sandiness encourages many people -- particularly the Tripolinos — to call it 'As-Sahara' (the desert). Generally speaking the sands are of two types: coastal and continental; the former are much whiter and coarser than the latter (see chapter 3).

East of the Wadi Mejenin, the Jefara Plain is almost completely covered by sand and in many places the dunes are well-developed and high enough to affect contouring of maps (see fig. 8). Bernet emphasises this (5 p.386): 'Ailleurs encore et surtout dans les environs de Tripoli les sables donnent naissance à des dunes, qui s'étendent de Gargarech à Sayt-Bemealemmet atteignent le bord de la mer à Karabouli, couvrant ainsi une surface de plus de 50,000 hectares.' Such large areas of sand seem anomalous with a rainfall of 10-12".

From Tajiura eastwards, dunes border the sea but in the opposite direction the coastline is rocky and only beyond

Sabrata does the consolidated material disappear in favour of coastal dunes; these then stretch almost continuously to the Tunisian border.

Not only the eastern corner of the Jefara is sandy, since to the south of Tripoli there is a menacing zone of dunes. The main sand area starts a few kilometres south of the town and continues to the neighbourhood of Gasr Ben Gashir, and when travelling from Tripoli to Idris airport, unfixed dunes can be seen barely a kilometre from the road. This wide belt of sand, lying south of Libya's largest town, extends westwards and a considerable area of dune-land had to be levelled when the Italians established their agricultural settlements in the Azzahra (formerly Bianchi) region. In this latter area and also a little farther west the dunes are smaller, but even so there is still a generous sprinkling of sand; this is well seen along the Zawia-Bir el Ghnem road.

Sandy conditions prevail over most of the western Jefara but are more severe in the south-west, where dunes are evident north of Bir Zigzau. Here, however, in contrast to those in the east, the higher dunes are underlain by solid rock, probably of Triassic age. This south-western area is the territory of the Siaan people and also a favourite breeding ground of the desert locust, when there are invasions from Tunisia and Algeria.

Quite large unfixed dunes extend from Tripoli westwards right up to the Tunisian border. These lie a few kilometres inland from the coast on the south side of a continuous band of salt marshes.

Amid the Dune Jefara are depressions which fall into two categories: on the one hand salt marsh or swamp areas (sebkh in arabic) and on the other the normally dry depressions which may hold water for a time, following winter rains. The sebkh are confined to the western part of the Jefara and are usually found in basins which run a few kilometres inland, parallel to the coast and between two lines of dunes. There are low-lying areas, which have saline characteristics, in the central part of the western plain, but these are better developed in Tunisia. Saline regions will be given a more detailed consideration in chapter 3.

With certain exceptions, the Jefara Plain constitutes a vast expanse of sand, thick in the east but thinning westwards. Only a belt 15 kilometres wide running at the foot of the escarpment (the Pre-Jebelic hills and basins), the sebkh and the rocky coastal area around Tripoli interrupt the monotony of this pattern. Despite the abundance of sand, the menace of moving dunes is only a real danger south of Tripoli in the neighbourhood of Ain Zara, in the Sidi Ben Nur and Garabulli districts, and along the western coastal oases. A vigorous planting and fixing programme has been started in these localities over the past few years.

5. <u>Wadis</u>. (For names of major wadis see fig. 13). The morphological map (fig. 2) clearly shows the wadi pattern and it reveals several interesting facts. In the eastern part of the Jefara at least six wadis flow to the sea, but west of the Wadi Mejenin none flows beyond the Inner Jefara zone. Again in the

east, several wadis rise behind the escarpment and have sizeable catchment areas in the Jebel. These, since they are so near base-level, have captured large parts of the upper Soffejin system, but capture of this nature only occurs once in the west. This readjustment of drainage patterns can be attributed to a past pluvial phase in Pleistocene times when headward erosion in the upper reaches of the eastern wadis was accelerated.

As the wadis of the eastern Jefara have large drainage basins in relation to their length and also a steep gradient to base level, they flow to the sea in most winters and manage to maintain their channels through what has already been described as an extensive sand area. Furthermore, since they are striving to attain a graded profile, downcutting is in progress and incision of up to 10 metres is evident in some of the wadis both in piedmont and coastal areas. Wadis Raml and Turgut, since they are fed by springs near the coast road, have a perennial flow for a few miles and their channels are quite deeply incised into unconsolidated material.

The wadi Rbea has a small catchment area and is easily defeated by the Dune-Jefara. Not far to the west, however, the Wadi Mejenin flows 60 kilometres across the plain and still reaches the sea during the majority of winters. It achieves this because it has the largest drainage basin of all the wadis. The Wadi el Hira, lying immediately to the west of the Mejenin, has a catchment area of a similar size to its neighbour, but it fails to reach the sea; instead it spreads its water over the Inner Jefara.

In the west there is only one wadi which collects water behind the escarpment. This flows on to the Jefara east of Jaush and at some former and more humid time captured the headwaters of a dip-slope stream. When arid conditions developed this was probably the last wadi to flow across the western Jefara since there is an interesting alignment with sebkh in the north, which appear to mark a former wadi channel.

So far we have seen that in the east there are major wadis which, because of their large catchment areas and nearness to base-level, easily flow to the sea after periods of heavy winter rainfall. Most of the other wadis, with one exception already mentioned, are different. They are short, obsequent streams which start on the scarp face and having a small volume of flow soon lose themselves by percolation and evaporation in the Inner Jefara.* Most of them collect water from the northern side of the Jebel and from springs at the foot of the Nalut limestone. A few wadis rise several miles north of the escarpment (see fig. 2); these are definitely related to the small bench and cuestas already discussed and are nourished by intermittent springs which usually only flow in the winter.

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* Bernet (5) suggests that there has been warping in the inner zone of the western Jefara with the result that wadi beds slope southwards instead of northwards. Wadi flow is therefore easily defeated.

Table 1.[illegible]

TABLE OF GEOLOGICAL HISTORY

ERA	SYSTEM	STAGE	DEPOSITS	NOTES
QUATERNARY	HOLOCENE	FLANDRIAN	Alluvial and Aeolian	Slight ingression. Continental conditions for most of the Jefara.
	PLEISTOCENE	WÜRM	Red calcareous crust with siliceous aeolian elements Sandy, reddish clayey material which is slightly ferruginous Marine sand	Mainly Continental
		RISS	Argillaceous and reddish sand.	Continental
		TYRRHENIAN	Almost continuous thin clay layer.	Marine
		MINDEL	?	?
TERTIARY	PLIOCENE	-	"Gefarico"	Continental, marine regression
	MIOCENE	PONTIAN	Sand and clay	?
		TORTONIAN	White and yellowish limestones	Marine
		HELVETIAN	Green and very fossiliferous clays and marls.	Marine
		LANGHIAN	Sand, sandstones, gravels and shingle.	Marine
	OLIGOCENE	-	"Gefarico"	Continental
	EOCENE	-	"Gefarico"	Continental
MESOZOIC	MIDDLE CRETACEOUS	DANIAN		Retreating Sea
		SENONIAN	Marls, chalks, limestones and crystalline limestones.	Transgressive and oscillating movements of the sea. Doming of the Jefara and N.W.-S.E. faulting near Tarhuna.
		TURONIAN	Massive limestones (Nalut Limestone in the west). Soft marls with lesser yellow, red and white limestones (Tigrina formation in the east).	Marine
		CENOMANIAN	Tufaceous limestones, variegated marls and sandstones. (In the Gharian area Christie divides the deposits as follows: Gharian Dolomitic Limestone, Yefren Marls, and Ain Tobi Limestone)	Total immersion of land by the sea.
	LOWER CRETACEOUS	ALBIAN	Sandstones, quartz, conglomerates, cemented sands	Continental. Deposits thin and disappear to the east.
		WEALDEN	Marls and Clays	Continental. Deposits in the east more of a sandstone and conglomeritic nature. Albian and Wealden rocks form small côtes in the west.
	JURASSIC	BAJOCIAN	Bu Gheilan Dolomitic Limestone.	Marine and lagoon conditions.
		LIAS	Bu Sheba Sandstone & Conglomerates. Bir el Ghnem Gypsum.	Deposits make up much of the El Menshar Hills.
	TRIASSIC	MUSCHELKALK	Grey to dark grey, buff compact limestone.	Marine. Outcrops evident at Azizia and Sidi Bu Argub.

After Archambault (4) planche I
Brichant (6) p.8
Christie (9) p.6
Despois (16) p.16
Lipparini (21) pp.226, 227, 248 and 260

C. Structure and Lithology.

Outcrops of the solid geology are limited because Quaternary deposits cover most of the plain. The table of geological history shows that Jurassic, Tertiary, Quaternary and Recent deposits are found above the Triassic sediments which are the oldest rocks of the Jefara (Table 1.1).

1. The Escarpment. A brief study of the geology of the escarpment and the Pre-Jebelic hills will facilitate an understanding of the general build of Northern Tripolitania. This is essential for a thorough appreciation of the structure and distribution of Tertiary and Quaternary deposits, within which all important aquifers are found.

In Tunisia Pervinquière (25) has shown that the escarpment is Middle Cretaceous: mainly Cenomanian and Turonian, but some Albian. A section at Kabao in the western part of the Tripolitanian escarpment gives a succession from Turonian to Jurassic as follows:-

Table 1.2 Geological Section at Kabao.

Thickness from top downwards	Deposit	Age
0-40 metres	Nalut Limestone	Turonian
40-80 metres	Gypsum	Cenomanian
80-120 metres	Limestone	"
120 metres	Sandstones, marls some sand.	Wealden
	Dolomite	Jurassic

(Supplied by Compagnie Francaise des Pétroles)

The Nalut Limestone is massive here in the extreme west and has a spring-line at its base; it dips gently to the south but at the same time rises gradually to the east -- at Nalut its upper surface is 600 metres above sea-level but at Gharian 700 metres.

However moving eastwards the situation changes since the sedimentary beds vary laterally both in thickness and lithology. The Nalut Limestone loses its importance since it is less compact and homogeneous. Even south of Jaush it has disappeared from the top of the escarpment and at Gharian it lies well south of the escarpment. At this latter place the structure of the Jebel is more complicated than elsewhere due to the disruption of the normal cuesta form, but at Bu Gheilan the picture is fairly clear. Here Lower Cenomanian forms the top of the cliff with outcrops of Wealden and Jurassic lower down its face. To the east there are two major N.W.-S.E. orientated faults with their downthrow side to the east (see fig. 2); these bring Gharian limestone, which is Upper Cenomanian, to the top of the escarpment, but only temporarily, because north of Tarhuna and Breviglieri the escarpment is Lower Cenomanian again.* This state of affairs persists until the Cretaceous finally disappears below the Miocene between Kussabat and Khoms.

The escarpment in Tripolitania, as in Tunisia, is thus largely composed of Middle Cretaceous, but Lower Cretaceous is more evident in the 'cliff' face in central regions than elsewhere. The sedimentary beds of the Jebel have a gentle dip

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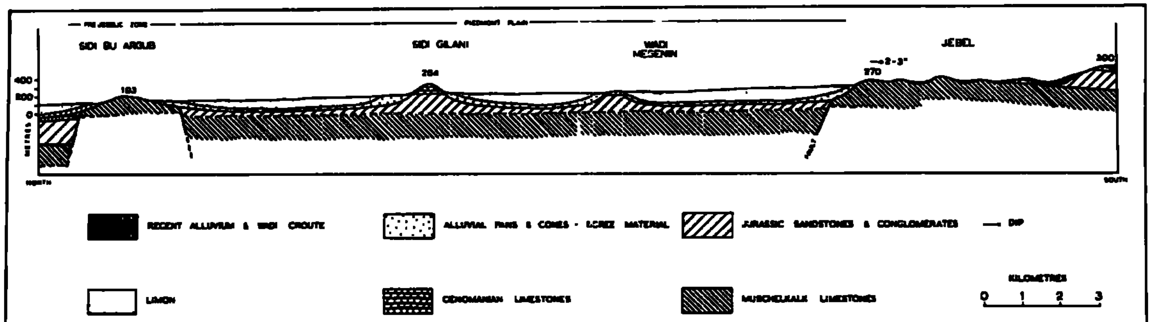
* As evidenced by the work of the D'Arcy Exploration.

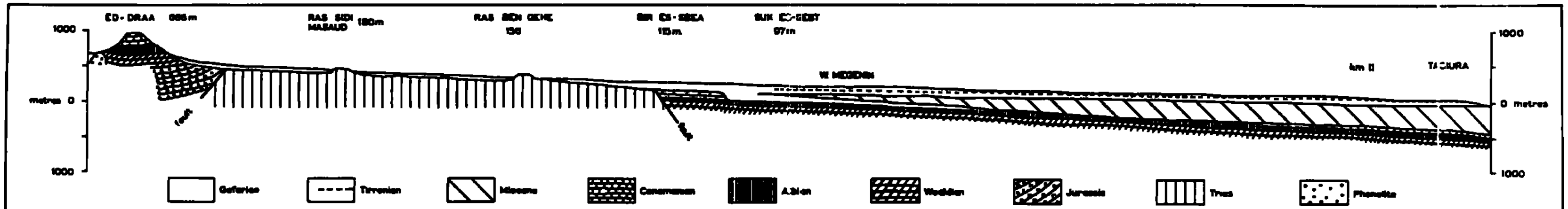
southwards of 1-3^{o}, but they also dip slightly east and west from its highest part between Gharian and Yefren. This generalization naturally omits irregularities which are not relevant to this study.

2. Pre-Jebelic Hills. The structure of these hills is intimately related to that of the Jebel. We have noted certain small cuestas and bench features in the south-west of the Jefara, not far from the escarpment and a spring-line was discovered in association with these. The bench is described by Zaccagna (34) as follows:- 'A Giosc tant, due villagi componenti l'abito, che il castello trovasi sopra uno scaglione roccioso pianiggiante formato dalla stesso calcare giallastro, sabbioso, siliceo che abbiamo trovato a Gasr el Hag e Scecsciuk sormanta la formazione lignitifera'. Zaccagna dates the rocks of the bench as Wealden and Christie (9) confirms this. Bernet (5 p.390) is much less precise and vaguely writes of a zone of gypsum stretching continuously from the north of Nalut eastwards for 150 kilometres to Shakshiuk. According to Despois (16 p.14) the festoon of small sandstone and marl cuestas round Gasr Tekut is also Wealden. The south-west dip of the cuestas contrasts with a southward dip of the bench in the east and it is interesting to note that the Wealden rocks which form these small cuestas are found near the top of the escarpment at Bu Gheilan.

Between the Yefren spur and Bir el Ghnem are the El Menshar hills. These are largely Jurassic sediments but there



DETAILED GEOLOGICAL SECTION OF THE INNER JEFARA IN THE NEIGHBOURHOOD OF THE WADI MEGENIN after COTHA

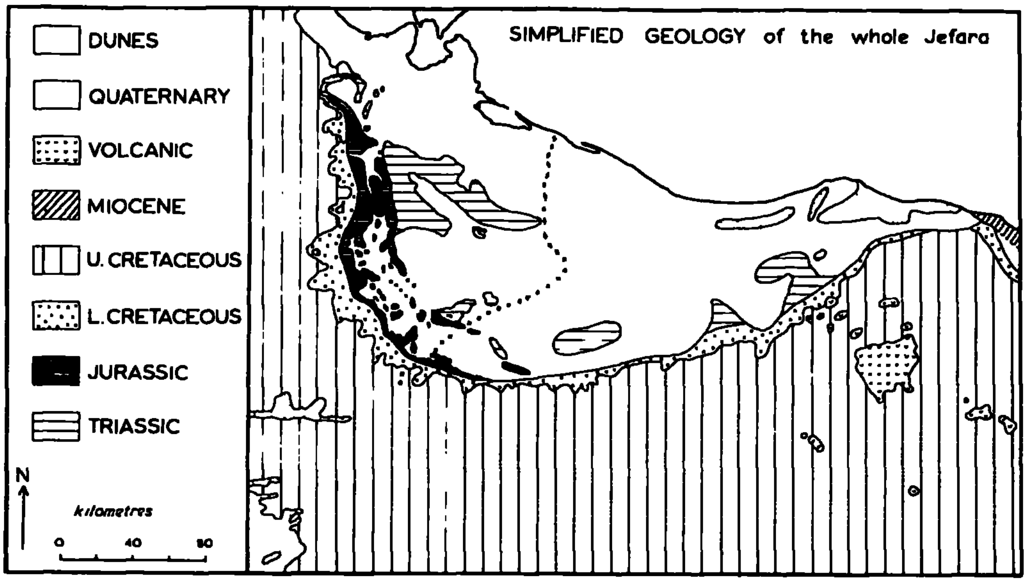


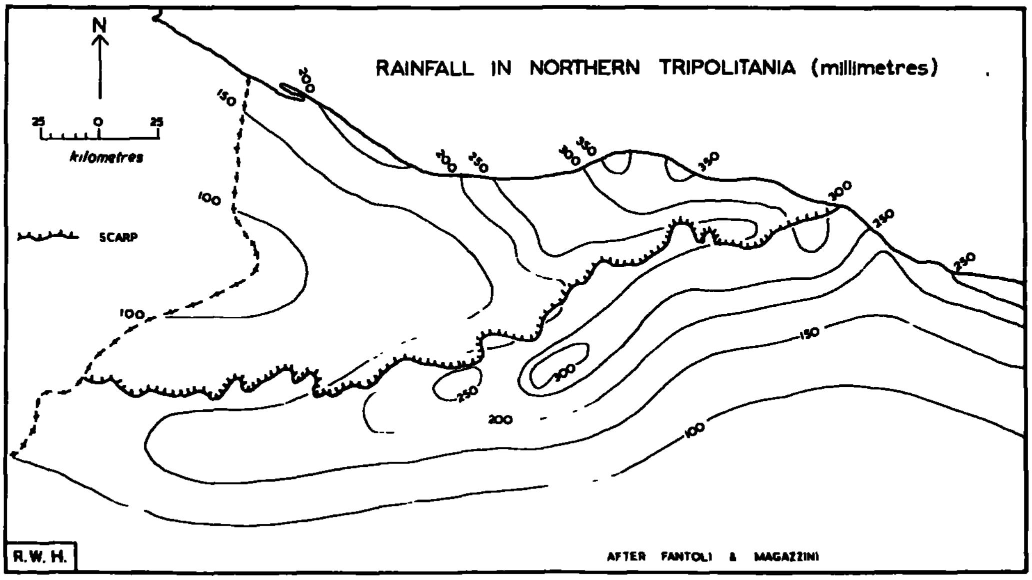
GEOLOGICAL SECTION ACROSS THE JEFARA PLAIN is a trace of Wealden and even Cenomanian on their summits.

North of the central part of the escarpment, the Inner Jefara is more complex than elsewhere; this is due to considerable faulting (see fig. 4a). West of the Azizia-Bu Gheilan road the isolated Pre-Jebelic hills are Triassic (see fig. 4b), but to the east they are remnants of younger rocks — Jurassic and Cretaceous, except to the north where Triassic is upfaulted. The C.O.T.H.A. report (20) gives the best description of the area 'les pointements crétacés, dans notre hypothèse et étant donné la structure quasiment tabulaire de tous les affleurements de la zone piedmont, pourrait être considérés comme les buttes-témoins laissées pour compte sur le substratum triassique par l'érosion fluviale des uadis avant l'effondrement de la zone'. The Triassic hills are composed of Muschelkalk which is well exposed at Azizia, Ras Ben Sehe and Sidi Bu Argub; the younger rocks are lithologically similar to those of the same age in the escarpment. The Muschelkalk, which belongs to the Middle Trias, is the oldest rock to outcrop on the Jefara and indeed in the whole of Northern Tripolitania. Upper Trias, which occurs as a thick series of gypsum in the Tunisian Jefara, is absent in Tripolitania and Cretaceous and Jurassic rocks rest directly on Middle Trias. Archambault (4 p.8) is convinced that this largely accounts for the better quality of groundwater found in the Tripolitanian Jefara.

3. <u>General structure</u>. The structure of the escarpment and the

Pre-Jebelic Hills suggests that northern Tripolitania is the eastern half of a breached pericline, the core of which is Triassic and outcrops as indicated in fig. 4b. The core has been modified in certain central regions by heavy faulting, sinking and minor doming associated with igneous activity (see fig. 4a). The southern limb of the pericline is the escarpment plus the dip slope of the Jebel, the eastern limb is the eastern end of the Jebel, and the northern limb lies under the Jefara plain north of the Triassic core. The western limb begins to appear around Nalut where the dip is already to the south-west, and emerges clearly in Tunisia as the escarpment swings northwards. Ahlmann (1) describes the great block of the Sahara as terminating at the Mediterranean like a wave, but Lipparini ~~(16 p.237)~~ (21, p. 237) is more definite: 'le formazioni mesozoiche del Gebel tripolitano costuiscono una vasta intumenscenza anticlinalica con l'asse orientata N.W.-S.E.' The map of the simplified geology of the whole Jefara (fig. 5a) also seems to indicate an elongated domal structure which may be tilted to the north-east. Extensive work carried out in Tunisia by the French gives further support to this theory and can be summarised thus (17, p.32): 'Les Matmatas, le Dahar et la Djeffara font partie d'un vaste dôme à pendage très faible; celui-ci dont le flanc Nord est masqué, se continue ver l'Est en Tripolitaine jusque au delà de Tripoli. Le coeur de ce dôme est formé par les affleurements de Trias de Kirchaou, Ksar Morra et Sidi Toui. L'ensemble est affecté de très faibles ondulations'.


SIMPLIFIED GEOLOGY of the whole Jefara
DUNES
QUATERNARY
VOLCANIC
MIOCENE
U. CRETACEOUS
L. CRETACEOUS
JURASSIC
TRIASSIC
N
kilometres
0
40
80

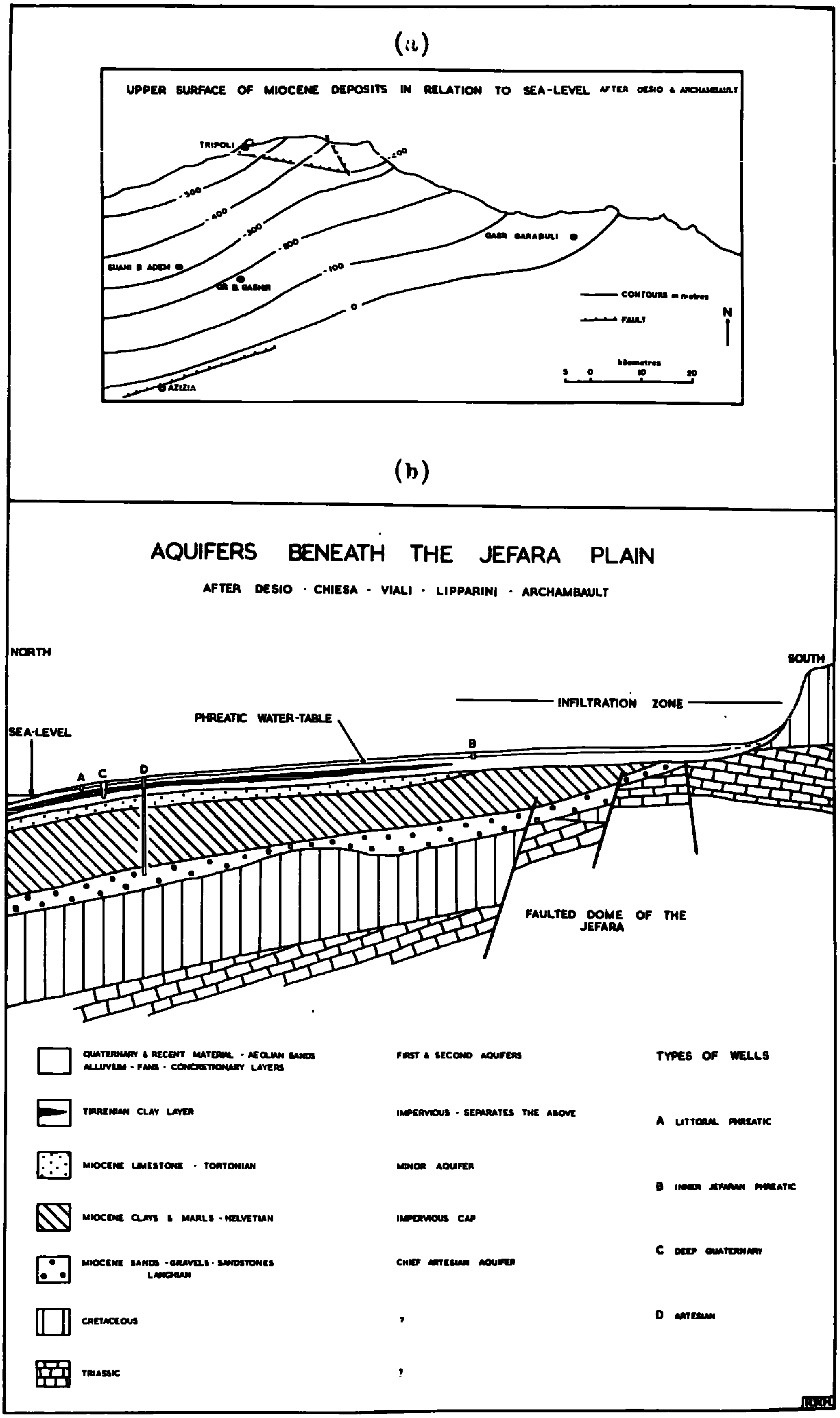

RAINFALL IN NORTHERN TRIPOLITANIA (millimetres)
N
25
0
25
kilometres
SCARP
150
200
100
250
300
350
R.W.H.
AFTER FANTOLI & MAGAZZINI

4. The Jefara Plain.

a) Miocene. Tertiary, Quaternary and Recent material cover much of the Jefara. Of the Tertiaries, Miocene sediments are by far the most important, but they do not outcrop on the plain except in the extreme east, where, as fig. 2 shows, they appear over the Cretaceous deposits of the Jebel. As a result of drilling for artesian water along the coast, Miocene has been recognised beneath the Quaternary. A typical section (4.) is given in the table of geological history. Basically this gives three sub-systems: Tortonian, Helvetian and Langhian, although Amato (3) suggests a further one, the Pontian. Fig. 6b shows how the Miocene is divided into two by a thick band of clay and marl, above which is mainly limestone and below, sandstones, sands and gravels.

It seems that the Miocene deposits thicken to the west, since Castany (8 p.130) quotes clays with lenticular sands 400-800 metres thick at Ben Gardane just over the frontier in Tunisia, while Brichant (6 p.8) maintains that Miocene deposits never exceed a thickness of 500 metres in Tripolitania. For the eastern Jefara this is probably true since at Es-Sbabil they are only 170 metres thick (3). The sediments were deposited under transgressive conditions and the Miocene sea was halted by Triassic hills in the south, about 30 kilometers south of the present coast line. The Miocene layer is 31 metres thick at Suk Es-Sebt but at

Figure 6.


(a)
UPPER SURFACE OF MIOCENE DEPOSITS IN RELATION TO SEA-LEVEL AFTER DESIO & ARCHAMBAULT
TRIPOLI
SUANI B ADEM
GASR GARABULI
AZIZIA
-500
-400
-300
-200
-100
0
CONTOURS in metres
FAULT
N
kilometres
5 0 10 20
(b)
AQUIFERS BENEATH THE JEFARA PLAIN
AFTER DESIO · CHIESA · VIALI · LIPPARINI · ARCHAMBAULT
NORTH
SOUTH
INFILTRATION ZONE
PHREATIC WATER-TABLE
SEA-LEVEL
A
B
C
D
FAULTED DOME OF THE JEFARA
QUATERNARY & RECENT MATERIAL - AEOLIAN SANDS ALLUVIUM - FANS - CONCRETIONARY LAYERS
FIRST & SECOND AQUIFERS
TIRRENIAN CLAY LAYER
IMPERVIOUS - SEPARATES THE ABOVE
MIOCENE LIMESTONE - TORTONIAN
MINOR AQUIFER
MIOCENE CLAYS & MARLS - HELVETIAN
IMPERVIOUS CAP
MIOCENE SANDS - GRAVELS - SANDSTONES LANGHIAN
CHIEF ARTESIAN AQUIFER
CRETACEOUS
?
TRIASSIC
?
TYPES OF WELLS
A LITTORAL PHREATIC
B INNER JEFARAN PHREATIC
C DEEP QUATERNARY
D ARTESIAN

Bir Sbea it has disappeared (21).

Along the northern edge of the Jefara the upper surface of the Miocene slopes down distinctly westwards as is shown in fig. 6a and confirmed by the following figures which are in metres below the surface.

Es-Sbabil	Hashian	Casa Cantoniera	Garabulli
80	72.5	34	28

Since the land also falls to the west, the slope of the Miocene must be considerable.

b) Other Tertiaries. It is often extremely difficult to differentiate between some of the Tertiary, Quaternary and Holocene deposits since fossils are usually absent and lithological characteristics are so very similar. Lipparini attempts a solution by calling them all "Gefarico". This Gefarico series is composed of the following: beds of sandstones and molasses, aeolian sand, limestone cements, fluvial breccia and conglomerates and other alluvial material. Eocene, Oilgocene and Pliocene deposits are represented by this Gefarico series. Eocene and Oligocene systems occur as marine facies in the Sirte area and are easily dated, but not so on the Jefara where the facies are continental. All the Tertiaries dip gently north or northwest.

c) Quaternary and Recent. The continental Gefarico series of Holocene, Pleistocene and Pliocene (?) overlie marine Miocene rocks in the north, and Triassic, Jurassic and Lower Cretaceous rocks in the south. These are the real surface deposits and consist of crusts, sebkha, dunes and alluvial sands. Solid geology is obscured by these superficial deposits except where the Pre-Jebelic hills manage to break through them.

The thickness of the material is very variable but averages 50 metres; for instance on the flanks of the El Menshar Hills it is 47 metres, at Sidi Jilani 20 metres, and on the piedmont plain between Sidi Bu Argub and the Jebel 100 metres.

The piedmont plain is very interesting and has been studied in some detail by C.O.T.H.A. as it lies in the diversion zone of the Wadi Mejenin (see fig. 4a and reference 20). To the north it is bounded by the Triassic horst of Azizia and Sidi Bu Argub and to the south by the Cretaceous escarpment. This basin, which is largely stripped of its Jurassic and Cretaceous deposits, is now filled with unconsolidated material washed and blown from the Jebel. Arab wells have failed to reach the base of the Quaternary at 80 metres. As we shall see later this downfaulted area is significant when considering movement of water in the 'nappe phreatique' because Pioger visualises a considerable flow of underground water towards Azizia.* In the Gefarico there is one small but very important clay layer which is the result of a brief marine transgression in Tyrrhenian

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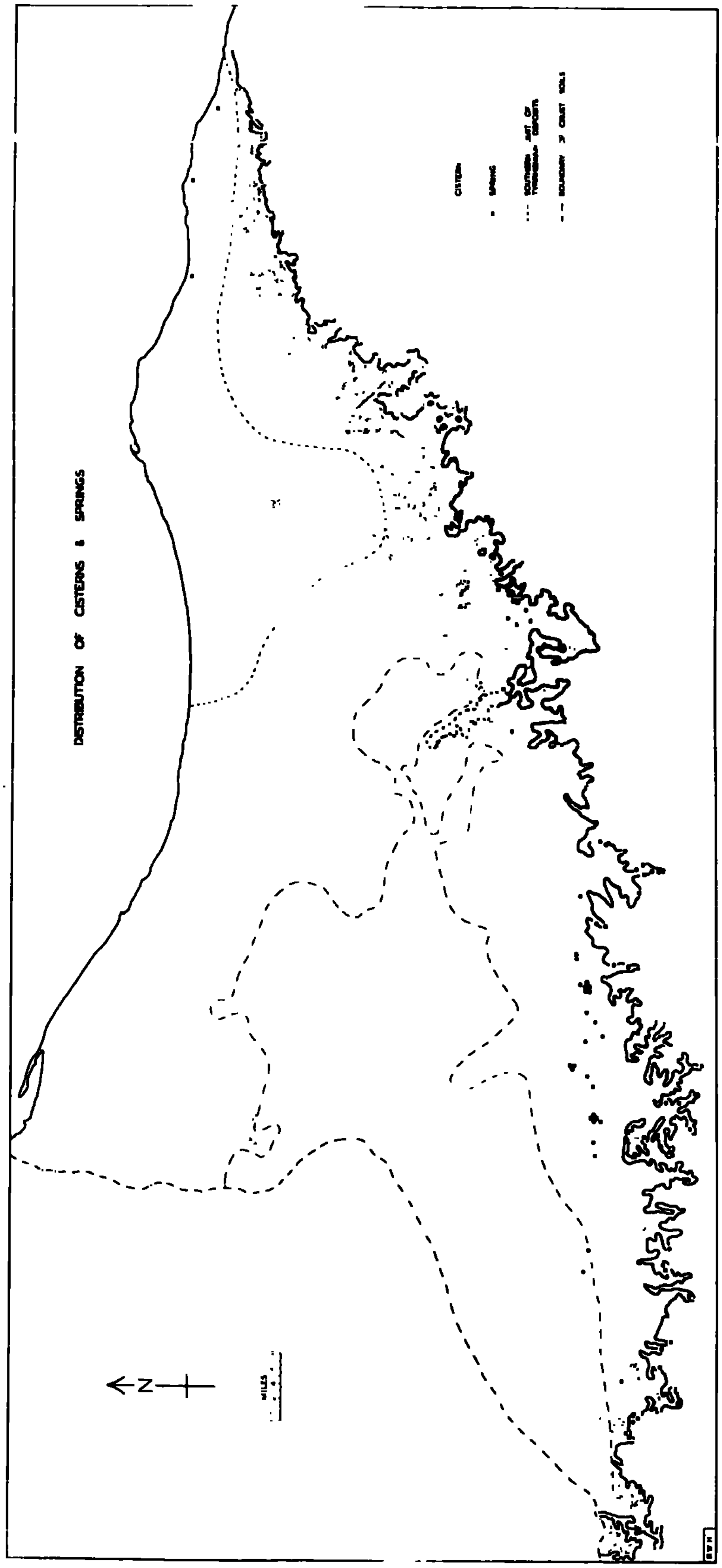
* B/44 May 1952.


DISTRIBUTION OF CISTERNS & SPRINGS
CISTERN
N
MILES

times: 'Nella serie pleistocenici si intercala verso la parte superiore la panchina marina del Tirreniano' (21 p.230). This thin clay layer which is found up to 35 kilometres south of the present coast, occurs south of Tripoli as a band 8 metres thick and 54 metres below the surface; it outcrops principally at Ain Zara and at the base of the fringing reef west of Tripoli (see fig. 7).

D. Palaeogeography of Tertiary and Quaternary times.

The sea, which covered much of the Jefara in Miocene times, retreated as a result of an uplift of up to 100 metres and during the Pliocene period continental conditions prevailed. The glacial phases -- Mindel, Riss and Würm — occasioned negative base-levels. During the Riss glaciation in Europe there was a major negative eustatic change of sea-level in Tripolitania and the sea retreated even farther north than the present coastline. In the Mindel-Riss Great Interglacial (Tyrrhenian) there was a positive eustatic movement and the sea moved inland about 25 miles south of Tripoli to Suk Es-Sebt, the remainder of the Jefara experiencing continental conditions. In the Würm glacial period continental steppe conditions developed again and many of the present superficial deposits were accumulated, even some of the coastal dunes. Since the Flandrian marine transgression of immediate Post-Glacial times there has been a minor drop in base level accompanied by a weak marine ingression giving rise to small cliffs along the coast; at the same time coastal dunes and inland continental deposits have been augmented (21 p.260).

E. Morphological Units.

Following our study of morphology and structure the area under consideration may be divided into the following units:

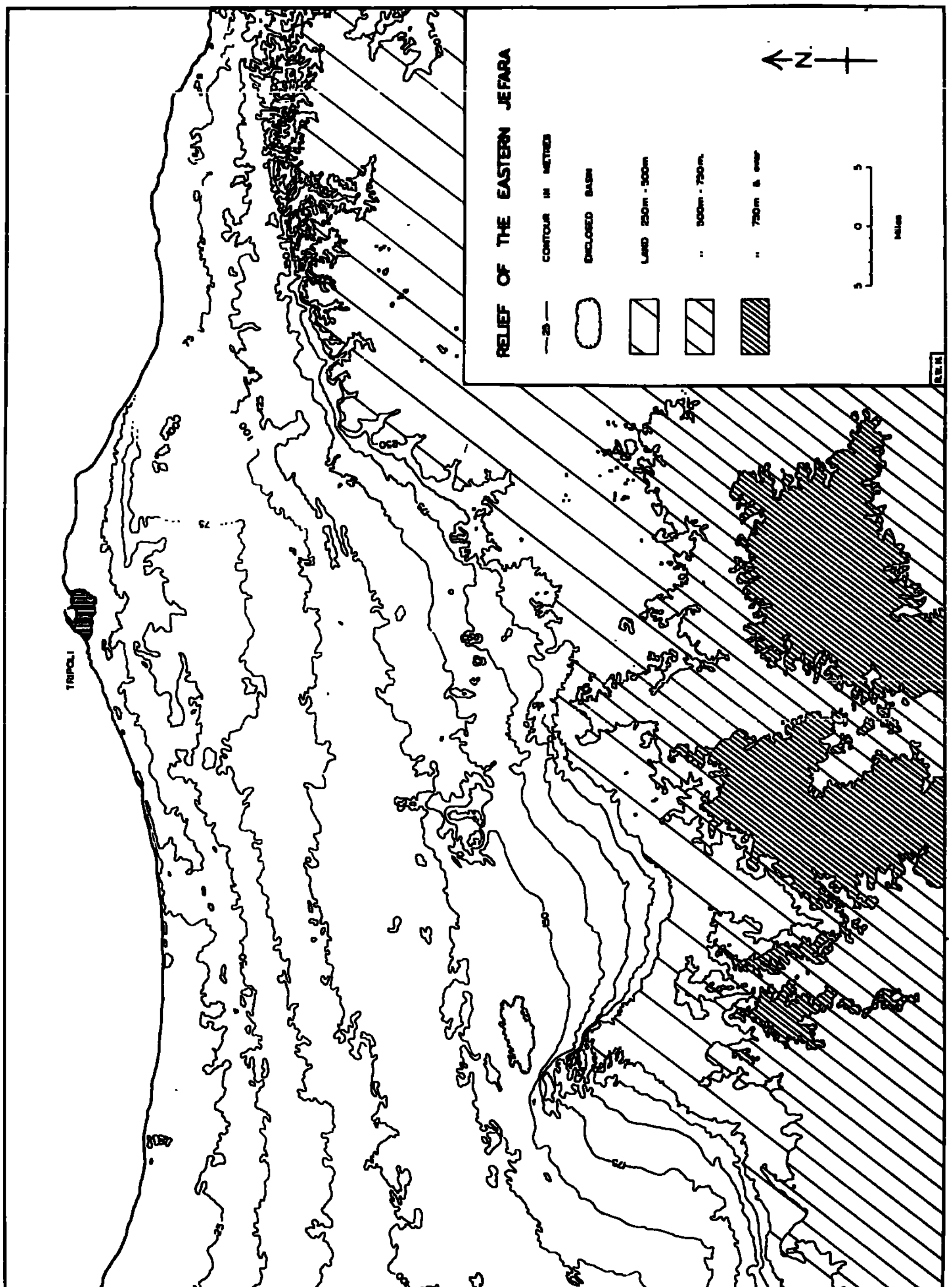
1) Rocky coastal littoral round Tripoli where consolidated Quaternary and Tertiary material is exposed.
2) Coastal dunes to the north and south of lagoon sebkh.
3) Sebkh: lagoon and inland.
4) Dune Jefara stretching from Gasr Khiar to the Tünisian border and divided into two by the Wadi Megenin:-
   a. Eastern Jefara - area of exoreic drainage.
   b. Western Jefara - area of endoreic drainage.
5) Inner Jefara:-
   a. Alluvial outwash zone of plains and basins at the foot of the escarpment.
   b. Faulted piedmont zone in the vicinity of the Wadi Megenin--infilled basin.
   c. Pre-Jebelic Hills.
6) The Escarpment.

F. Conclusions.

A plain area of nearly 20,000 sq. kilometres would appear to have good agricultural possibilities but the study of its morphology has already revealed extensive negative areas such as sand and salt marshes.

The area of sedentary agriculture, which is shown in the frontispiece is mostly confined to the Eastern Jefara. The relief of this area, as shown in fig. 8, is that of a gently undulating plain inclined seaward; there is no steeply sloping land. From the point of view of slope and aspect the whole of the Jefara

Fig. 3.



RELIEF OF THE EASTERN JEFARA
25 CONTOUR IN METRES
ENCLOSED BASIN
LAND 250m - 500m
" 500m - 750m
" 750m & over
5 0 5
Miles
N
TRIPOLI
ZUARA

Plain, with perhaps the exception of the higher dunes in the east, is suitable for cultivation, but unfortunately relief is not the main determinant of the distribution of cultivated land. In many ways the flattest and best land is in the waterspreading zone of the Inner Jefara.

Most of the Jefara consists of Tertiary and Quaternary sediments which have been deposited on the northern flanks of a dome formed in Upper Cretaceous times. Lithologically they are largely pervious and porous, making excellent aquifers; furthermore they dip gently northwards so that any underground water within them will flow in this direction. Conditions are therefore favourable to the accumulation of groundwater. The hydrology of these young deposits is also closely related to the wadi systems. Most of the eastern wadis flow directly to the sea and very little of their water finds its way underground, but to the west there is a considerable amount of natural 'épandage' and a certain percentage of water percolates downwards to supply the Tertiary and Quaternary aquifers.

Finally it is quite clear that superficial formations (Gefarico) of Quaternary and Recent age are the dominant parent material of Jefaran soils. Outcrops of solid rock are few and are usually limestone, rarely marls/or clay. Soils will therefore be of a sandy nature rich in calcium carbonate but deficient in clay.

CHAPTER 2

Agriculture and Land-Use

A. Introduction

In Libya, estimates of land-use areas are very approximate, and since they are based usually on unreliable statistics they should be used with caution. The Jefara Plain only covers about 6% of Tripolitania's total area but it has 20% of the productive land. Figures for Tripolitania are as follows:-

Total area .... 35,000,000 ha.
Productive .... 10,000,000 ha.

The productive land is composed of 8,000,000 ha. of rough grazing, 1,600,000 ha. of shifting cultivation patches, and 400,000 ha. of sedentary agriculture. The area of sedentary agriculture can be broken down into 127,000 ha. of Hawāza farm land, 103,000 ha. of Demographic settlement land, 50,000 ha. of irrigated saniya land, and the remainder, which is dryland Arab farming (mainly in the Jebel) and a small afforested area.

Although well organised statistics are available for land-use areas in Cyrenaica, it is difficult to make comparisons with Tripolitania because the two provinces use a dissimilar classification. However, statistics supplied by Kroeller* appear to indicate that the area of productive land in Cyrenaica, 1,902,000 ha. is much less than that in Tripolitania. Other figures given by Kroeller are:-

Arable land	420,000 ha.
Land under tree crops	30,000 ha.
Forest land	450,000 ha.
Irrigated land	1,000 ha.

The only conclusions that can be drawn from these figures are that

* B/97 Kroeller - Land utilisation and crop production estimates for Cyrenaica, 1956/7.

the area of forest land is much larger in Cyrenaica but the area of irrigation is much smaller and almost insignificant.

B. Land-use on the Jefara Plain (see fig.9)

About 2-3% of the plain is irrigated land, about 15% dryland whether sedentary or shifting cultivation, about 60% is grazed and the remainder is waste. The main land-use divisions are:-

Unused land
Forest land
Shifting cultivation
Grazing land and grazing land with cereals
Areas of sedentary agriculture (see frontispiece) which include Libyan private and demographic saniya farms, Italian concession farms, Libyan hawāza farms, demographic Italian farms, specialised commercial farms, and Government farms.

C. Unused Land: Afforested Areas.

The unused land shown in fig. 9 can be related to the sebkh (salt marshes) and the dune lands which are shown in fig. 2. The salt marshes offer very little prospect for development except for the better control of grazing and a possible introduction of improved varieties of salt-tolerant grazing plants. The dune lands, particularly those in the east, could be utilised when they have been fixed by the Forestry Department.

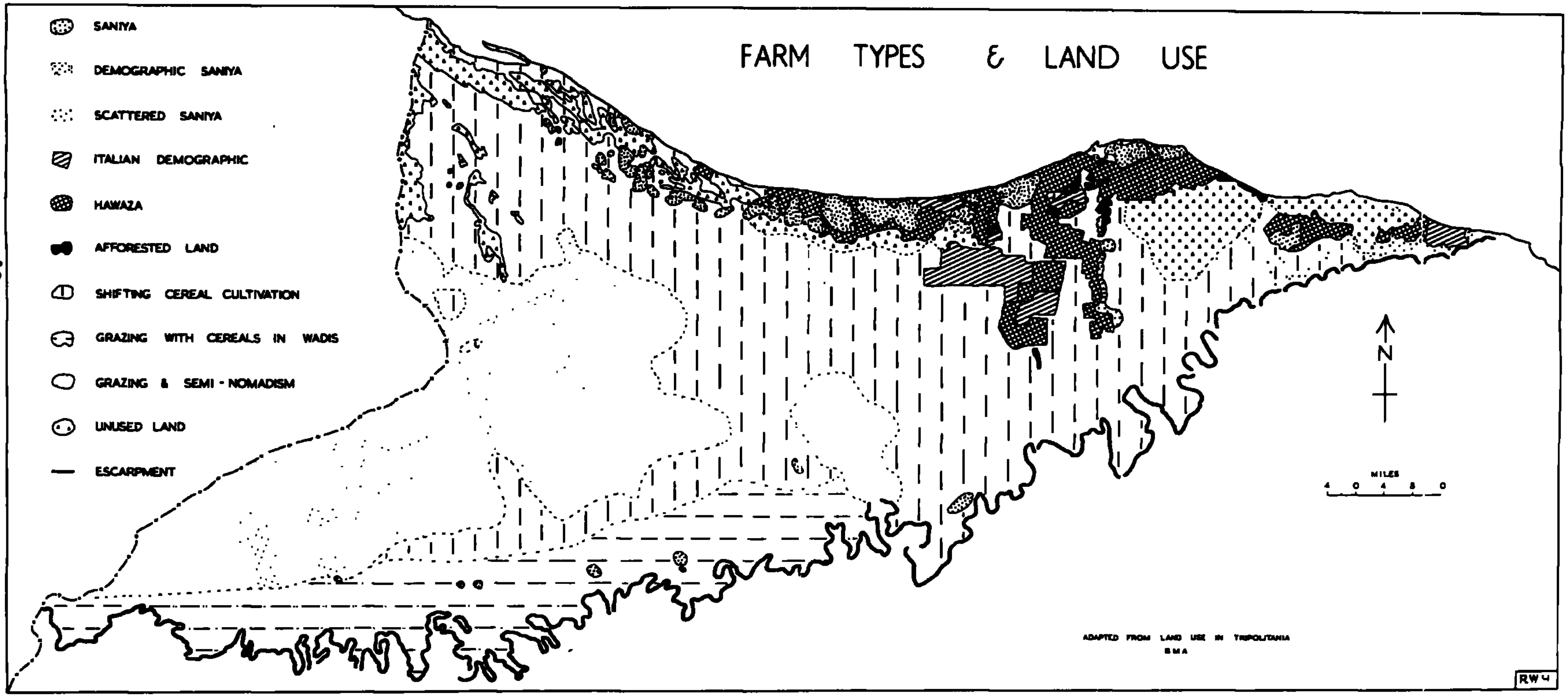
The areas of forest land have not been measured, but the following estimates give an idea of the distribution pattern:-

Table 2.1 Estimates of state forest land on the Jefara*

Ain Zara	1,000 ha.	Abu Salim	723 ha.
Sidi Ben Nur	2,300 ha.	Tripoli (Suani B. Adem-Azizia road)	3,102 ha.
El Guea	1,250 ha.	Sghedeida	250 ha.
Bir El Ferhian	4,078		
Victory Forest near Jialo Barracks, Tripoli			900 ha.

The Italians started planting trees soon after their arrival

* Jiumaa Jiaddui, Forestry Officer.


FARM TYPES & LAND USE
SANIYA
DEMOGRAPHIC SANIYA
SCATTERED SANIYA
ITALIAN DEMOGRAPHIC
HAWAZA
AFFORESTED LAND
SHIFTING CEREAL CULTIVATION
GRAZING WITH CEREALS IN WADIS
GRAZING & SEMI - NOMADISM
UNUSED LAND
ESCARPMENT
N
MILES
4 0 4 8 0
ADAPTED FROM LAND USE IN TRIPOLITANIA
B M A
RW 4

because of the need to protect the coastal oases, and by 1940 2,000 ha. were under trees. Unfortunately several of the Italian forests were cut down during the 1939-45 war, as for example between Tripoli and Gasr Ben Gashir. Today it is estimated that each year private farmers are planting about 1,000 ha. of eucalypts and acacias, and at the same time the Forestry Department, which produces several million seedlings per annum, is slowly fixing dunes. In 1956/7, 1,700 ha. of sand dunes and steppe were planted. It is presumed that it will take at least 30 years to fix the most important dune areas in the eastern Jefara.

D. Pre-Italian pattern of agriculture and land-use.

Today, despite the development of agriculture during the last 30-40 years, the old form of traditional Arab farming is still evident; the superimposed Italian system has failed to destroy it.

1. Saniya Farms. The Libyan speaks of two types of farms; the large farm known as hawāza and the small farm known as saniya. Fig. 9 shows that the saniya farms are mainly confined to coastal area, although a few are found inland in the Dune Jefara and occasionally near the Jebel.

(a) Coastal Saniya. The farms are generally confined to several oases which are found in areas of lower relief where the first water-table is very near the surface. With water so accessible it can easily be lifted by the dalu (skin bucket). Agriculture is very intense because the oases have to support a crowded population which sometimes reaches a density of 7 and even 10 persons per hectare.

Farm holdings are often fragmented, land ownership is vague, methods of cultivation are very primitive and as a result the standard of living is low. (Farm Studies 41, 42 and 43 are examples of coastal saniya).

In summer, the main crops are pumpkins, water-melons, groundnuts, vegetables, millets, tobacco, henna, pepper, lucerne (safsfa); in winter, barley, wheat, potatoes and broad beans. Trees abound on most farms and are always closely spaced; they are nearly all fruit trees and the most important are dates, olives, citrus, peaches, apricots, almonds, figs, pomegranates, medlars, and mulberries. The Tripoli-Suq El Jiumaa-Tajiura oases are the best endowed with water and here cultivation is the most intense.

The coastal oases have been studied in detail by the Italians and their work can be summarised thus (3,15 & 21):-

Table 2.2 Libyan Saniya Farms 1932

Locality	Total area ha.	Irrig. gardens no.	Dry Orchards no.	Wells no.	Palms no.	Olives no.	Other fruit trees no.	Other trees no.
Tajiura	1626	1229	58	1242	54991	1631	11629	280
Tripoli) Menshia) Sahel))	5102	4017	210	4053	227314	53669	8893	1759
Gurji	55	29	20	40	412	2246	1977	31
Gargaresh	82	65	-	65	2282	406	361	9
Zanzur	2243	1681	228	1702	167131	15110	9762	15
Zawia	3590	2406	207	2465	177127	34714	14294	18
Sorman	1490	1007	271	1031	77629	10015	2009	89
El Alalga	1850	1237	365	1261	74315	3844	2506	-
El Ajelat	1780	616	602	623	38802	537	1433	-
Zuara	2825	47	2895	2766	83657	9108	111907	-
Approx. totals.	26643	12334	4856	15257	903660	131280	244871	2201

The total number of wells in the coastal oases is 15-16,000, and of the tree crops, palms are by far the most important and then olives. The average size of the saniya farm is 1.5 ha.* The date palm is most numerous in the Tripoli and Zanzur areas where densities approach 100 per ha., compared with 46.3 per ha. at Ajelat and 43.8 per ha. at Zuara. Olives reflect the same pattern although densities are lower - Zuara 2.8 trees per ha. and Zawia 14.2. Many of the saniya farms in the western oases do not grow any summer crops and they rely on winter wheat and barley; this poorer state of agriculture in the western areas is due to the limited quantity of fresh water that is available for irrigation. The importance of the various tree crops in the western oases is illustrated in table 2.3:-

Table 2.3 Percentage of Palms, olives and other fruit trees in the Western Coastal Oases

Oasis	Palm	Olive	Others
Zuara	40.8	4.4	54.7
Ajelat	95.1	1.3	3.5
Alalga	92.1	4.7	3.1
Sorman	86.22	11.12	2.66
Zawia	77.873	15.24	6.98
Zanzur	87.04	7.86	5.084

The high percentage for other fruit trees at Zuara is due to the large numbers of vines that are grown there. According to Theodorou date palms only made up 47% of the trees in the Zawia area in 1952 compared with 77% approx. given in table 2.3, which refers to the early 1930's. The decline in the percentage of palm trees is brought about

* This is often only part of a larger farm holding

by an increase in the number of olive trees, which in 1952 amounted to 42% of the trees in the area.

Theodorou (32) carried out detailed work in the Zawia area in 1951/2 and he discovered several important facts about land ownership in the oasis zone. He calculated the average size of farms in the Zawia area to be 50.1 ha., most of which is not located in the oasis zone, because many of the farmers who run saniya farms also own land in the Dune Jefara and Inner Jefara up to 70 kilometres to the south. On page 16 of his report he gives the following table which indicates exactly where the Zawia farmers' land is located:-

Table 2.4 Distribution of land belonging to coastal farmers at Zawia

Kind of land	%	Average per farm (ha.)
Irrigated land in the oasis	2.6	1.3
Dry farmed land in patches around the oases	9.9	5.0
Pasture land	2.1	1.0
Land in Inner Jefara	17.2	8.6
Land in Dune Jefara	68.2	34.2

(b) Inland Saniya. These have been developed since the Italians arrived and particularly since the last war, but they have been included here because they are a traditional type of farm. They are found in small clusters in the Dune Jefara and along the Wadi Mejenin in the Gasr Ben Gashir area. The Bir Langar district east of Ben Gashir is an example where prosperous small Libyan farms have been developed at the edge of the dunes. In this area the first water-table is about 25 metres down and when the wind pump was introduced by the Italians in the 1920's and 1930's, it was found to be ideally suited for raising water on these small farms. Today, a few diesel pumps are scattered here and there, one sometimes being shared by several farmers. One of the most enterprising farmers, who was visited, has installed an 11 h.p. diesel-generator to drive an electric pump which is capable of raising 35 m3/hr. New saniya farms are constantly being developed in the Dune Jefara. One farmer south of Zawia sold his sheep in order to buy a pump and with encouragement from American extension officers has gradually expanded his small farm in the dunes. Farm Study no. 44 is an excellent example of a new saniya farm which lies a few kilometres N.N.W. of Suani Ben Adem.

In many respects the inland saniya have the same appearance as their coastal counterparts; the same crops are grown and water is distributed by the same jedawl method; but the deeper water-table means a different technique for lifting water and fewer palm trees. There is likely to be a steady but small increase in the number of inland saniya in the future.

(c) Scattered saniya. In fig. 9 these appear in the eastern corner of the Jefara. Here the first water-table is much deeper because of the increased altitude of the land, and very few summer crops are grown. The escarpment is difficult to trace and there is an extension of Jebel olive cultivation almost down to the sea. Most of the farmers rely on the olive and to a lesser extent winter cereals.

(d) Spring-line saniya. In the west, not far from the foot of the escarpment, are several groups of springs which have been mentioned in chapter 1; they can be seen quite clearly on air photographs. These give rise to small oases at Rabta, Gasr el Haj, Shakshiuk, Jaush and Tiji. Sometimes the water-table is not quite at the surface and then only palm trees are evident. None of the springs gives a large quantity of water. Most of the oases grow large numbers of date palm which yield poor quality dates, and have small patches of irrigated land where millets, melons, pepper, onions, barley, and chickpeas are grown. The sap of many of the date palms is used to make a fermented local drink known as lagbi.

2. Shifting Cultivation. Fig. 9 suggests that a large part of the Jefara Plain is devoted to shifting cultivation but this is misleading, for only the more favourable patches of land are in fact utilised, the remainder, if it is not bare sand, being used for grazing animals which belong to farmers in the coastal zone. Barley and wheat are the two crops grown in this area, the former which is much the most important is found almost everywhere, the latter is limited to the heavier lands (Tin). When the first substantial autumn rains fall, the shifting cultivator arrives and broadcasts his seed by hand over the land and then ploughs it in with a primitive scratch plough,

which is usually pulled by a camel. He generally leaves the sown land during the growing season and then returns for the harvest. If the winter rains have been sufficient to give some sort of crop; at harvest time the whole family may come to the area. The name shifting cultivation stems from the idea that the farmer travels to an area where there has been a good rainfall and then sows his seed, with the result that different areas of land may be cultivated from year to year depending on the distribution of rainfall (see chapter 4 for the patchy distribution of rainfall each year on the Jefara Plain), although if one area has heavy rains three years running then it will often be cultivated three years running. The exact nature of the movement of people in the area of shifting cultivation during the spring and autumn has never been studied, and the ownership of land in the Dune and Inner Jefara seems to be very complicated. Some reports on agriculture state that the land in the shifting cultivation zone is tribal and is allotted out to the various heads of families each year. It does appear that people belonging to certain tribes move to areas within the tribal limits (these usually coincide with the mudiriyah boundaries which are shown in the frontispiece), but that the actual land is privately owned. It is known that people in the oasis of Zawia own land in the Dune Jefara, but many never make use of it personally, instead they rent it out to anybody that wants to graze it or sow barley on it.* In

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* Personal Communication, Hadi Bulugma, Durham.

the frontispiece certain parts of the Jefara are shown outside the limits of Tripoli and Western Province, and it is to these areas, particularly those of Gharian and Tarhuna districts, that some of the Jebel tribes come to sow wheat and barley.

Shifting cultivation has several disadvantages. The shifting cultivator scatters his seed very widely in order to make best use of the limited moisture available; he is interested only in a large multiplication of his seed and his yields per ha. are very low (see plate 28). Only in years of very good rainfall, when the Inner Jefara is one mass of green in the late autumn, is a satisfactory harvest gathered. The shifting cultivator is using the land that would produce the best grazing plants and he is also constantly destroying much of the bush vegetation when he ploughs.

3. Grazing and Semi-Nomadism. Reliable figures for the number of livestock on the Jefara Plain are not available and estimates tend to be meaningless because numbers fluctuate so sharply from year to year. It is probably reasonable to assume that the totals of livestock in Tripolitania fluctuate round the following figures: Sheep 200,000, goats 330,000, camels 50,000, cattle 40,000 and donkeys 30,000. On the Jefara Plain cattle, camels and donkeys are mainly used as ~~beats~~ beasts of burden and for raising water, and sheep and goats, which probably number 130,000 and 200,000 respectively, are the main grazing animals. Many of the coastal farmers own sheep and goats and pay shepherds to look after them in the Dune Jefara.

The isolated area of grazing land in fig. 9 is the territory of the El Hod tribe who live in the Bir El Ghnem mudiriya (see no. 11 in frontispiece). The large area of grazing land in the west is the territory of the Siaan semi-nomadic tribe. Most of its 9,500 members have no permanent place of residence and they are continually on the move in an area of about 2,000 sq. miles. In the winter they live in black tents and in the summer in palm frond huts known as khus. They depend almost entirely on livestock and in 1957 they had 18,500 goats, over 6,000 sheep and over 6,000 camels. In the winter they travel to a few areas of land, mainly in the north-west, where they grow patches of barley; in autumn they may go to the coast to help with the date harvest; at other times they travel in search of pasture, occasionally calling in at the oases of Tiji and Jaush on market days to sell animals and buy food (6). The area of grazing land with a little cereal cultivation in the wadis, is often used by certain of the Jebel tribes. The terrain is very rough because of the many boulders that are brought down by the winter floods, but it is possible to grow barley in a few of the moister and flatter areas.

Overgrazing is a serious problem on the Jefara Plain and a rigid programme of range management is needed. The goat, which is the most numerous animal, will eat almost anything and at the same time it grazes the vegetation so low that it easily kills it. Over the centuries, overgrazing has been one of the factors causing the formation of large dune areas in the more humid Eastern Jefara. Because much of the grazing land is furnished with too few wells, the vegetation within a radius of about 10 kilometres of each of the existing wells is over-grazed in the summer, when the animals have to be watered frequently

E. Italian and Post-Italian Pattern of Agriculture.

By 1921 the Italians occupied Tripoli and the western oases, by 1922 they had captured all the western Jefara, and in 1923 they took control of the whole plain when the eastern Jefara region finally surrendered. Thus from 1923 to 1939 they had complete freedom to develop the area in whatever manner they desired.

1. Italian Concession Farms. The Italians obtained land by general expropriation; they revised Muslim law and then declared that all land for which private ownership could not be proved, should automatically become state land. By 1925 the Italian state had taken over the following areas of land on the Jefara:-

Table 2.5 Land on the Jefara Plain expropriated by the Italians 1914-29.

Locality	Area in hectares
Gasr Garabulli	10,172
Gasr Khiar	5,249
Tajiura	7,400
Mellaha	400
Ain Zara	4,500
Gasr Ben Gashir	4,831
Suk Es Sebt - Fonduk esh Sherif	3,310
Er Regiat	16,190
Khetna	6,088
Gurji - Suani Ben Adem	18,587
Azizia - Bir Miani	17,454
Azizia - Wadi El Hira	12,311
Sidi Mesri	3,600
Porta Benite	16
Porta Azizia	9
Zanzur	9,000
Zawia-Sorman	11,700
Sabrata	6,000
Mellita	2,000

Some private farmers arrived in Tripolitania in 1914, but then immigration was suspended until 1920 due to hostilities in Europe. By a concession scheme, which was established by decree in 1925 and later renewed in 1928, farmers were granted land by the state with the right of perpetual ownership on an immediate nominal payment of 40-50 Lira per hectare, but subject to them being able to raise the state mortgage on the concession when the land had been developed. The state also subsidised some farmers until the land started to yield crops. This type of rigid control, particularly the rule that a farmer had to pay for the larger part of his concession only when he had developed it, killed any desire for speculation.

By 1937 the total number of concession farms in Tripoli and Western Province had reached 592 covering a total area of 98,429.85 ha. (14) as follows:-

Number of farms in concession	332	area	86,605.66	ha.
Number of farms in full ownership	235	area	7,285.30	ha.
Number of farms part-concession and part-ownership	15	area	4,249.91	ha.
Number of farms in state ownership	10	area	288.98	ha.

At this time about 60% of the concessions were under 75 ha. in size, 20% were 75-400 ha., and 20% were 400 ha. to 1,000 ha. and over. These were the kind of private farms that were established by the Italians before the war and most of them are still in operation today, although some have been taken over by Libyans.

It is necessary to also study the type of agriculture that was developed on these concession farms before the war, because the crop combinations of today have changed very little from those that were originally established. Dryland tree cultivation formed the basis of the concession farms and figures for the area planted to the various trees in the whole of Libya by 1935 are given below:-

Table 2.6 Tree Plantings on Italian Concession Farms in Libya by 1935.

Olives alone	29,483	ha.
Olives in association	20,535	"
Almonds alone	1,991	"
Almonds in association	14,658	"
Vines alone	1,105	"
Vines in association	6,501	"
Varied fruit trees alone	266	"
Varied fruit trees in association	252	"
Forest trees (not on dunes)	1,558	"
Mulberries alone	470	"
Mulberries in association	109	"
Irrigated culture (mainly citrus)	2,799	

In the above table Olives, almonds and vines are the most important, the majority of them being planted in association with each other. The irrigated area is very small indicating that few farms planned to grow summer field crops, although most of them cultivated dryland winter cereals between the trees. The Italian concessions were laid out in the areas shown as hawāza in fig. 9.

Today the cropping pattern on many concession farms has not changed — see for example farm studies 4-11. In the Eastern Jefara, an area not covered by farm studies, concessions El Allus (formerly Calo) and F.A.T.M.A., both about 3,000 ha. in size, still rely on dryland olives and almonds. The farmer on the neighbouring Variani Concession, however, drilled an artesian well before the war and is now irrigating a substantial area of citrus and groundnuts. In the far west of the coastal area, in the Sabrata district, the concession farms have changed very little, but elsewhere, where underground water is more copious and of better quality, changes are evident. Many olives and winter cereals are now being irrigated, vines are being destroyed in large numbers, and not all the arable land lies fallow in the summer for an increasing area of groundnuts and lucerne is being grown. In the height of the summer with the temperatures over 100°F. extensive, rich green patches can be seen between the olive trees on the Azienda Agricola de Micheli Concession; the groundnut has transformed much of the summer cultivated landscape. Most of the concessions can boast 2-4 ha. of irrigated land, but the olive still remains the most important crop, making up about 75% of the trees on many farms.

2. Libyan Hawāza.

Most of these were originally Italian concessions so basically the pattern of tree crops is the same. It does appear that the new Libyan owners have less faith in the olive and have more enthusiasm for irrigated field crops -- see farm studies 13-23. Farm study no. 12 describes one remarkable farm that was not formerly an Italian concession. This is 82 ha. in size and is found in the oasis of Ajelat; the number of trees is small and the farmer tends to favour winter cereals and groundnuts.

3. Specialised Commercial Farms.

Most of these farms concentrate on the production of certain commercial crops for export. Today, as in pre-war days, most of them grow citrus (see chapter 11 for classification of citrus farms), but new commercial types of farms are appearing; farm study no. 1 describes a commercial farm, financed by a trading company, that has appeared in the last few years; this endeavours to produce high quality crops for the United Kingdom, particularly groundnuts, early potatoes, asparagus and carrots.

4. Demographic Farms. These are so called because they were developed for the purpose of settling or resettling farmers. During the late 1930's, the Italian Fascist Party began to transfer to Libya farmers from the depressed parts of Southern Italy and from Sicily. Since the War the Libyan Government has so far made one trial attempt to resettle local farmers on the Jefara Plain.

(a) Italian Demographic Farms. The latest information on the demographic settlements is as follows:-

Table 2.7 State of Italian Demographic Settlements in 1957

ttlement Name byan	Italian	Agency	Total Pop.	Original area for development ha.	Present area ha.	No. of holdings originally	No. of holdings in private ownership	No. of holdings still being developed	No. of holdings transferred to G.O.L.	Av. size of holding ha.	Av. area under trees per holding. ha.	Remarks
izia	Azizia	Ente	171	1510	1090	30	9	13	9	40	?	5 families transferred
hduk	Fonduk	Ente	142	810	810	27	27	-	-	26	?	All private
uddaim	Oliveti	Ente	281	1470	1470	49	50	-	-	30	?	All private
zahra	Bianchi	INPS	867	6121	5982	167	-	170	2	34.6	8.7	Still being developed
rabulli	Castelverde	INPS	8	2577	90	58	2	-	56	45	21.5	Abandoned
anima	Corradini	INPS	171	2973	2331	64	-	52	12	43.9	21.5	Still being developed
nasira	Giordani	INPS	776	5207	4747	193	-	184	17	25.6	4.3	Still being developed
shian	Hashian	INPS	94	356	356	20	19	-	-	18	9.9	All private
iria	Micca	INPS	597	4833	3555	148	-	141	18	26	6.4	Still being developed
uddaim	Oliveti	INPS	475	1397	1397	72	74	-	-	18	14.8	All private
	Totals		3582	27254	21828	828	181	560	114			

Demographic farms were generally established later than concession farms, mostly in 1937, 1938 and 1939; they are smaller in size but have a larger average area of irrigated land. Usually the farms are 25-30 hectares with 20-25 ha. of dry land and 5-6 hectares of irrigated land; dry land consisting of 12 ha. of olives, 5 ha. of almonds, 3 ha. of olives and vines; and the irrigated land of 1-2 ha. of citrus in addition to small areas of wheat, fodder and industrial crops. Several of the settlements, namely Bianchi, Giordani, Micca and the Olivetis, had electricity installed when they were developed.

Two out of the three agencies settling people in Libya, operated on the Jefara Plain: Ente per la Colonizzazione della Libia and Istituto Nazionale della Previdenze Sociale.*

Ente per la Colonizzazione della Libia was constituted by royal decree in June 1932 for the purpose of colonising Cyrenaica, and in 1936 its activities were extended to Tripolitania. It derived its financial resources from the state and other organisations in Italy, particularly banks. On the Jefara it took over land that has been confiscated from the Turkish Government. The land thus acquired by the agency was sub-divided into holdings, on which were constructed houses, outbuildings, wells, storage tanks and other farm necessities. Village centres were built by the state and remained state property. When the settler first moved into his farm he was given a subsistence allowance for five years, and during this time all his produce was handed over to the Agency and credited

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* Following information supplied by Mr. Evans, Department of State Property.

to him. After the initial five year period the settler had to buy all his own seed, manure and animals etc. and at the same time pay back a proportion of the capital expenditure on his holding, plus a certain percentage of the general running expenses of Ente. Ente's official policy decreed that all holdings on the Jefara Plain should be legally transferred to the settlers after the elapse of 20-24 years. The Agency was still intact when the British Military Administration took over after the war and it continued to operate under the guidance of the Director of Agriculture. It is now winding up its activities.

Istituto Nazionale della Previdenze Sociale (INPS) started in Italy in 1898, as a national provident institute for sickness and old age, and in 1919 it became a social insurance institute. It commenced its insurance activities in Tripoli in 1928 and later entered the field of demographic colonisation, for which purposes a separate organisation was established with its headquarters in Rome. The Agency took over state land, or private land that had been expropriated by the state against payment by INPS. Holdings were developed on similar lines to those of Ente, and it was intended that they should be transferred to farmers after 24 years, with any outstanding farmers debts being converted into a mortgage. As table 2.7 indicates most farms belonging to both agencies had been transferred into private ownership in 1957; today all Ente farms have been handed over and within the next two years INPS will have relinquished control of all its farms.

At Azizia all farms were in private hands by the end of 1958. Here holdings average 45-50 ha. in size and are slightly larger than those on many other settlements. When the Italian and Libyan Governments drew up their agreement in 1956 (33 Allegato H.) 13 farms still remained in the agency's control and needed further developing. Today these farms are complete and should have, on average, 500 almonds on 10 ha. 600 eucalypts on 3 ha. and 50 irrigated olives. Cereals are grown in the winter and tobacco, groundnuts, tomatoes and lucerne in the summer. Most farms have a 4-6 h.p. electric pump and 100 m3 storage reservoir; some however still have wind pumps.

All farms on the Ente settlement at Oliveti were in private ownership even in 1957. Electricity is laid on to every farm (see fig. 20) and enough water is raised by each electric pump to irrigate at least 3 ha. of land — for details of cropping see farm studies 35, 36 and 37.

All the farms on the Ente settlement of Fonduk Et-Togar are also in private ownership. Water is scarce here, not because the underground water reserves are poor, but because only wind pumps are available (or were available originally) to raise water; only about one ha. of land is therefore irrigated. Every holding was established with a wind pump, but today some farmers are installing electric pumps. Three examples of farms on this settlement are given in farm studies 38, 39 and 40. Farms 38 and 39 still retain the wind pump and only have

2 ha. of irrigated land each; relying mainly on the dryland cultivation of olives, almonds and vines; farm 39 started with the same dryland crops, but now with an electric pump, 12 ha. of the farm are irrigable.

Many of the INPS farms were still controlled by the agency during the writer's stay in Libya and much of the detailed information, which was available, is incorporated in later sections of this study, particularly sections IV and V. According to the 1956 agreement (33) the remaining INPS settlements were to be made economically independent within four years. In the Bianchi, Giordani and Micca areas this was to be achieved by ensuring that every farm had, on average, 300 olive trees (mainly Tunisian), 100 almonds, 1 ha. of vines, 150 citrus, 5-600 eucalypts and other trees and 2½-3 ha. irrigated land. Further information about INPS at Bianchi and Oliveti is given in farm studies 23-31.

Ghanima is the youngest of the INPS settlements and transference of ownership will take place here last of all. Since the water-table is up to 40 metres down, only dryland cultivation was developed, with olives, almonds, vines and dryland cereals the main crops. Originally 29 wind pumps were installed but today only 23 remain, some even being shared by several holdings. The farms on this settlement are the largest demographic farms on the Jefara and they average about 50 ha. There is to be an expansion of irrigation at Ghanima because in the 1956 agreement (33) provision was made for the construction of 15 new wells and storage tanks, with a new generating plant to provide the power for electric pumps. About 1 ha. of land is to be irrigated on each holding allowing sufficient wheat to be grown for family consumption and sufficient forage for the animals. When development is complete the average holding will have 450 olives, 450 almonds, 5 ha. of vines, 350 forest trees, and 1 ha. of irrigable land. In addition Allegato H. of the agreement stated that 1500-2000 olives and fruit trees were to be distributed so that each farm should have 50 irrigated trees. Farm studies 32, 33 and 34 describe three typical holdings in the Ghanima area.

(b) Libyan Demographic Saniya Farms at Maamoura. The Government settlement scheme at Maamoura is unique, and represents the Department of Agriculture's only attempt to develop and settle an area of the Jefara Plain. If it is successful there may be similar development in other districts. The area in question was chosen by the Italians for the resettlement of Libyan soldiers who had supported the Italian cause, but plans and development were not completed when the 1939/45 was started. The Italians originally divided the land into Maamoura A and Maamoura B, and for the moment the Libyan Government has concentrated on developing the former. Work started in 1954 and farmers were soon settled, at first to be under contract and supervision but later to become owners if considered suitable.

At Maamoura A about 628 ha. of land have been developed and 462 ha. remain as sand dunes. Of the developed land, 500 ha. have been divided into 125 farms, each of 4 ha. Wells have been dug at 200 metre intervals and there is one on each farm. Water is taken from the first aquifer which is usually 6-8 metres down, and is raised by 1.25 - 1.8 h.p. electric pumps, which were bought by each farmer at a cost of £L110 each and being paid for in annual instalments of £L22. Each pump has a discharge of 20 m3/hr. and it pumps water into a 25 m3 storage tank; irrigation is by channels and jedawl and enough water is available for the irrigation of 6-8,000 jedawl.

One half of the farm is cultivated each year and the rest lies fallow. The main summer crops are groundnuts (usually 4-6,000 jedawl), lucerne, tomatoes, maize and peppers; the main winter crops are wheat (½ ha.), barley (½ ha.), beans (½ ha.), autumn sown potatoes (¼ ha.), and spring sown potatoes (½ ha.). Tree crops are very varied and mixed because of the small size of the farm; citrus and olive trees are dominant and each farm has an average of 50 citrus trees and 100 olives (local and Tunisian which are all irrigated).

Farm practices are controlled by the Nazara of Agriculture and they are therefore of a higher standard than on any other saniya farms. Land is irrigated every 7 days if 2 ha. need watering, and every 10 days if 3 ha. need watering. Winter crops are irrigated and wheat receives 2-3 irrigations. If no fertilizers are applied then the rotation is groundnuts, wheat and three years fallow; if fertilizers are used then a crop of beans follows wheat.

Results seem most promising by local standards and other schemes should be started as soon as possible in other parts of the plain.

5. Government Farms. A survey of agriculture is not complete without a brief mention of the four main Government farms at Sidi Mesri, Gasr Garabulli, El Guea and Bir El Ghnem.

Sidi Mesri is easily the oldest and it was established in Turkish times. Of the total area of 180 ha. about 50 ha. are irrigated. The nine wells on the farm, each with a capacity of 60-100 m3/hr., tap the second aquifer, and water is distributed over the land by all methods, sprinklers, jedawl and furrows. The farm is strictly experimental and many types of crops and animals are to be found there. Established local varieties of crops and trees are tested under various conditions to see how yields fluctuate, and new varieties are tried to establish whether they can adapt themselves to local conditions. This Government farm is very different from the private farms.

The newer farms are more important to this study because they illustrate how certain experts consider that agricultural land should be developed. On the Government Sheep Ranch at Garabulli, amid the remnants of the INPS settlement of Castelverde, water from an artesian well, drilled by the Italians, was running to waste, and it was decided to develop an area of land around this well for the growing of lucerne and other forage crops. It was assumed that lucerne needs an irrigation of 800 m3/ha. every 4-5 days in the summer and every 10-12 days in the winter, and with this in mind 16 ha. of land were developed for this crop. Altogether about 20 ha. were developed for irrigation. 11.5 ha. were levelled and 2,500 metres of lined canals were constructed for gravity irrigation and sprinklers were introduced for 8 ha. Today the farm is still devoted entirely to forage but it now has two artesian wells.

At El Guea, another farm has been developed for the production of fodder for livestock at the Government Sheep Station. Two artesian wells were drilled by L.A.T.A.S. near kilometre 47 on the Tripoli-Garabulli road; both these have a capacity of about 250 m3/hr. and supply enough water for 5-6 ha. The main crops grown are lucerne, vetches and oats. There are at present 4 artesian wells and the development is as follows:-

Gravity irrigation and syphon tubes	8.4 ha.
Gravity irrigation and gated pipes	4.1 ha.
Sprinklers for full irrigation	8.9 ha.
Sprinkler for semi-irrigation	13.3 ha.
Dry farming	27.6 ha.

Recently a seed multiplication farm has been built at Kilometre 52 on the same road. This has two artesian wells and a shallow well and has the low cost canal type of irrigation.

At Bir El Ghnem is a very significant farm. This was started in March 1955 and is located in one of the hottest and driest parts of the plain where there is no sedentary cultivation. Water is found in the first water-table about 84 metres below the surface and is raised to a 500 m3 capacity storage tank. The farm was established for two main reasons: firstly, to grow standard local crops and see how they react to the adverse conditions of heat and aridity; secondly, to investigate the feasibility of irrigation development from deep wells requiring high lifts of water. Both field and tree crops are grown. A large part of the farm is devoted to growing cereals, mainly oats and barley, for the animals at Sidi Mesri, but other crops, such as potatoes, lucerne, maize, chickpeas, peanuts, water-melons and cucumbers are grown to produce seed. Cotton was even tried in 1956. Tree crops include peaches, pears, plums, apricots, oranges, olives, vines and castor. The Government owns about 3,000 ha. of land in this district, but, although further expansion is anticipated, so far only about 30 ha. have been developed, largely dependent on low cost canal irrigation.

SECTION II

SOIL & WATER RESOURCES

CHAPTER 3.

Soil and soil material

A. Introduction

At the outset we are confronted with the problem of what is a true soil. Strictly speaking, soil is the medium in which plants grow and should not be confused with weathered rock, which is nothing more than parent material. Due to the aridity, plant and animal activity, which is necessary for true soil formation, is often lacking in many parts of Libya. However, much of the Jefara Plain has some measure of vegetative cover and animal life, even the drier western parts, so true soils are to be found. Only where there is overgrazing or excessive aridity is vegetation deficient, and even in these areas soils will develop if the density of grazing animals is lowered or water introduced. In this chapter, the polemics of soil definition will be avoided and consideration of soil material will be detailed in order to understand the problems besetting agricultural development. In the first half of the chapter one must constantly bear in mind that in arid countries physical rather than chemical processes of rock weathering are dominant and soils have a close relationship to geological parent material.

Water, either from rainfall or underground supplies, is the critical factor affecting agriculture in Tripolitania and this determines the general boundaries of sedentary cultivation (frontispiece). Farming of this nature is only found in the Eastern or Coastal Jefara where there is either a rainfall of over 200 mms., sufficient for dry farming, or an abundant supply of good quality underground water, permitting intense irrigation. Within the general limits of sedentary agriculture, soil can have an important control on the types, yield and distribution of crops grown and can also prohibit cultivation when saline or crusted. Soil is also very important when considering the shifting cultivator, since it may determine whether he grows wheat or barley and sometimes whether he harvests a crop, for in drought years it is the heavier land which retains the most moisture.

B. Problems of classifying Jefaran soils

W.M. Davis, the great geomorphologist, emphasised that landscape is the function of "structure, process and stage". This formula can be applied to soils, and pedologists (26) use this genetic approach to classify the Great Soil Groups: zonal, intrazonal and azonal.

Zonal soils are closely related to climatic belts and their profiles are an expression of this relationship; they can be broadly sub-divided into Pedalfers and Pedocals. In Pedalfers the dominant direction of translocation is downwards from the surface, with resultant leaching of bases etc. from the A. horizon and deposition of sesquioxides and humus in the B. horizon. Pedocals arise from the reverse process; since they are found in dry areas, the dominant movement of soil water is upwards, giving deposition of calcium carbonate and perhaps soluble salts at or near the surface under true arid conditions, and below the surface under semi-arid conditions. Zonal soils are a true function of structure, process and stage, since environmental processes are actively at work on parent material and the soil type depends on the stage of development reached.

Most of the Jefaran soils are Pedocals and theoretically at least, should be intrinsically fertile. The plain is a semi-arid area with a rainfall round Tripoli of 350 mms., decreasing to 100 mms. in the extreme west; this dryness plus high summer temperatures results in water constantly being drawn to the surface by capillarity. Usually, this water is a solution of calcium bicarbonate, and as it nears the surface carbon dioxide is given off and calcium carbonate is deposited in the soil. This addition of calcium carbonate to the soil profile is known as calcification; it may be hard or soft, a continuous pan or concretionery layer. Some of the calcium compounds brought up combine with colloidal substances and encourage a granular structure in the soil. It is difficult to decide if a true zonal Pedocal is found on the Jefara Plain, but the Intermediate type soil, which will be discussed later, may fall into the Suborder 3 'Light coloured soils of arid regions'. (26) — perhaps a Sierozem, Red Desert or Reddish Brown soil.

Intrazonal soils are anomalous in that because of some local factors, they are found in more than one of the Zonal belts. Their profiles have distinctive characteristics which are not those to be expected under the climatic conditions which prevail. The local factors which operate are three:-

Calcimorphic; Halomorphic; Hydromorphic.

Jefaran soils are either calcimorphic (crust soils) or halomorphic (sebkh soil).

In Azonal soils the local processes are allowed to operate but the parent material does not remain 'in situ' long enough for the development of a profile characteristic of a zonal soil. Azonal soils, which are represented in the area under study by dune and detrital material, are immature and sometimes called skeletal.

Thus the Jefara Plain has examples of all three orders of soil: zonal, intrazonal and azonal. Parent material is derived partly from the weathering 'in situ' of superficial Quaternary formations and Mesozoic sediments (mainly limestone) of the Prejebelic Hills, and partly aeolian material transported from source regions in the south and alluvium which is composed of weathered fragments of the Jebel formations. Taking into account the Great Soil Groups classification already indicated and given the type of parent materials just mentioned, it is possible to make a tentative classification of the region's soils and soil material:-

1) Coastal and inland dunes and sandy areas - Azonal regosols.
2) Alluvial soils of the Inner Jefara, known as the 'gattis' (flood lands) by the shifting cultivator - Azonal.
3) Intermediate type of soil which is perhaps a Pedocalic zonal soil, 'terre de la Gefara' of COTHA (20).
4) Intrazonal calcimorphic crust soils which are found in the west where intense calcification is evident at the surface.

5) Halomorphic intrazonal soils, known as Solonchaks, or white alkali soils and in their extreme form are called 'sebkh' by the Libyans.

6) Skeletal eroded soils of the Pre-Jebelic Hills - Azonal.

7) Detrital soils found skirting the Jebel front - Azonal lithosols.

C. Study of soil and soil-material types.

1. Coastal and Inland dunes and sandy areas.

As the morphological map (fig. 2) shows there are large areas of sand covering the Jefara Plain and in many cases the mantle is of considerable thickness. There are two types of sand: continental and marine.

Continental sands are by far the most important. The sand grains are reddish in colour if coated with iron oxide (hematite) and brownish in colour if coated with hydrated oxide of iron (limonite). They are finely grained with a diameter generally less than 0.5 mm., largely composed of quartz with a notable absence of mica, and they are polished and rounded by attrition. Everywhere profile development is lacking and the sands present an unstratified and homogeneous mass. Organic material and colloidal elements are deficient and there is little cohesion; the sands are therefore easily eroded by water flow. Sands which occur as dunes are very unstable and are ceaselessly moved by the wind, resulting in a soil which is undeveloped and permanently immature and therefore belonging to the azonal order. The continental sands can be divided into three types:-

a) Dunes proper: in these areas the sand completely covers the land to a depth of several metres and in places even more than 20 metres. These are the moving sands which according to Principi (22) are found in a belt 10 kilometres long, stretching from Zanzur in the west and reaching the coast at Wadis Raml and Turgut.

b) Intermediate dune land: in these areas there is a much thinner sprinkling of sand, with small dunes of one to two metres average height. In the eastern Jefara the small dunes usually overlie the Intermediate soil type, but in the west they are a thin veneer on top of a crust soil. Intermediate dune land is well developed in the Azzahra (Bianchi) region, in the area marked 'mainly sandy' on fig. 2, and also on the southern margins of the dunes proper.

c) Calcite sands: in Tripolitania there are numerous earth walls in coastal areas which have been built by dampening and beating these sands. Varying degrees of calcification are evident in most continental dunes and in the coastal zone the sands are highly cemented to give an almost solid formation. Principi (22) mentions such an area near Tripoli between the Israel cemetery and the submarine cable station. The results of intense calcification will be studied in no. 4 soil type.

Marine sands, on the other hand, give rise to large dunes along much of the shoreline. Because they are derived from marine shells such sands are usually much coarser and lighter in colour than their continental counterpart. As dunes, they are found along the west coast beyond Zawia, associated with a westward moving spit and a lagoon type of shoreline. They are absent round the town of Tripoli but appear again in the east beyond the Wadi Raml and finally attain their greatest development towards Misurata well beyond the confines of the Jefara Plain. Most coastal dunes are cemented in their lower layers.

2. <u>Alluvial soils of the Inner Jefara.</u>

These soils are found at the foot of the Jebel and further north along the wadis; they vary from fine gravel to silt and limon. For instance, above the barrage of Wadi el Hira soils are heavy, but along the Wadi Snennant, below Bir Bragen, they are light and sandy. Wadis leave the Jebel heavily charged with material eroded from the hills and as they emerge on to the plain velocity of flow is sharply checked. As a result their traction load is deposited on the northern margins of the escarpment and their suspension load in the basins and depressions of the Inner Jefara; in the latter areas flooding occurs following winter rains. The heavier soils are usually found away from the wadis, since as the flood-water breaks out from the main wadi channel the coarsest part of the load is dropped first, but eventually, when the water is static and spread out, the finest elements of the suspension load settle on the land. This final phase of deposition gives limon - the clayey lands which the Libyan farmers call 'tin'. In general the alluvial soils have an interstratified structure of gravels, sands, silts and clays; such profile development is the result of varying conditions of deposition as wadis change their course from year to year. With a process of continuing deposition soils remain permanently immature.

Limon has a more compact structure than any other soil material in Tripolitania and this is due to its inherent clayey qualities. Usually it is only a few centimetres thick and can overlie sand, alluvium or Intermediate type soil; its distribution is patchy and always coincides with present or former zones of natural 'épandage' (water spreading).

3) <u>Intermediate type of soil</u>.

This soil type has been given this name since it is composed partly of alluvial and partly of aeolian material. It is a very similar soil to that found in Southern Tunisia and Despois (12) maintains that this soil is the nearest to loess in Tripolitania. It is, however, very difficult to define it precisely as previous studies often give differing interpretations, which have led to some confusion of thought.

COTHA (20) gives the most specific description of the Intermediate soil type. It is a fine, grey-brown, sandy soil with a little clay and limon, and it is occasionally covered by small dunes of about one metre height. It is usually about ten metres thick, low in organic matter (but not so impoverished as the sandy soils) and it has some measure of cohesion. In the northern parts of the Inner Jefara it gives a vast monotonous surface, broken only by limestone buttes (Sidi Jilani and Sidi Bu Argub) and small mounds covered by Zizyphus lotus. There is no true profile development but there is a hint of stratification. The grey to grey-brown colour is due to the presence of illuvial layers of calcium carbonate at varying depths. The slightly stratified appearance of the profile also reflects the nature of the parent material which is derived from three sources:-

(a) Breakdown 'in situ' of the Quaternary Gefarico series (see Chapter 2).

(b) Imported aeolian material, either sand from the extreme south or wind-sorted limon from the alluvial lands in the southern part of the Inner Jefara.

(c) Alluvial material of varying particle size from sand to clay, which is occasionally spread out by the wadis.

The parent material has some form of stratification before the pedogenic processes start to operate.

In distribution this Intermediate soil is generally confined to the Inner part of the Eastern Jefara where wadis have at least some flow across the plain (see fig. 2). It lies between the Dune Jefara in the north and the true alluvial soils in the south and it is best developed just south of Azizia and Suk es-Sebt, where it has been studied in some detail by COTHA (20). There is flooding as some of the wadis flow through the dune Jefara to the sea and very fine silt or clay is deposited; the F.A.O. Report (14) quotes soils of higher clay content at Ben Gashir, Azizia and

Gasr Chiar, and Willimot[*] has reported similar deposits at Sidi Mesri. The Intermediate soil type therefore also stretches northwards in narrow tongues from the margins of the Inner Jefara.

4) Calcimorphic crust or cemented soils.

The processes of calcification are at work throughout most of Northern Tripolitania but only in certain areas are they evident on the surface. In order to fully understand the complicated pattern of illuvial layers it is first necessary to refer to certain observations made by various workers in this field:-

Principi (22) describes a crusty, rocky, tan-coloured soil which is found in the south-western part of the Jefara Plain beyond Shakshiuk; the actual crust which is rich in iron oxide, is formed of quartz particles cemented with calcium carbonate. The same kind of travertine-like crust even appears around and on some of the rocky Pre-Jebelic Hills, and reference has already been made to Principi's observations on the calcite sands.

Caswell (5) refers to a deposit of calcium carbonate or mixed calcium magnesium carbonate, which usually occurs at a depth of 20-30" in the Central Jefara region. Sometimes this deposit, which appears as one or several layers, becomes hard and cemented and is then known as 'caliche' or 'calcrete' by the Americans. When this occurs, adverse drainage conditions will develop.

Christie[e] reproduces several well logs at the end of his

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[*] Personal communication, Dr. S.G. Willimott, Dept. of Geography, Durham Colleges.

[e] B/36.

report on geology, and the sections for Sghedeida, Bir el Ghnem, and Garabulli testify that calcium carbonate is accumulating at certain levels.

a) Sghedeida: a finely-grained, sandy limestone, which is overlain by brown sand and which is undoubtedly a hardpan, is found 8 to 14 metres below the surface.

b) Garabulli: at 14.3 to 16.1 metres from the surface there is a hardpan made up of fragments of porous limestone admixed with sand and brown compact limestone. This is overlain by brown sand whose grains are composed of 90% quartz.

c) Bir el Ghnem: from the surface to 43 metres down there is a fine grained brown sand, which since it contains some brown sandy limestone is undoubtedly calcified. A crust is evident at the surface.

COTHA's observations (20) are limited to the Megenin area of the Inner Jefara; they can be summarised thus:-

In many parts of the main wadi bed the alluvium and gravel give place to rocky-brown outcrops (platiers de croûte). These have developed over a considerable period of time and are now being eroded away by wadi flow. Their thickness varies from 15-35 centimetres and they are hard, rocky, very calcareous, sometimes conglomeritic, have a stratified profile and are found on top of clayey limon. These 'platiers de croûte' are thicker towards the Jebel (up to 35 centimetres) than near Sidi Jilani (15-20 centimetres).

The writer's own observations, made in dunes south of Tripoli, confirm the presence of not one but several zones of sedimentation. On the Suani Ben Adem backroad to Tripoli (that is along the railway) a section is exposed where there is quarrying in sand dunes. The face of the section reveals a whitish layer 3'6" to 6' thick, with sand juxtaposed above and below it. Within the whiter zone the illuviation of calcium carbonate increases upwards until at the top it becomes solid and hard and very much like limestone in appearance.

On the Ben Gashir to Tripoli road another interesting section is seen alongside a lime-kiln. Here, from a bed 6' thick, workmen can be seen levering out blocks of what would appear to be limestone. 12" of sand lies on top of this hardpan and then there is a thin concretionery layer of only 6" which is in turn overlain by sand.

From the above observations it seems there are several zones of illuviation in many of the Jefara soils and only when one of these appears at the surface is the true crust met. The normal process of calcification, which has been discussed in an earlier part of this chapter, does not really give an adequate explanation for these numerous illuvial layers. Thus far we have to account for the following types:-

(a) Crusts found along the bed of the Wadi Megenin.

(b) The main hardpan layer which is found below the surface in the east and at the surface in the west.

(c) The several layers of calcium carbonate, which are found at greater depth and may be fossilized.

Having made this classification it is interesting to examine each type in more detail.

(a) Wadi Megenin crust. This crust, which has the appearance of a limey sandstone, is formed by the capillary upward movement of water containing calcium carbonate, followed by intense evaporation. During the winter, heavy rain may fall in the Jebel and wadis course out on to the plain (flash floods of the Americans); since the Jebel is mainly limestone it is not surprising that the floodwater is heavily charged with calcium carbonate. As it sinks into the ground more calcium carbonate is dissolved, so that when the heat of the summer brings the solution to the surface a crust is soon formed, eventually to become impervious. This process accounts for crusts found in or near beds of most Jefaran wadis.

(b) Main hardpan layer. Its position is the result of an equilibrium, which is established under given environmental conditions, between downward leaching in the winter and upward leaching in the summer. In the central part of the Jefara, the zone of cementation is found about one metre below the surface but it may be revealed in sandy areas if there is excessive deflation; in the east it may be fourteen metres below the surface (Garabulli for example). Moving westwards it gradually rises and comes to the surface and as fig. 7 shows a considerable part of the

Western Jefara is crusted land. Since much of this area has less than 6" of rain, the amount of eluviation is small; furthermore this is the hottest part of the Jefara during the summer. All these factors encourage intense capillary movement of water to the surface and subsequent evaporation. Water may also be drawn up from the first water-table in the west, since as fig. 15 shows, it is often less than 10 metres from the surface; this cannot happen in the Wadi Megenin area since the first water-table may be up to 80 metres below the surface.

(c) Calcium carbonate layers at greater depth. Examples of several concretionery layers in sand dunes have already been quoted. How can these be explained ? Principi (22) argues that if the water-table remains fixed over a long period of time the sand may become highly cemented by calcium carbonate or sulphate; a fluctuating water-table in Quaternary times would explain these zones of cementation. However, it may be that the dune or sand area has grown in size or moved its location; the varying hardpan levels may then be related to the calcification processes which are adjusted to present environmental conditions and may therefore be of much more recent origin.

5) Saline soil - Solonchaks.

The solonchak or white alkali soil is a halomorphic intrazonal and is well developed in the Western Jefara. Here, surface and/or underground water does not drain away satisfactorily and evaporation leads to the accumulation of soluble salts, such as sodium chloride and sulphate, at the surface. There is little evidence of stratification in the profile and the development of a structure is limited. At the surface there is a thin greyish-white salty crust, which in turn overlies a fine granular horizon and then a friable salty soil. However, many of the saline areas marked on the morphological map (fig. 2) are salt marshes (sebkh in Arabic) rather than soils. These swamp areas usually have a white crust at the surface and then beneath it a soft zone with almost 'quicksand' qualities. It seems there are three main reasons for the occurrence of saline soils and sebkh:-

(a) The coastal sebkh, which are often below sea-level, are found in depressions which lie behind a line of coastal dunes. There has been longshore drift along the west coast of Tripolitania for some considerable time and this has been associated with spit development in the same direction. Lagoons have been formed only to be cut-off from the sea and silted up. Seawater still seeps into some of them; in others groundwater accumulates because the cemented coastal dunes prevent it from percolating further northwards to the sea. The presence of substantial quantities of largely saline water at or very near the surface encourages high rates of evaporation and in summer months leads to severe salt impregnation.

(b) In the Western Jefara the land only rises gently to the south and the first aquifer is never more than a few metres below the surface (see fig. 15). Capillarity can easily bring this groundwater to the surface and if it is charged with salt, a saline soil will develop.

(c) Some depressions in the west may not be near the phreatic water-table so water is not drawn to the surface from this source. However, winter rains sometimes fill these depressions with water and when this has continued for a long time an impervious floor develops. Any subsequent water flowing into them is bound to collect and not percolate underground. If such conditions persist, halomorphic tendencies are inevitable.

Principi (22) quotes a case which is a combination of (b) and (c). In the Ain Zara and Tajiura regions there is a flat, low-lying area, where during the rainy season the phreatic water-table rises above the surface and pools are formed - probably on the top of Tyrrhenian clay. These sheets of water only disappear by evaporation leaving behind sodium chloride and sulphate, which can be clearly seen on the surface.

6) Eroded soils of the Pre-Jebelic Hills.

Most of these hills are so eroded and bare that even soil material is scarce. The parent material of limestones, sandstones and arenaceous marls and shales, gives rise to small pockets of coarse shallow soils amid the denuded slopes; even these are immature and therefore Azonal. Caswell (5 p.38) classifies this type of land as no. 6 - non-arable, steep, rough, broken or badly eroded, with soils coarse in texture and very shallow. Soils of this category have no agricultural value.

7) Detrital Soils.

These are Azonal and are termed lithosols by the Americans. When the wadis leave the Jebel they build up fans of boulders and coarse gravel, these subsequently coalesce, giving a narrow belt of very coarse material at the foot of the escarpment. To this is added angular scree which falls from the scarp face. This detritus is continually being augmented and the resulting soil remains permanently youthful and has little agricultural potential. However, if the water-table is near the surface, then an occasional palm may grow.

D. Soils in relation to agriculture.

Of the soils and soil materials described in the first half of this chapter, only types 1, 2 and 3 are utilised for agriculture. The agricultural significance of these depends on physical characteristics, organic content, salt content, nutrient status and chemical availability at existing pH values.

Physical characteristics of Jefaran soils and soil material.

It is important to study these physical characteristics since they influence irrigation and water-spreading, and also root development of crops. Conditions of porosity, permeability and drainage all influence water movement and affect aeration of the soil. Most Jefaran soils are open, friable and granular.

1. Coastal and inland dunes and sandy areas.

These sands are composed of single grains which are generally less than 0.5mm. in diameter. The following figures for sand at Bir Freuan are typical (20):-

Table 3.1 Composition of sand at Bir Freuan.

Particle size	% of dry earth
less than 0.002mm. (clay)	0.4%
less than 0.002mm. (silt)	1.6%
greater than 0.05mm. (sand)	94.3%

Of the grains greater than 0.o5mms., 50% are 0.05 to 0.08mms., 43.5% are 0.08 to 0.1mms. and 2.6% are 0.2 to 0.5mms.. The particle size is therefore predominantly 0.05 to 0.1mms. which puts it in the "fine-sand" category. Such soils are extremely permeable and infiltration rates are high, usually over 100 centimetres per hour; this does not encourage evaporation so they tend to act as a great water trap. The clay fraction is almost non-existent.

2. Alluvial soils of the Inner Jefara.

Most of the alluvial soils have similar physical characteristics to those of the Intermediate type but limon is quite different. This has up to 30% clay, about 60% silt and only 5-10% sand (20), with the result that it is impermeable and does not favour artificial water-spreading, since water remains at the surface instead of percolating underground. To avoid this a percolation rate of 5-6 centimetres an hour is needed. COTHA's figures (20) show that limon percolation rates are generally lower than this:-

Table 3.2 Percolation rates in limon.

Water absorbed before measuring.	Infiltration time of 8mms. of water.	Speed in centimetres per hour.
0	8 seconds	6
8	20 min. 44 seconds	2
16	27 min. 25 seconds	1.75
24	34 min. 18 seconds	1.4
32	48 min.	1

Only by mixing limon with a lighter sub-soil can adequate percolation rates be achieved.

3. Intermediate type of soil.

The particle size of this soil is roughly the same as that of sand; a sample from Bir Gurji bears this out.

Table 3.3 Composition of Intermediate Soil at Bir Gurji.

Particle size	% of dry earth
less than 1.002mms. (clay)	5.3%
less than 0.02mms. (silt)	19.1
greater than 0.05mms. (sand)	64.5

The dominant grain size is 0.05 to .1mms., the same as for sand, but the percentage of grains over 0.05mms. has dropped from 94.3 for sand to 64.5% for Intermediate soil. Although the clay content of this soil is slightly higher than sand, it is still very porous, having a porosity of 50% and a retention capacity of 15-20% of dry earth. Infiltration rates are still very high (20).

Table 3.4 Percolation rates in Intermediate Soil.

Mms. of water already absorbed before measuring.	Time of infiltration of 8mms. of water.	Speed in cms. per hour.
0	20 seconds	144
8	40 "	72
16	51 "	58
24	59 "	47
32	70 "	41

This rate of percolation is constant throughout the profile.

All three types of soil are composed largely of fine sand and are very porous and permeable. The clay content is generally low: sandy soils less than 5%, Intermediate and alluvial soils 5-10%, limon 10%+. Infiltration rates are often excessive and when irrigating through earth channels by gravity flow water losses must be considerable. However, good drainage helps to prevent the accumulation of salts and also facilitates the leaching of them if they are already present. Limon, with its higher clay content, may present drainage difficulties, but since it usually occurs as a very thin deposit it can easily be mixed with a sandier sub-soil. Hardpan layers of calcium carbonate may be an asset in very permeable soils, provided they impede and not prevent drainage. With this check on infiltration, irrigation water or rainwater is held in the upper part of the soil long enough for plants and trees to take full benefit. In much of the eastern part of the Jefara the first water-table is usually over 10 metres below the surface and water rapidly percolates downwards to it.

All three soil types offer unlimited scope to root development of plant crops, but the presence of concretionery layers of calcium carbonate may affect the growth of tree roots, although most experts think that the calcified layers are not hard enough for this to happen, not in the Eastern Jefara anyway.

<u>Organic content of soils and soil material</u>.

Soils vary in colour from yellow-grey to brown, but none is a dark rich brown. Since the red and the brown are due to coatings of hematite and limonite respectively, it is quite clear that the light colour of Jefaran soils reflects a deficiency in organic material. Figures vary from 0.3% for sandy soils to 2.5% or occasionally 4% for the alluvial soils of the Inner Jefara because the intermediate soils are no better endowed than the sandy soils: a good average for the whole area would be about 1%.

Cultivated soils are also very low in organic material. Borzi's study (2) at Gargaresh gives a virgin sand 0.9% and a cultivated sand 1.2%; COTHA's analyses of citrus grove soils indicate even lower figures: Zawia - 0.3%; Zanzur - 0.5%; Azizia - 0.9%; Tajiura - 1%; Ben Gashir - 0.3%.

As it is one of the main sources of nitrogen in the soil, the near absence of organic material will encourage deficiencies of this element.

Salt content of soil.

Generally speaking the Solonchak soils cannot be utilised for agriculture, although they do support a halophytic vegetation which provides limited grazing. The three soils which are cultivated are rarely saline but with the introduction of irrigation, the chances of a salt problem developing are increased enormously.

The principal salts which accumulate in Jefaran soils are sodium chloride, sulphate and carbonate and magnesium chloride. Some of these hinder the absorption of water by osmosis, others are toxic. COTHA (20 p.57) gives useful information on the salt content of the three important soil types:-

Table 3.5 Salt Content of sandy, alluvial and Intermediate Soils.

	Conductivity in micromhos/cm.	Salts: total mmgr./lit.
1. Sand	0.133	133
2. Alluvium (limon)	0.22	189
3. Intermediate	0.119	140

The salt content of soil types 1 and 2 is very similar and does not vary much with depth and distribution. Caswell's work (5) in the Inner Jefara zone gives a very similar picture and reveals no serious salinity problems. Like COTHA, he finds that the limon has a higher salt content, and this ties in with the minor drainage problems mentioned in an earlier section. For the Eastern Jefara it is safe to assume an average salinity figure of 120-125 mmgr. per litre (a concentration of 1.3‰ is not toxic).

In the Western Jefara the water-table is often less than two metres below the surface, drainage is bad and the content of soluble salts increases enormously. In the same area the hard compact 'caliche' layer is more evident and tends to hinder drainage, particularly so when trying to leach slightly saline soils with irrigation water. Caswell (5 p.56) describes serious salinity problems developed near a well drilled at Bir el Ghnem and continues "if the 60 foot caliche layer, present at 7' below the top-soil, is quite extensive and impermeable, satisfactory leaching of harmful accumulations of salts will be very difficult, if not impossible".

In summary, the soils of the Eastern and Central Jefara are low in soluble salts and have excellent drainage; with good quality water, no salt problem will develop. In the North-western Jefara conditions are negative because many soils already contain harmful quantities of salt, and drainage is poor. In certain inland areas of Central and Western districts the salt content of the soil is not too high and given good quality irrigation water and drainage, sufficient leaching can be effected. However, in this rather marginal area (from the salinity point of view) the hardpan layers are likely to be a great nuisance.

The quality of irrigation water is intimately related to soil salinity problems and this will be discussed, in detail, in a later chapter.

For later reference, it is worthwhile to include here a table showing crop tolerance to salt constituents in the soil. This is taken from Thorne & Peterson (25 p. 57, table 9). Trees and plants are arranged in order of decreasing tolerance.

Table 3.6 Crops and Salinity.

Fruit Crops

Good Salt Tolerance	Moderate	Poor
Date Palm	Pomegranate	Grapefruit
	Fig	Pear
	Grape	Almond
	Olive	Apricot
		Peach
		Plum
		Apple
		Orange
		Lemon

Field and truck crops

Good Salt Tolerance	Moderate	Poor
Sugar beet	Lucerne	Vetch
Garden beet	Flax	Peas
Milo	Tomato	Celery
Rape	Asparagus	Cabbage
Kale	Foxtail millet	Artichoke
Cotton	Sorghum (grain)	Eggplant
	Barley	Sweet potato
	Rye (grain)	Potato
	Oats (grain)	Green beans
	Rice	
	Cantaloupe	
	Lettuce	
	Sunflower	
	Carrot	
	Spinach	
	Squash	
	Onion	
	Pepper	
	Wheat	

Important Jefara crops are underlined with a solid line and minor crops with a broken line.

Nutrient status of the soil.

Certain elements are essential to satisfactory plant growth and they can be divided into three groups according to the quantity needed by the plant:-

a) Major nutrients

1. Nitrogen is different to most of the nutrients in the soil in that it is derived from the air, not the parent material. In virgin soils the nitrogen which is present is generally combined with organic matter and it can be maintained by adding manure or growing certain nitrogen fixing legumes.

According to F.A.O. (14 p.317) and Vivoli (27 p.5) the average nitrogen content of Jefaran soils is 0.05% reaching 0.1% in some alluvial and Intermediate soils. Sandy soils have a very low content with figures often well below 0.05%. The following information which is taken from Borzi (2), Caswell (5) and Vivoli (27) helps to clarify the picture:-

Table 3.7 Nitrogen content of Soils.

Sandy soil	Sidi Mesri	0.037%
	El Guea	0.035%
	Gargaresh	Trace
Alluvial soil	Azizia	0.98%
	Bir el Ghnem	0.11%
	Bir el Behera	0.104%
Intermediate	Ben Gashir	0.042%
	Azizia	0.09%
	Bir el Behera	0.09%
	Gasr Chiar	0.1%
	El Guea	0.1%

Irrigation farming along the coast is usually developed on sandy soils which are inherently low in nitrogen and since very little organic manure is applied and few deep rooted legumes are grown, nitrogen deficiencies are to be expected.

2. Phosphorous. As most of the soils in the Jefara region have pH. values of over 7, phosphorous occurs in complex compounds of tri-calcium phosphate with calcium hydroxide or calcium carbonate and organic phosphorous may be up to 10% of total phosphorous. According to Thorne and Peterson (25) the phosphorous content of the soil varies from 0.4% to 0.2%, with an average of 0.1%. Jefara soils are very poorly endowed with this element and although percentages reach 0.01%, 0.007% is a more usual figure (14 p.317) and (27 p.5). Further details are provided by the following figures (2) (5) (27):

Table 3.8 Phosphorous content of Soils.

Sandy soil	El Maia	0.008%
	Tajiura	0.007%
	S. Ben Ademo	0.007%
	Sidi Mesri	0.012%
	El Guea	0.006%
Alluvial soil	Azizia	0.013%
	B. el Behera	0.02%
Intermediate	Azizia	0.018%
	B. el Behera	0.016%
	Gasr Chiar	0.006%

It is quite clear that all the three types of soil are intrinsically deficient in phosphorous. Borzi (2) quotes a much higher phosphorous content for the sandy soil type at Gargaresh (0.166% for uncultivated land and 0.111% for cultivated land) and also for the same soil at el Guea (0.1137%). These figures are well above those of more recent workers and hence may be considered as suspect.

As with nitrogen, it is the alluvial soils of the Inner Jefara which have the highest percentages.

3. Potassium. In arid areas the usual potash content is 0.15% for sand, rising to 4% for clay. In the area under study, sandy soils at Sidi Mesri have 0.075% potash (27 p.30), poorer soils at Azizia 0.04% - 0.056% and the heavier clay lands 0.4 - 0,9% (5). These figures would appear to be low. However, there is no real deficiency since potassium is readily available as water-soluble salts and also as the potassium absorbed in exchangeable form on soil colloids. In sandy soils, where the initial potassium content is low, irrigation may lead to a further reduction, since the irrigation water may be low in soluble salts (few irrigation waters contain sufficient amounts of potassium). But bearing in mind that many of the arid soils of Asia and Asia Minor show little response to potassium, even though they have been farmed for perhaps several thousand years, deficiencies of this nutrient are unlikely.

4. Calcium. There are ample supplies of calcium in all three types of soil. It is usually represented by calcium carbonate, and the quantity of this compound increases from east to west - Caswell (5) reports 4.33% in soils at Gase Chiar and up to 15% at Bir el Ghnem: COTHA has analysed soils in citrus groves and lists the following:- Tajiura 4%, Azizia 8%, Zanzur 6% and Zawia 10%.

b) Minor nutrients.

Sulphur and magnesium are plentiful in most Jefara soils. Irrigated soils rarely suffer from a deficiency of sulphur because irrigation water generally contains reasonable quantities of this element. Magnesium, which is usually closely associated with calcium, occurs in the colloidal complex and, if the soil is saline, as part of the soluble salts. Taking this into account a deficiency is unlikely. Little is known about the iron content of the region's soil, but it should not be abnormally low.

c) Trace nutrients. Unfortunately in Tripolitania no research work has been carried out on these vital nutrients, but by studying observations in similar arid environments certain conclusions may be drawn:-

Copper - sandy soils are likely to be deficient if fruit trees and vegetables are grown; this problem has been experienced in Florida.

Zinc - Zinc deficiencies occur principally in sandy and siliceous soils. They are rare in irrigated areas where the soil is calcareous, but they may arise in some of the Jefaran sandy soils if deep-rooting tree crops such as apricots, peaches and citrus, or crops like corn, tobacco and tomatoes are grown.

Boron - Deficiencies of this element are not common in arid and irrigated areas.

Molybdenum - Very little is known about this but deficiencies have been recorded in South Australia when the land is cropped with lucerne and clover.

Manganese - It is well known that deficiencies of this element occur in alkaline, calcareous soils and very sandy soils.

pH values and availability of plant nutrients.

Most soils in the area being considered are alkaline and often have pH. values of over 8. Broc (*p.83) quotes a pH. of 8.7 at Suk es-Sebt and 8.6 at Garabulli and COTHA's figures for citrus orchards are all eight or over: Tajiura 8, Ben Gashir 8, Azizia 8.3, Zanzur 8.2, Zawia 8.2.

If calcareous soils are free from soluble salts, pH. values cannot exceed 8.4 but unfortunately this is not the case for the Jafaran soils. However, as most of the soils of this region are very open and well aerated, the amount of carbon dioxide in the soil air is high and this tends to keep down the pH. value. The result of the interaction of these factors is a high pH. figure, but rarely, if ever, does it exceed 8.8 -- the point at which alkalinity becomes toxic.

The solubility of a given element in a certain chemical solution is referred to as its 'chemical availability'. The chemical availability of plant nutrients at high pH. values is poor, and plants experience difficulty in absorbing enough phosphate, iron, manganese, boron and other trace elements. The iron content of the three main soil types studied is not accurately known, but the iron that is present is not likely to be available when pH. values are 8.2 - 8.4: this arises particularly when an illuvial layer of calcium carbonate is within 12" of the surface,

* B/94.

as may happen in the Western and central Jefara. It is probable then that beans and fruit trees will be chlorotic (iron deficient) on many alkaline irrigated soils.

With a pH. of 8 or over plants will also suffer from phosphate starvation, the most insoluble range of this element being 8.0 to 8.5; all trace elements will suffer the same solubility problem in the high pH. range.

With the intrinsic low nutrient status of many Jefaran soils, plus the fact that many nutrients are insoluble in the ecological conditions prevailing, deficiency diseases are imminent, particularly if the monoculture of cash crops continues to increase.

Symptoms of deficiency diseases (25)

Iron.	Plants turn bright yellow (chlorosis).
Nitrogen.	Foliage a uniform light green colour, with the lower leaves lighter in colour than the upper leaves. Leaves may turn light brown colour and drop off; growth stunted.
Phosphorous.	Foliage is dark green in colour, lower leaves may be yellowish or purpled between veins. Leaves may drop early, growth is stunted.
Potassium.	Yellowing starts at the margins of the leaves and extends to the centre. In advance stages the leaves turn brown and drop off.
Manganese.	Plants go a yellowish brown colour.

E. Conclusions.

Crust soils and sebkh (see figs. 7 and 2) plus eroded and detrital soils cover large areas of the Jefara Plain and offer no opportunity for cultivation. The three remaining types of soil or soil material - aeolian sand, alluvial and Intermediate soil -

often give a false impression of fertility when first given water and brought into cultivation. Crop yields, however, soon decline.

This chapter has shown that the amount of nitrogen and phosphorous is inherently low in the three soil types and furthermore this is aggravated by high pH. values, which result in phosphorous, manganese, iron and trace elements not being readily available to crops even if these elements are present in appreciable quantities. This low level of fertility is significant in several ways. Firstly, to ensure sustained high yields, soils need heavy applications of chemical fertilizers to overcome nutrient deficiencies, and also heavy applications of organic manure to raise the organic and nitrogen status of the soil. This only adds to production costs, which are already high due to the expense of raising irrigation water from underground. Secondly, land needs careful rotational cropping because continuous monoculture may lead to disastrous yields and the appearance of deficiency diseases of sufficient magnitude to curtail production. Thirdly, nitrogen deficiency can be overcome by planting more nitrogen fixing plants, but such crops usually have high water — consumption rates. Finally, as the alluvial soils of the Inner Jefara are generally much more fertile than most of the poor sandy soils already in cultivation, the possibilities of further agricultural development in this zone need further investigation.

The physical characteristics of the three soil types have been described in detail and their permeability and lack of cohesion has been emphasised. This is important in two respects:

firstly, since infiltration rates are so high, the system of gravity irrigation through earth furrows into Jedula would seem a most uneconomic use of underground water. Secondly, the fact that the soils are so friable and loose means that they are susceptible to wind and water erosion. The greatest danger is wind erosion in the hot dry summer, and the growth of a cover crop instead of fallow would seem advisable during this part of the year, but this is only possible with irrigation.

CHAPTER 4

Climate and Agriculture.

Introduction.

The climatic regime of the Jefara Plain is typically Mediterranean, with moist, mild winters and hot, dry summers. However, because of the heat and aridity in the summer and the low and unreliable rainfall in the winter, the sedentary farmers in this part of Tripolitania have to overcome a climatic adversity unparallelled on the Mediterranean littoral of European countries, and only encountered along the North African littoral east of Gabes. This difficult and unstable climate stems mainly from the interaction of Saharan and Mediterranean influences. Libya, unlike Morocco, Algeria and Tunisia, has no mountains of over 3,000' to act as a barrier to the northward surge of desert winds. These winds known as the 'Ghibli' (south wind) by the Libyans, frequently invade Tripolitania in the spring and scorch many of the crops.

Rain is usually brought by the north-west winds which accompany eastward moving depressions. Because these depressions are very fickle, plus the fact that they usually follow a northern rather than a southern path across the Mediterranean, rainfall amounts fluctuate sharply from year to year, and from month to month. Severe droughts, often of two years' duration, occur about every ten years, and crop failures are the inevitable result. A dry winter followed by a spate of Ghiblis in the spring, can transform the Jefara Plain into a veritable desert. With such climatic vagaries even dry subsistence farming becomes almost impossible, and the commercial farmer is either tempted to leave his land or to turn to irrigation.

This chapter describes weather conditions, analyses climatic fluctuations and finally considers their effects on agriculture. It is sub-divided as follows:

1. Pressure systems and air masses affecting the Jefara Plain; wind directions.
2. Climatic regions of the Jefara Plain.
3. Temperature and relative humidity.
4. Precipitation.
5. Climate, agriculture, water resources and irrigation.

1. Pressure systems, air masses and winds.

a) Winter. From late September onwards the Mediterranean area comes under the influence of eastward moving depressions, which develop over the Atlantic. In the summer these depressions travel across Northern Europe, but as high pressure builds up over Russia with the advent of winter, the disturbances are forced to follow a more southerly path. Those that move through the Mediterranean area enter by various gaps such as the Straits of Gibraltar, and the Gate of Carcassonne; they may then move through the Gulf of Lyons and the Adriatic towards the Black Sea, or follow the north coast of Africa and pass over Sicily to the eastern Mediterranean littoral. It is the depressions on the southerly path that bring most rain to the Jefara Plain, particularly when they travel between Tunisia and Sicily. The main rain bearing winds are north westerly and they travel over Tunisia before reaching the western parts of the Jefara. Since this latter area lies in a rain shadow zone it is naturally the driest part of the plain. The number of depressions travelling along the southern track in the Mediterranean varies from winter to winter, and at the same time few of them are as active as those which move in the northerly track. These are the fundamental reasons for a fluctuating rainfall and a high frequency of droughts.

Sometimes depressions form over North Africa and are often referred to as Ghibli depressions. These, like the Atlantic depressions following the southerly track across the Mediterranean, draw air from the south. The path of both types is along the north coast of Libya and winds at the front of the depression are from the south, veering to north-west as the depression passes. Ghibli depressions and shallow local depressions are most frequent in spring and early summer, that is February to June, and two to three may be expected from March to April. All depressions moving eastwards along the North African coast give rise to Ghibli winds of varying intensity and duration. Such winds may, of course, occur in the autumn, but at this time they are usually the result of widespread low pressure, and since gradients are weak the associated winds are light. If south winds are drawn into the front of a deep and active depression, they reach gale force and because they often travel over large dune areas, sand is frequently lifted several thousand feet and carried northwards in the form of a sandstorm.

Depressions in the south Mediterranean attract air masses from tropical maritime, polar maritime, arctic and tropical continental source regions. The actual intermixing of warm and cold air is not so well marked as it is in depressions which move across Western Europe, and warm fronts seldom develop. It is the cold front and the cold unstable air mass behind it, which brings most of Tripolitania's rain. As the front passes by there is a short but violent rainy period, which is followed by showery weather, with the frequency of the showers depending on the degree of instability of the air mass. Rainfall on the Jefara Plain is nearly always intense and is never the gentle drizzle, which we in Britain associate with warm fronts.

The winter months provide all the rainfall, but the actual rainy periods are brief, and fine spells of almost cloudless weather are regularly experienced. Showers may persist until mid-May and occasionally even into early June, but then fine weather is the rule until about mid-September.

b) Summer. Summer conditions are much more stable than those of of winter. Tripolitania lies between the semi-permanent high pressure of the sub-tropical Atlantic and the seasonal low pressure over North-West India and Persia and over the southern Sahara. The Mediterranean is an area of descending air and pressure is high. The North-East Trade Winds which move southwards over Tripolitania to the thermal low in the southern Sahara region, are steady but light in force, rainless but humid. Along the coast they are strengthened by sea breezes, which naturally modify temperatures; Tripoli usually has a daily mean of almost 80°F., whereas inland it is usually around 95°F. Clear skies and bright sunshine are experienced day after day, and occasionally a southerly wind may raise temperatures to a maximum of 100°F. along the coast and 120°F. inland. Away from the coast temperatures drop considerably at night, because the cloudless skies permit the maximum radiation of heat; land breezes move northwards to the coast.

c) <u>Winds</u>, particularly those from the north-west and the south, are extremely important factors affecting crop production and for this reason they need closer study. At Tripoli, during the winter month of December, only 12% of winds come from the north-west, compared with about 60% from the south, south-east and south-west. The rain bearing winds are therefore infrequent. In March also, nearly all the winds come from the south-east, south or south-west as the following table shows (12):-

<u>Table 4.1</u> <u>Frequency of wind readings at Tripoli (%)</u>

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
December	6	2	1	5	22	33	16	12	3
March	3	2	8	16	22	25	7	14	3

Ghibli conditions are clearly more likely to develop during the spring than any other time of the year. Graif[*] (page 8) has worked out the frequency of Ghiblis in the season October to May, during the period 1928-38 as follows:-

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[*] Graif, G.L.: 'Contributo alla cerealicoltura libica'. Agricoltura Libica, Jan. 1941, no. 1 pp. 1-31.

Table 4.2 Frequency of Ghibli winds.

	Zawia	Sidi Mesri	Castelverde (Garabulli)	Azizia
October	0.3	0.0	1.8	2.9
November	0.0	0.3	0.2	1.0
December	0.0	0.3	0.0	1.0
January	0.0	0.2	0.2	0.1
February	0.0	0.1	0.4	1.2
March	0.1	1.4	0.4	2.4
April	0.3	2.1	1.8	4.4
May	0.2	2.0	1.8	3.9
Average	0.9	7.3	6.8	13.7

For the 10 year period, Zawia, a coastal station, barely managed to average one Ghibli a winter season, but further east, Sidi Mesri, only about 5 kilometres inland averaged 7.3 and Castelverde, also fairly near the coast, 6.8. Azizia, on the other hand which is farther to the south and more exposed to the southerly winds, suffered an average of 13.7 Ghiblis. The spring months have the highest incidence with October the only other month worth taking into account. As will be shown later, the desert wind from the south brings high temperatures and these can have disastrous effects on winter and summer field crops, and also tree crops. Ghiblis in June arrive just when the young groundnut plants are establishing themselves, and more frequent irrigations are needed. The certainty of scorching winds in the spring is one of the factors encouraging the use of supplementary irrigation for winter crops, particularly the second crop of potatoes.

Along the coast the general pattern of wind direction in summer is obscured by land and sea breezes, and it is therefore unwise to use figures for Tripoli. The figures for Idris airport for the month of August give a better picture of the winds to be expected. They show that 42% of the winds are north-east and 17% from the north:

Table 4.3 Frequency of wind readings at Idris Airport (12)

N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm
17	42	9	10	2	4	4	11	1

2. Climatic Regions of the Jefara (see fig. 11c).

On the basis of rainfall and temperature it is possible to divide the Jefara into three climatic regions (4 pp. 9 and 21): maritime, steppes and pre-desert.

a) Coastal maritime. This is a narrow coastal strip stretching from the frontier near Pisida to Ghanima, where the eastern Jebel impinges on the coast; the strip is rarely more than 8 kilometres wide. The annual curve of daily mean monthly temperatures is similar in pattern to that of Sicily, but a shade higher. Maximum monthly mean temperatures rarely exceed 100°F., but when a Ghibli blows temperatures increase and the absolute maximum for the last few years is 116°F. As to be expected in an area of maritime influence, August is the hottest month and January the coldest; furthermore daily ranges of temperatures are small, and never more than

8°F.; seasonal variations between January and August rarely exceed 12-14°F.. The annual isotherm for the whole area is 68°F. and sunshine amounts are high and average at least 70% (Tripoli 71%). Rainfall is over 200 mms. everywhere, but is less in the west than in the east; relative and absolute humidity are constantly high and the former averages 60%.

b) Steppe zone. This includes most of the Jefara. In this area desert influences begin to supersede Mediterranean marine influences, although autumn temperatures are still higher than spring temperatures. July, not August, is the hottest month, but January still remains the coldest month. Diurnal and annual ranges of temperature are higher than in the coastal zone; and evaporation is usually four to five times greater than rainfall. As the hot southerly winds leave the Jebel and descend to the plain they are compressed and further heated; these account for the extreme high temperatures and evaporation rates experienced in the Steppe Zone. On the basis of rainfall it is possible to divide this climatic zone into three sub-regions:-

i. Eastern Jefara with over 300 mms. of rainfall.
ii. Central Jefara with over 200 mms. of rainfall.
iii. Western Jefara with over 125 mms. of rainfall.

c) Pre-desert or Semi-desert. Continental conditions are best developed in this region and the diurnal and annual ranges of temperature are the highest on the Jefara Plain. However, rainfall, not temperature, is the determinant of this climatic region and the whole area is extremely arid with generally less than 100 mms. of precipitation. De Martonne (9 and 10) considers it desert steppe, with an aridity index constantly below 10. It covers an area surrounding Hebilia and El Wotia, stretching south to Tiji and Jaush, north almost to El Assa and westwards across the Tunisian border.

3. <u>Temperature and Relative Humidity</u>.

a) <u>Temperature</u>. Detailed temperature figures for a ten year period and over, are not available for all parts of the Jefara. However, figures for Tripoli (57 years), Idris Airport (22 years), Azizia (13 years), Zuara (16 years), El Wotia (11 years) and Garabulli (6 years) will suffice to give the general temperature picture.

Azizia is reputed to hold the world's highest recorded temperature at 136°F.. The figures in Appendix **IVa** certainly show that this station is sited at or near the hottest part of the Jefara, for its yearly mean is 70°F., compared with 69.37°F. for El Wotia, 69.04°F. for Garabulli, 68°F. for Idris, 67°F. for Tripoli and 66.92°F. for Zuara. Theoretically one would expect the central part of the western Jefara to be the hottest place, but figures for El Wotia fail to reach those of Azizia, El Wotia being slightly cooler in both summer and winter. The yearly mean for Zuara is the lowest; that for Garabulli is surprisingly high, being due more to warm winters than hot summers.

During the summer months Tripoli and Zuara are typically maritime stations with their highest means in the month of August, 79°F. and 79.7°F. respectively. Idris airport has its highest mean in two months, 82°F. for both July and August, a hint of continental influence. Surprisingly however, Azizia has its highest monthly daily mean in August. El Wotia shows its continentality with a maximum of 83.3°F. in July; Garabulli is very similar to Idris Airport in that the figures for July and August, 80.78°F. and 80.96°F. respectively, are almost the same.

Winters are mild for the Mediterranean and mean monthly daily means never fall to freezing point. For every station except Tripoli, the lowest mean is in January: Idris 53°F., Azizia 53°F., El Wotia 51.98°F., Garabulli 55.4°F. and Zuara 52.52°F.. In contrast Tripoli has a double low of 54°F. in December and January.

The figures for monthly maxima and minima are valuable (Appendix IVa) since they give some idea of temperature conditions when hot or cold spells occur. The Ghibli winds, account for the warm spells and along the coast give averages of 95-100°F. in the summer and 70-75°F. in the winter. Inland, summer temperatures hover around 110°F. and winter temperatures approach 75°F. and even 80°F. In the critical months of October and March Tripoli has recorded 102°F. and 95°F. respectively, Idris 109°F. and 113°F., Azizia 115°F. and 112°F. and Zuara 106.26°F. and 98.8°F. Generally speaking Ghibli winds make up only 16% of total winds, but their significance is tremendous. When they first appear, humidity can drop as much as 50-60%, with the result that the evaporating capacity of the atmosphere is greatly increased. When cereals for instance are at the milk stage, a few weeks before harvest, a severe Ghibli will ruin a potentially good crop; likewise a Ghibli at the time of almond pollination will have disastrous effects on yields. The scorching Ghibli is likely to affect the yields of all dry-land winter crops, and also necessitate frequent irrigation for summer crops. Only the date palm thrives in the burning heat brought by this wind, and a Ghibli in the autumn rapidly ripens the dates.

Average temperatures for the winter months, as we have already seen, never fall below freezing point anywhere on the Jefara Plain. Along the coast monthly minima average 40-45°F., so that even cold spells fail to bring frost. Inland, conditions can be slightly cooler and cold snaps bring temperatures down to the upper thirties; mild frosts occur very occasionally, with Idris Airport experiencing an absolute minimum of 25°F. in January and Azizia 32°F. in December. These mild winters mean that crop growth is continuous throughout the year (42°F. being the limit). Autumn, spring and summer sowings are possible, so that three crops can be harvested in a year. Under average temperature conditions, farmers are in a position to produce early crops for overseas markets. The Mediterranean is a noted area for supplying vegetables to the European market during the late winter and early spring, and it is interesting to compare Tripoli and Azizia temperature figures with those for other agricultural areas in the Mediterranean region:-

Table 4.4 Temperatures in the Mediterranean Region. Monthly means for the winter half of the year in degrees F.

Station	Oct.	Nov.	Dec.	Jan.	Feb.	March
Tripoli	73	65	54	54	55	60
Gibraltar	67	60	$\underline{56}^{*}$	$\underline{55}^{*}$	$\underline{56}^{*}$	57
Oran	66.5	61	$\underline{55}$	53	54.5	57.5
Algiers	68	62	$\underline{57}^{*}$	53	55	58
Bizerta	70	61.5	$\underline{55}$	52	53	56.5
Alexandria	$\underline{75}$	$\underline{68}^{*}$	$\underline{61}^{*}$	$\underline{58}^{*}$	$\underline{60}^{*}$	$\underline{63}^{*}$
Marseilles	59	51	46	44	46	50
Malta	69	62	$\underline{56}^{*}$	53	55	59
Palermo	67	59	53	51	52	55
Athens	66	57	52	48	49	52
Azizia	75	65	55	53	55	61

$\underline{50}$ figure higher than that for Tripoli.

50^{*} figure higher than that for Azizia.

For the period October to March, Tripoli and Azizia are warmer in every month than Mediterranean France, Sicily and Greece; of the other Mediterranean areas, Oran, Algiers, Malta and Northern Tunisia only have one monthly mean

(December) higher than those for the Jefaran stations. Alexandria is quite clearly warmer throughout the whole winter, and Gibraltar, which is affected by strong maritime influences, also has very mild winters. Table 4.4 does illustrate that the Jefara Plain is generally warmer in winter than most other agricultural areas fringing the Mediterranean sea and therefore autumn sown crops should mature 20 days or so earlier than elsewhere. Tripolitania would seem well placed for the production of early vegetables, although the higher winter temperatures are often the result of Ghibli influences, and this, as we have seen already, can be a 'blessing in disguise'.

b) Relative Humidity. Evaporation rates depend on the saturation deficit of the air, which in turn is a function of the humidity, temperature and rate of movement of the air. It has already been established that much of the Jefara has high temperatures, with a yearly mean exceeding 65°F., and one of the characteristic features of Libya is the limited number of calm days. Tripoli has the equivalent of about 22 days (6%) a year which are calm, Ben Gashir 12.5 (4%), and Azizia 25.5 (7%). Temperature and wind conditions favour high rates of evaporation. Relative humidity is the third factor which must be considered.

Relative humidity is the amount of water vapour in the air at a given temperature, divided by the total amount of water vapour that the air can assimilate at that temperature;

the result being expressed as a percentage. Relative humidity is therefore an expression of the dryness or wetness of the air. If the relative humidity of the air is very low and the temperature high, evaporation rates are enormous, as the following figures for Helwan (south of Cairo) show[*]:-

Mean daily evaporation		Mean annual evaporation
Month with most	Month with least	
10.3 mms. (June)	2.8 mms. (December)	2387.6 mms.

Helwan has an annual average temperature of 71°F. and an annual average relative humidity of 47%; these are very similar to Azizia's figures of 70°F. and 49%.

Studying the means of relative humidity for the few stations for which figures are available, we find that the coastal areas average about 60% and over, while inland stations, 20-30 miles from the coast, average just under 50%.

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[*] Kendrew, W.G.: 'Climatology', p. 237.

Table 4.5 Relative humidity %

	Tripoli			Ben Gashir			Azizia	Zuara
	Mean	9 a.m.	3 p.m.	Mean	9 a.m.	3 p.m.	Mean	Mean
Sept.	63	55	68	47	59	37	47	69
Oct.	60	55	59	50	63	43	47	66
Nov.	61	59	56	57	67	48	53	66
Dec.	62	62	54	60	72	53	61	65
Jan.	62	58	68	57	69	42	61	69
Feb.	61	63	57	55	69	44	60	68
Mar.	60	57	61	51	62	39	53	65
Apl.	59	54	61	43	53	31	43	64
May	62	61	69	43	50	33	40	70
June	63	59	70	40	48	33	36	72
July	65	63	71	41	53	31	40	73
Aug.	65	62	69	45	59	30	43	71
Mean	62	60	63	49	60	39	49	68

Notes. 9 a.m. and 3 p.m. figures for Tripoli and Ben Gashir are taken from reference 12 (pp. 26-28).

The mean figure for Azizia is $\frac{1}{3}$ (0900 and 1500 and 2100) (12 p. 28).

The means for Tripoli, Ben Gashir and Zuara are taken from reference 18.

The means for the summer months, particularly the 3 p.m. readings, are the most important. For Azizia, June has the lowest monthly mean with 36%. Relative humidity at Ben Gashir at 3 p.m., the driest part of the day for inland stations, is only just above 30% from April to August inclusive, and only from October to February does it exceed 40%. In the summer months therefore the air is extremely dry in the early afternoon. Figures for 9 a.m. are much higher and suggest saturated air conditions during the night.

Coastal station present a totally different picture. The mean for each month fluctuates just above or below 60% and only in the months November, December and February is the 9 a.m. relative humidity higher than the 3 p.m. Along the coast in the summer the North-east Trades give relative humidities at 3 p.m. of 70%, and sometimes even 80 or 90%. This is very significant because if a farmer intends to irrigate a crop during the day, the afternoon is the most suitable time; inland, in contrast, the afternoon is the driest part of the day and irrigation at this time should be avoided.

The Jefaran littoral has high relative humidities throughout the year, with peak figures during summer afternoons. The rest of the plain lies away from the immediate influence of the sea and dry air is the rule, except in the wettest months. Taking into account temperature, humidity and air movement, conditions clearly favour high rates of evaporation, particularly in the steppe and semi-desert climatic zones.

4. Precipitation.

Precipitation in Tripolitania is mainly in the form of rainfall and dew, although hail is not infrequent. Snow is almost unknown but in February 1939 there was a three day blizzard, which swept across the Jebel and left snow a metre deep. Hail is usually small in size, but occasionally, as in 1955, it can be large enough to kill animals and damage crops. It is sufficient here to confine our attention to rainfall and dew.

a) Dew. Very little is known about the amount of dew deposited on the Jefara Plain and no figures are available. Only estimates, based on the work carried out in similar environments in other countries, can be made. Dew is most copious during clear, cloudless and calm nights. The amount of cloud cover at Azizia during the summer months is given below; the figures are the means of observations at 0.900, 1,500 and 2,100 hours (12 p. 28).

Month	Cloud amount %
June	27
July	9
August	10

Cloud amounts are low during these months and clear night skies predominate: conditions are therefore ideal for dew formation. It is not uncommon to find the vegetation absolutely soaked in dew, and the amount of moisture which drops from the trees is often sufficient to give the impression that rain has fallen. Drivers, who leave their vehicles out overnight, find them covered with condensation when they collect them at 6 a.m. in the morning. The rising sun soon evaporates the thin film of moisture deposited during the night, and many people are unaware that it ever existed. When depressions traverse the country during the winter, little dew is deposited at night, but the advent of one of the fine sunny spells, that is likely to appear between depressions, brings clear still nights, and copious amounts of dew are again deposited.

Went (21) describes experiments which have been carried out along the coast of Israel. These show that squash and corn grow almost twice as rapidly when they receive dew during the night. Dew is common in the Negev, the northern part of which is very similar climatically to the Jefara Plain, and the amount deposited is greater in the dry summer than in the wet winter. The quantity of dew involved is small, averaging about one millimetre a cloudless night and about 25 mms. a year, although favourable areas may receive up to 250 mms. of dew per year.

Fortunately dew is precipitated at night, when plants are growing, and it is therefore absorbed by the leaves and foliage. When the dew is heavy, however, it drips from the leaves to the ground, and because it is in such small quantities, it is unable to percolate underground and be used by the plant, instead it is evaporated as soon as the sun appears. If dew could be concentrated in sufficient quantities to allow percolation, then it would be a useful source of soil moisture. This is tried in a primitive way in Tripolitania and parts of the Middle East, where stones are piled round olive trees; moisture condenses on these stones, trickles to the base of the tree and then into the soil.

Dew, an occult form of precipitation is commonly formed during summer nights and occasionally during winter nights. Even though total amounts may be small they are very important on the Jefara, much of which has less than 10" of rainfall. Natural vegetation and crops must benefit from a nightly soaking in dew.

b) Rainfall.

i. Distribution. Water is the critical factor over the greater part of the Jefara Plain since rainfall amounts are generally so small and unreliable. The pattern of rainfall distribution is well marked (see fig. 5 b. and table 4.6), reflecting distance from the sea and rain shadow effects.

Table 4.6 Rainfall averages for certain Jefaran stations
(in millimetres)
For Agricultural Years

	Maritime				Steppe		Pre-desert	
	Zuara	Tripoli	Sidi Mesri	Garabulli	F.B. Gashir	Azizia	B. el Ghnem	Tiji
Sept.	5.7	10.2	10.0	8.3	8.9	6.6	5.8	1.0
Oct.	24.8	36.5	27.6	36.6	23.9	16.0	6.5	6.0
Nov.	42.9	65.9	69.8	38.7	41.3	27.1	17.7	27.5
Dec.	37.4	93.8	106.0	76.0	66.2	50.5	20.2	13.1
Jan.	42.8	76.9	73.4	65.3	62.4	47.5	13.7	19.6
Feb.	27.1	42.9	38.9	38.3	48.0	33.2	20.6	21.2
Mar.	19.0	24.6	23.3	25.5	23.0	21.1	13.5	44.2
Apr.	9.4	9.3	10.1	9.7	8.2	9.6	7.4	4.1
May	6.4	5.3	3.9	3.5	3.9	4.6	1.9	3.3
June	1.2	1.3	0.7	0.1	1.2	1.2	1.3	0.4
July	0.0	0.5	0.9	0.0	0.8	0.1	0.0	0.0
Aug.	0.1	0.8	0.6	0.4	0.7	0.1	0.9	0.0
Year	216.8	368.0	365.2	302.4	288.8	217.0	109.8	140.4
m3/ha.	2168	3680	3652	3024	2888	2170	1098	1404
Period	36 yrs.	76 yrs.	20 yrs.	20 yrs.	28 yrs.	37 yrs.	16 yrs.	10 yrs.

The further one travels southwards across the plain and away from the sea, the lower the rainfall. Tripoli averages 368 mms. and Azizia 217 mms.; likewise moving westwards along the coast rainfall decreases; Zmara, 216.8 mms. has a rainfall almost the same as Azizia. The dominant rain bearing winds are from the north-west, and only Tripoli and the eastern Jefara, which are the extreme east and northern parts of the plain, catch these winds after a long passage over the Mediterranean sea. Most of the moisture is dropped in the coastal zone and there is little left for the Inner Jefara; it needs the orographic effects of the Jebel to raise rainfall figures to 300 mms., as for example at Gharian. These higher figures for the eastern Jebel are indirectly of great importance, since it is in this area that many of the Jefaran wadis have their catchment areas (see chapter 5). The western Jefara is an area of low rainfall, partly because it is in a rain shadow zone, and partly because much of its area lies so far from the coast compared with the rest of the plain. In this area the only two stations with records of 10 years or more are Bir El Ghnem and Tiji; the former has an average rainfall of 109.8 mms. over a period of 16 years, and the latter 140.4 mms. over 10 years. The dryness of the north-west winds as they pass over the western Jefara is further borne out by the fact that when they rise up the Jebel front at Nalut, rainfall amounts do not increase appreciably as one would expect; Nalut only has a rainfall of 138.3 mms. The most favoured area on the Jefara

Plain therefore is a small region in the east, around Tripoli, Tajiura and Garabulli, where the rainfall is 300 mms. and over.

Table 4.6 also expresses the average rainfall amounts for certain Jefaran Stations in cubic metres per hectare. These figures are interesting because they can be related to the needs of the two types of irrigated farming. An average of figures for Zuara, Tripoli, Azizia and Bir El Ghnem, selected stations from varying parts of the Jefara, is 2,279 m3/ha.; this figure is almost the same as Ahmed's* estimate of 2,000 m3/ha.. According to Ahmed 2,000 m3/ha. is roughly one sixth of the requirements of irrigated farming and half the requirements of semi-irrigated farming, the deficit being made up by the use of underground water. The relationship between the water needs of crops and rainfall will be considered later in more detail.

Rainfall varies in 'time' as well as 'space', and amounts fluctuate from season to season and year to year. The Jefara has a typical Mediterranean regime with rain falling in the winter only. Rainfall usually starts as showers in September, the beginning of the agricultural year, and finishes in the same manner in May. During December and January the rainfall is much more continuous and torrential. Figures for Tripoli show that 97.7% of its rainfall falls between September and April. The autumn months, September - November, with 30.55% of total rainfall receive more than the spring months which have 20.86%. 46.4% of the total rainfall falls in December and January, and the most rainy months in order of importance are: December 65.5%, January 20.9%, November 17.9%, February

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* Ahmed, A.A., B/85.

11.64%, October 9.91%, March 6.69%, September 2.7% and April 2.53%.

A brief study of the averages for Azizia shows slight variation from the Tripoli pattern. In the period September to April 97.6% of total rainfall is recorded; this is the same as for Tripoli. The rainiest months in order of importance are: December 23.3%, January 21.9%, February 15.3%, November 12.5%, March 9.72%, October 7.48%, April 4.43%, and September 3.04%. This means that 23.02% of the total rainfall falls between September and November, 45.2% in December and January, and 29.4% between February and April. Along the coast more rain falls in the autumn than the spring, but inland, as at Azizia, the situation is reversed.

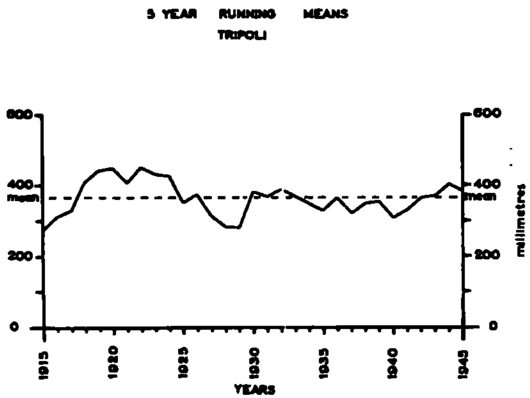
During the wet season the rainfall is not evenly distributed over the months and intensities are very variable. As has been noted already, rain is usually brought by a cold front or the cold air mass behind it. At Tripoli rainy periods are generally 3, 4, and 5 days in duration, although they can vary from 1 to 12 days. Periods of three days and over occur on average 5.4 times a year. The intense nature of the rainfall is brought out by Fantoli's figures for the frequency of rainy days at Tripoli (4 p.76):-

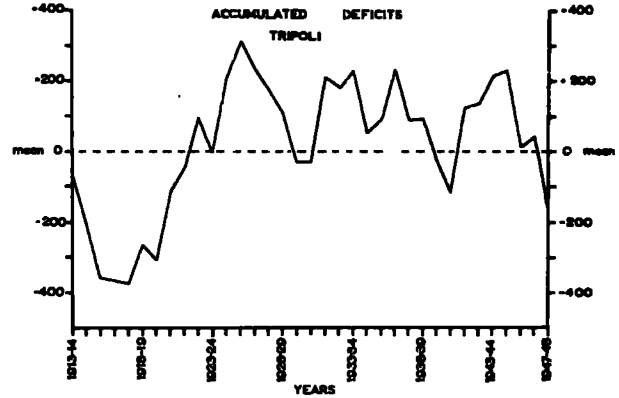
	S.	O.	N.	D.	J.	F.	M.	A.	M.	J.	J.	A.	Year
No. of days	1.8	4.6	7.4	10.5	10.7	6.7	5.1	2.8	2.2	0.9	0.3	0.3	53.3
%	3.4	8.6	13.9	19.7	20.1	2.6	9.5	5.3	4.1	1.7	0.5	0.6	100

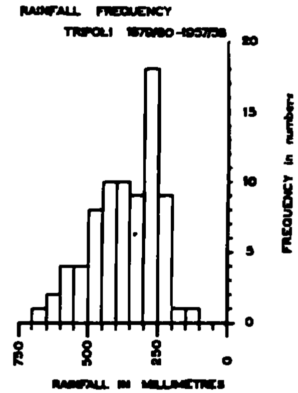
With 53 rainy days a year and a total rainfall of 368 mms., an average of almost 7 mms. falls each rainy day. Azizia with an average of 43.6 rainy days and a total rainfall of 217 mms. has just over 5 mms. per rainy day.

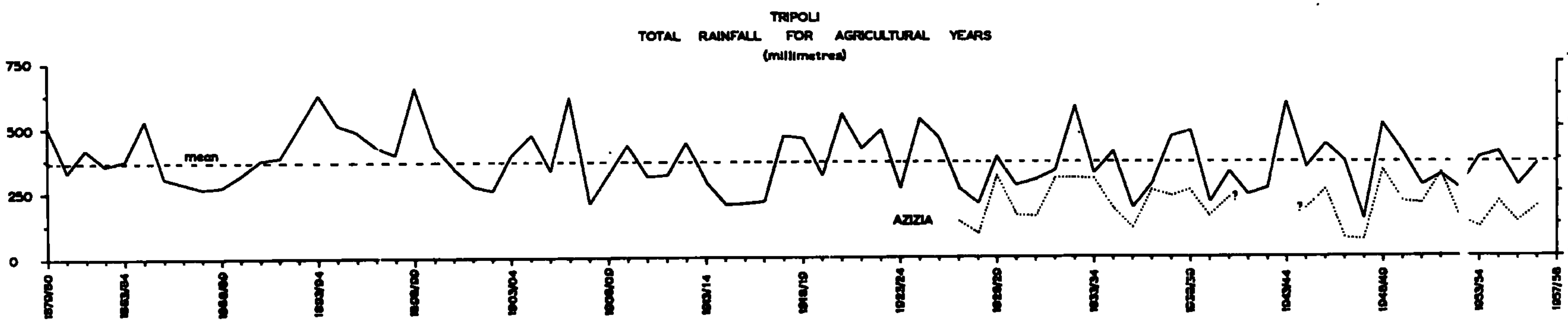
ii. <u>Reliability.</u> In semi-arid areas such as the Jefara, the rainfall is not only low but unreliable. One year the farmers' crops may thrive and give excellent harvests and the next year they may fail completely. A brief study of rainfall reliability will emphasize the unstable foundations of dryland agriculture.

Appendix IVe gives the rainfall amounts for certain Jefaran stations in recent years and indicates the annual and regional variations in the period 1949/50 and 1955/56. By comparing the isohyet patterns of wet and dry years (figs. 11a and 11b) with that for the average year (fig. 5b), several anomalies can be noted. 1952/3 is taken as a dry year, since in this year Tripoli's rainfall was 100 mms. below average. The isohyets confirm that whilst the rainfall in the Tripoli-Tajiura area was well below average, in the western Jefara it was only slightly below average and in the eastern Jafara in the Ghanima region it was at least 50 mms. above average. In the 1954/5 season Tripoli's rainfall was almost 50 mms. above the mean, but rainfall was deficient in the western and eastern parts of the Jefara. Rainfall distribution is therefore very patchy and varies from year to year; a drought in one part of the Jefara may contrast with abundant rains elsewhere. The 1947/8 season is quoted as one of the severest droughts of recent times, Tripoli only receiving 141.6 mms. and Azizia 70.3 mms. In the previous wet season, Tripoli's rainfall was average but that for Azizia was sadly deficient at 71.6 mms.. Azizia


5 YEAR RUNNING MEANS
TRIPOLI
mean
millimetres
YEARS


ACCUMULATED DEFICITS
TRIPOLI
mean
YEARS


RAINFALL FREQUENCY
TRIPOLI 1879/80-1957/58
FREQUENCY in numbers
RAINFALL IN MILLIMETRES


TRIPOLI
TOTAL RAINFALL FOR AGRICULTURAL YEARS
(millimetres)
mean
AZIZIA

and other parts of the Jefara experienced two severe droughts in succession. The average rainfall map should therefore be treated with circumspection for it conceals many irregularities which have adverse effects on agriculture.

It is interesting to look at Tripoli's yearly rainfall amounts for the last few decades. These amounts are tabulated in appendix IVd and they range from a maximum of 653.2 mms. to a minimum of 141.6 mms.. However it is the most frequently occurring amounts, rather than the extremes which are really important. Figure 10c shows that the most frequently occurring annual rainfall at Tripoli is in the range 250-300 mms. (23%), that is just below the mean, and then the next most frequent 350-400 mms. and 400-450 mms., that is, just around and above the mean. Of the 78 totals given in appendix IVd, 36 are above the mean and 42 below the mean.

The fluctuating behaviour of Tripoli's and Azizia's rainfall is graphed in figure 10d. Sometimes the two stations have the same trend, sometimes the reverse trend and in 1951/2 Azizia actually had more rainfall than Tripoli. Dryland crop yields are bound to fluctuate from year to year in response to changing moisture conditions. An attempt was made to plot the yield of dryland crops on the graph of Tripoli's rainfall, to see if there was any relationship between the two. This was not successful for two reasons: firstly, as already proved rainfall figures for one station do not necessarily give a true indication of rainfall on the rest of the Jefara; secondly, many of the crop statistics are suspect as they often represent calendar years, not agricultural years.

In order to smooth out fluctuations in Tripoli's rainfall graph, 5 year running means were worked out for the 35 year period 1913/14 to 1947/8; these are given in Appendix IVf and plotted in figure 10a. The general trend of rainfall seems to be broken up into the following periods: dry, wet, about average, dry, average and slightly above, fairly dry. Cumulative graphs are another means of showing cyclic fluctuations in rainfall. Accumulated deficits for Tripoli for the same 35 year period as above are graphed in figure 10b. and listed in Appendix IVf. There seems to be a sequence of 9 dry years, 7 wet, 2 dry, 8 wet, 2 dry, 6 wet and one dry, making a total of 14 dry and 21 wet. Over 35 years there is likely to be one long dry period, two short dry periods, and three intermediate wet periods. These wet and dry periods will be related to water-table levels, although a water-table takes time to respond to a change from a period of moisture deficit to one of surplus. It is during the dry periods that the aquifers have their lowest recharge and greatest discharge (increased demands for irrigation). In the 35 year period analysed rainfall deficits below the mean are approximately balanced by the water surpluses above the mean, so that the water-table should be static over this length of time. However before satisfactory conclusions can be drawn about the stability of the underground water-levels, a longer period than 35 years must be studied.

Rainfall totals for Azizia have not been closely scrutinised, but like those for Tripoli, they fluctuate sharply. Of the figures available, the highest is 336 mms. and the lowest 70.3 mms.

Averages of monthly rainfall have already been studied, but it is important to remember that the actual rainfall for any month bears little relationship to the average for that month. Fantoli (4 p.65) lists maximum and minimum figures recorded for Tripoli in a 70 year period:-

Table 4.7 Monthly extremes of rainfall - Tripoli.

	Maximum	Minimum
September	93.5	0.0
October	196.1	0.0
November	293.7	0.7
December	377.7	1.0
January	209.6	4.6
February	161.9	0.0
March	260.4	0.0
April	81.2	0.0
May	34.0	0.0
June	15.0	0.0
July	10.7	0.0
August	28.1	0.0

Every month except November, December and January has recorded no rainfall and at the other extreme, more than the mean annual rainfall fell in one December. A study of standard deviations, rather than extremes, gives a more adequate picture of the variability of monthly rainfall.

Table 4.8 Monthly standard deviations for Tripoli and Azizia.

Tripoli 35 years - 1913/14 to 1947/48

Month	Mean	Standard deviation	Coefficient of variability (S.D.% of mean)
September	10.46 mms.	19.21 mms.	184%
October	31.88 "	34.38 "	107.5%
November	69.71 "	59.01 "	84.6%
December	87.27 "	65.77 "	75.3%
January	72.01 "	42.9 "	58.5%
February	38.08 "	25.7 "	67.5%
March	28.93 "	45.8 "	159.2%
April	8.89 "	9.39 "	105.3%
May	4.73 "	6.21 "	129.4%
June	1.55 "	2.33 "	150.0%
July	0.60 "	2.49 "	415.0%
August	0.43 "	1.24 "	288.0

(For monthly rainfall see Appendix IVb)

Azizia 14 years - 1926/27 to 1939/40

September	7.83 "	12.17 "	155.5%
October	12.01 "	12.88 "	107.0%
November	25.04 "	16.62 "	66.5%
December	45.16 "	34.54 "	76.0%
January	56.06 "	33.71 "	60.0%
February	32.94 "	23.02 "	70.0%
March	23.09 "	14.35 "	61.8%
April	11.24 "	12.79 "	113.5%
May	2.35 "	3.44 "	146.0%
June	0.77 "	2.85 "	371.0%
July	0.44 "	0.18 "	450.0%
August	0.09 "	0.1 "	111.0%

(For monthly rainfall see Appendix IVc)

During the rainy season September to April, the figures for the two stations are generally comparable and in every instance they are high, all exceeding a 50% deviation. January is the most reliable month both for Tripoli and Azizia; September and October are wholly unreliable for both stations; March is unreliable for Tripoli but less so for Azizia. It is fortunate that the wettest months, December, January and February are the most reliable, but it must be remembered that a variability of 58.5% for Tripoli in January represents a large quantity of rainfall. The high percentages for the summer months can be ignored because the amount of rainfall involved is so small.

Rainy periods and rainfall intensity have already been mentioned but their variability was not described. The average number of rainy days for Tripoli is about 53 a year, but in the winter 1947/8 there were only 36. Fantoli (4 p.77) worked out the relationship of rainy days to the amount of rainfall as follows:-

Table 4.9 Rainfall and rainy days - Tripoli and Azizia.

Place	% of rainy days	Amounts received.
Tripoli	63.96	0.1 to 5.0 mms.
	27.39	5.0 to 20.0 "
	8.65	+ 20.0 "
Azizia	71.0	0.1 to 5.0 "
	24.0	5.0 to 20.0 "
	5.0	+ 20.0

According to the above table nearly 64% of Tripoli's rainy days have 0.1 to 5 mms. of rainfall, yet with a yearly mean of 368 mms. and 53 rainy days, the average amount of rainfall per rainy day is nearly 7 mms. This anomaly can only be explained by the fact that some rainy days receive very heavy falls. The maximum recorded precipitation at Tripoli occurred during the period 1-6th December, 1938, when 233 mms. fell, 122.3 mms. falling on the 2nd December alone. In contrast to this period of intense rainfall, Azizia experienced a prolonged wet period, lasting from the 1st-12th December 1932, and during this time only 30.7 mms. of rain fell. The maximum rainfall recorded per 24 hours for each month of Tripoli is as follows:- (4 p.80)

Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apl.	May	June	July	Aug.
81	86	130	122.3	72	125	151.8	49.7	20	+	-	28.1

It is clear that periods of violent and intense rainfall are likely each winter both on the Jefara Plain and in the Jebel, and conditions will therefore favour flooding (see chapter 5).

5. Index of Aridity.*

Rainfall figures alone do not give a true indication of aridity, and only by combining rainfall and temperature can the effectiveness of rainfall really be ascertained. De Martonne's formula, which divides the precipitation in millimetres, by the temperature in degrees centigrade plus 10, is one of the earliest attempts to establish an index of aridity. De Martonne classifies his yearly index as follows:-

Greater than 20 - Exoreic, drainage to the sea.

10-20 - Endoreic, water flow to inland basins.

Less than 10 - Areic, no surface flow.

Indices for selected stations have been worked out, and they show that if the above classification is employed, then the whole Jefara is either endoreic or areic. The figures are: Zuara 7.4, Tripoli 12.4, Azizia 7.1, Ben Gashir 9.5 and Gharian 12.2 (a Jebel station). The index of 10 is approximately the boundary between steppe and desert.

* Floger. B/44 p.14 uses De Martonne's index of aridity to calculate irrigation need. In section 5 above this index is used solely to relate temperature and rainfall but in section 6 more up-to-date formulae are used to work out irrigation need.

Yearly indices of aridity are however misleading because of the marked seasonal nature of the rainfall. Monthly indices can easily be worked out from the formula $\frac{12p}{t + 10}$, where p = monthly rainfall in millimetres and t = monthly temperature in degrees centigrade.

Table 4.10 Monthly indices of aridity for Tripoli.

Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apl.	May	June	July	Aug.
3.4	13.5	29.4	49.7	41.9	21.7	11.8	4.1	2.0	0.6	0.2	0.3

All the six months April to September have an index below 5, and June, July and August are in fact below 1. There is likely to be wadi flow in any of the months from October to March.

Winter aridity indices for the October-March period are the most useful. These are listed below in order of magnitude.[x] Notice how the rainfall figures do not necessarily follow the same order as aridity figures; Zuara has a higher index but less rainfall than Azizia. The inclusions of Jebel stations emphasizes that aridity depends on temperature as well as rainfall.

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x After Dr. G. Logozzini, Meteorological Service, United Kingdom of Libya.

Table 4.11 Winter Indices of Aridity

Station	Index	Rainfall
Tripoli	26.8	368.0 mms.
Gharian	25.6	291.8 "
Garabulli	22.6	302.4 "
Ben Gashir	20.9	288.8 "
Yefren	20.9	243.2 "
Zawia	19.2	251.1 "
Jiado	17.3	195.2 "
Zuara	15.8	216.0 "
Azizia	14.3	217.0 "
Pisida	13.7	164.0 "
Nalut	9.8	113.4 "
El Assa	9.4	118.1 "
El Wotia	9.2	113.5 "
Bir El Ghnem	7.8	109.8 "
Jaush	7.3	95.2 "

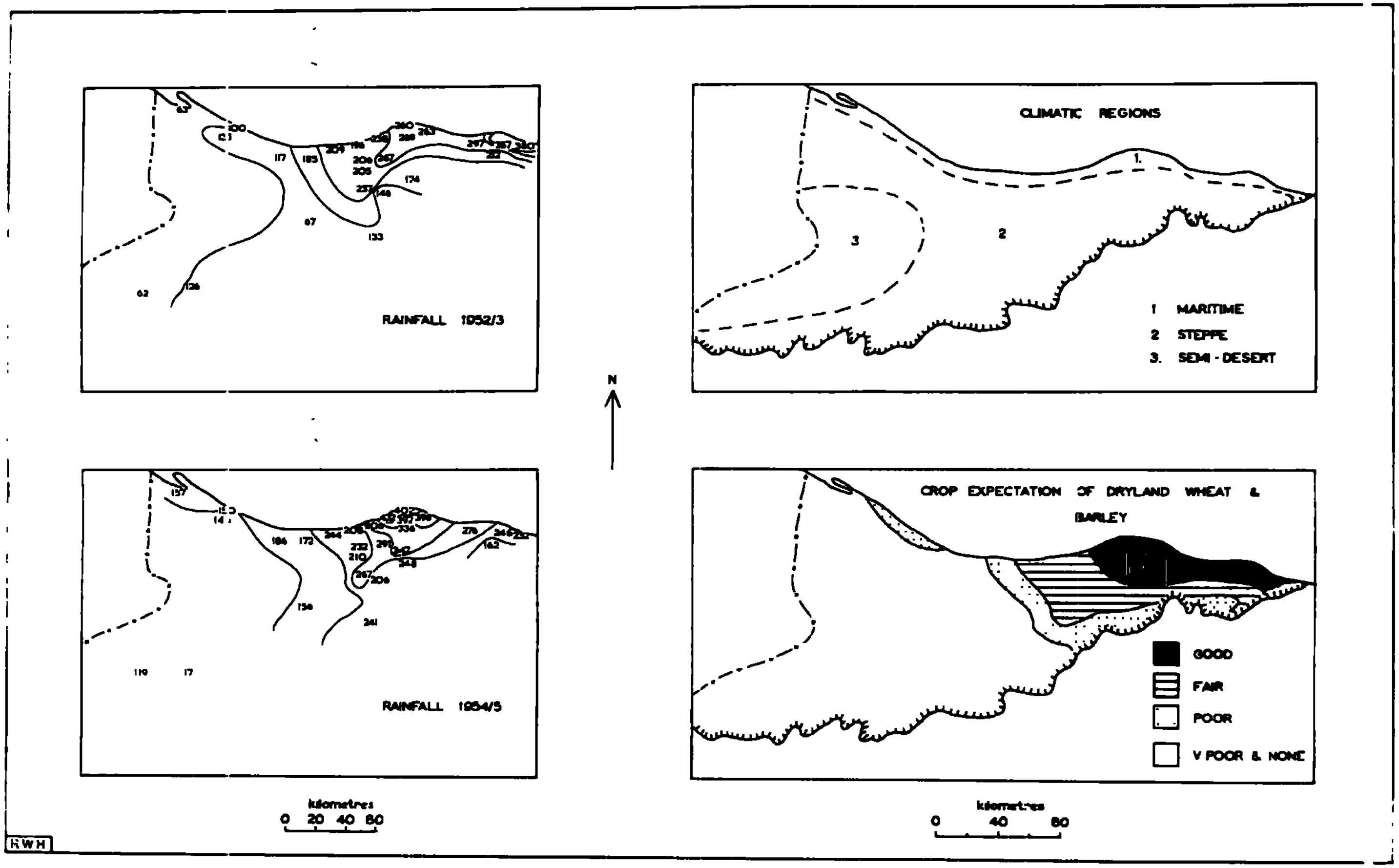
These figures indicate the favourable and unfavourable areas. The Tripoli, Ben Gashir and Garabulli triangle offers the best prospects for the cultivator but the western Jefara is extremely arid. All wadis with catchment areas in the Jebel which have a winter aridity index of 20 or over, will flow out on to the Jefara Plain.

6. Climate and Agriculture.

a) Dryland Crops. These crops depend entirely on natural rainfall. Dr. G. Magozzini's calculations of the precipitation necessary for given yields of cereals and olives are as follows:-

Table 4.12 Rainfall and Crop-yields

Crops	Nature of Yield	Minimum rainfall necessary
Olive	Good	300 mms.
	Fair	250 "
	Poor	180 "
	No crop	-150 "
Wheat and Barley	Good	300 "
	Fair	250 "
	Poor	200 "
	No crop	-200


RAINFALL 1952/3
RAINFALL 1954/5
kilometres
0 20 40 80
N
CLIMATIC REGIONS
1 MARITIME
2 STEPPE
3. SEMI - DESERT
CROP EXPECTATION OF DRYLAND WHEAT & BARLEY
GOOD
FAIR
POOR
V POOR & NONE
kilometres
0 40 80
RWH

According to table 4.12 the olive is hardier than cereals and will even give a crop, poor as it may be, with a rainfall under 200 mms. The figures for wheat and barley have been used to draw figure 11d, which shows the distribution of the varying yields in an average year. Good crops can only be expected in the Tripoli and Garabulli districts, fair crops in the Zawia and Azzahra areas, and no crops can be expected in the Bir el Ghnem, El Wotia and Sehera regions.

Azizia lies within the zone of Arab shifting cultivation. In this area during the 15 year period 1926/7 to 1940/1, there were 4 good crops, 2 fair crops, 2 poor crops and 7 failure crops. However, round Tripoli, where moisture conditions are infinitely better and where the Italian grows cereals under dry cultivation, crop yields for the same 15 years were 8 good, 4 fair, 2 poor and only one failure. The area of land suitable for dryland farming is nevertheless very limited and even on this land crop failures are unavoidable in some years.

The winter aridity index of 20 is considered the lower limit for good dryland farming and reafforestation. The Tripoli district and the eastern Jafara are the best suited areas, with Zawia and Azizia very marginal. According to the 1952 F.A.O. Agricultural Report*, the limit of olive cultivation is somewhere between the 10 and 15 winter index, and the boundary of shifting cereal cultivation coincides

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* B/90.

approximately with the 10 index. Relating this to table 4.11, it is obvious that the shifting cereal cultivator in the Inner Jefara, particularly in the west, must reap pitiful returns year after year, even in favourable areas such as wadi beds.

Dryland cereal crops are more critically affected by the fickle autumn and spring rains, than by the more reliable winter rains of December and January. The shifting cereal cultivator sows his barley with the first autumn rains, and the heavier and more prolonged the rains the larger the area he sows. However, a heavy autumn rainfall is often followed by a meagre rainfall in the spring and the resulting crop is poor. The autumn rains therefore determine the area sown, but the spring rains determine the harvest.

Three conclusions can be drawn from the above observations. Firstly, only a very small part of the eastern Jefara is suitable for satisfactory winter dryland farming; secondly, within this area yields fluctuate radically from year to year and only 8 good crops can be expected in 15 years; finally, it follows that there is only one way of stabilising the yields of dryland crops and that is by giving supplementary irrigation.

b) <u>Irrigation, evaporation, evapo-transpiration and soil moisture.</u>

In recent years several empirical formulae have been worked out for measuring aridity, which have more practical value, especially agriculturally, than that of De Martonne. Some attempt to measure the duration, and others the severity of drought conditions.

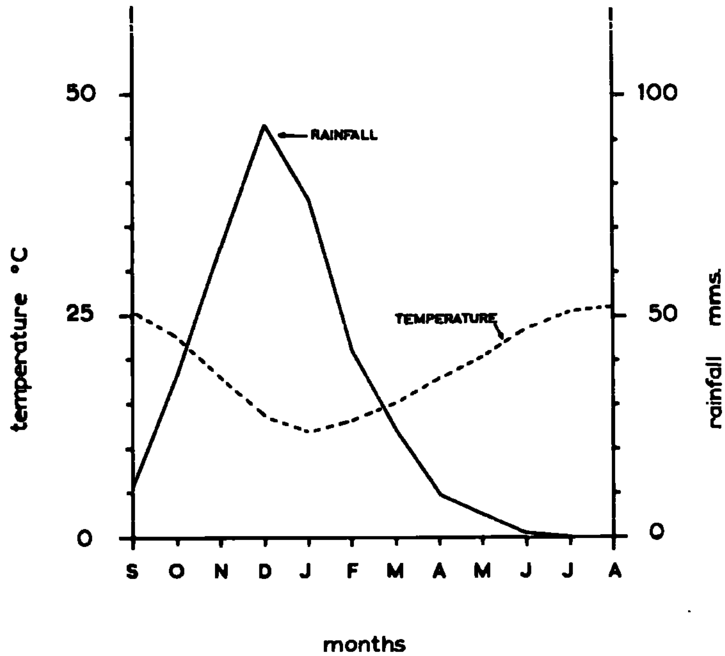
Gaussen (17) states that drought exists when the total monthly precipitation in millimetres, for a given month, is less than twice the mean centigrade temperature for the same month. This dictum was applied to Sidi Mesri and is plotted in graph form in figure 12a. In the Tripoli area there is a moisture deficiency at the end of September, which is not made good until about the first week in November; there is then a moisture surplus until about the third week in March and then drought conditions develop and persist throughout the summer. From the end of March until early November the moisture content of the soil is sadly deficient and only for a short period November to February is there a moisture surplus. The picture is much the same for Azizia, except that the period of drought is longer and more severe and the period of water surplus shorter. All irrigation rates are therefore necessarily higher in the Azizia area than along the coast.

Thornthwaite uses his moisture index as a means of classifying climate; he derives this from his formula $\frac{100s - 60d}{\text{water need}}$ where s = moisture surplus, d = moisture deficit and water need equals potential evapo-transpiration. Potential evapo-transpiration can be determined by another empirical formula which he supplies. According to Thornthwaite, a moisture index of -40 to -20 signifies a semi-arid steppe climate, and one of -60 to -40 an arid climate. One would expect Sidi Mesri

Figure 12.

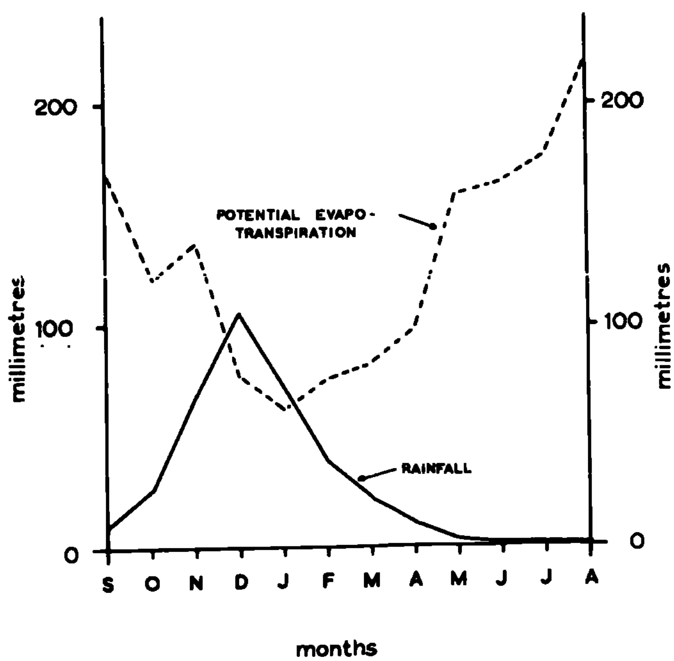
(a)

APPLICATION OF GAUSSEN FORMULA
SIDI MESRI



(b)

POTENTIAL EVAPO-TRANSPIRATION IN
MALTA AND RAINFALL AT SIDI MESRI



to be a marginal semi-arid steppe climate, but applying the Thornthwaite formula, with Mitchell's Malta figure for evapo-transpiration (14), the index for the experimental farm is -44.2, quite clearly in the arid category. The severity of the aridity is further emphasized by the fact that only December and January have a moisture surplus (index of + 26.3) and that from April to September there is a severe summer drought with an index of -97.1. The cultivation of summer crops is only possible with irrigation, and taking into account the overall aridity of the Jefara Plain, it is doubtful if there can be any rapid agricultural development without introducing or extending irrigation.

Willatts* has shown in Palestine that, of the rain falling on lands draining to the Mediterranean, 70% is lost to evaporation and evapo-transpiration, 24% percolates underground and 6% flows to the sea as storm water. That disappearing underground provides a reservoir of water which can be used for irrigation, but that flowing to the sea is lost. The hydrological aspect of the Jefara's rainfall will be discussed in chapter 5, but it is necessary at this point to make further brief observations on evaporation and evapo-transpiration.

Water is lost to the atmosphere in two ways: direct evaporation from water surfaces, e.g. pools in the Inner Jefara after rains, irrigation storage tanks, canals and sprinklers: and evapo-transpiration from the plant cover. Whenever the moisture is available, rates of evapo-transpiration are high. However there are no measurements available in

* Willatts, E.C.: 'Some geographical factors in the Palestine Problem'. G.J. 1946, v. 108, pp. 146-179.

Tripolitania, either for evaporation or evapo-transpiration. The C.O.T.H.A.* report quotes a formula for calculating evaporation. evaporation = 4.2 x temperature in degrees centigrade. Using this formula the evaporation at Tripoli is 990 mms. per annum, that is almost three times the rainfall, and at Azizia 1080 mms., about five times the rainfall. These would appear to be conservative figures because Helwan, as already stated, has a mean annual evaporation of 2387.6 mms. In order to avoid high rates of evaporation, the time and the methods of irrigation must be carefully chosen if water is to be used efficiently.

With optimum soil water conditions, evapo-transpiration is determined principally by climatic factors and is referred to as potential evapo-transpiration. Rates of evapo-transpiration are very high in the late spring when water in the soil is at field capacity and temperatures are increasing. Work on potential evapo-transpiration has been carried in several parts of the world but the nearest and perhaps the most relevant to this study, is that of Mitchell (14) who has taken measurements at Hal Far in Malta. Malta is situated only 200 miles north of Tripoli and conditions are only a little more humid and cooler than those on the Jefara; furthermore Mitchell claims a slight over-reading for his station. His figures,which can be considered minimal when applied to Sidi Mesri, are as follows:-

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* B/45, Sept. 1954.

Table 4.13 Potential Evapo-transpiration at Hal Far (Malta) and rainfall at Sidi Mesri. (in millemetres)

Month	Potential evapo-transpiration Hal Far	Rainfall, Sidi Mesri
September	172.7	10.0
October	121.9	27.6
November	137.2	69.8
December	78.7	106.0
January	63.5	73.4
February	76.2	38.9
March	83.8	23.3
April	99.1	10.1
May	160.0	3.9
June	165.1	0.7
July	177.8	0.9
August	210.8	0.6
Year	1546.9	365.2

The relationship between these two sets of figures is shown vividly in figure 12b. Only in two months do the monthly rainfall amounts at Sidi Mesri exceed potential evapo-transpiration. A moisture surplus is built up in the soil during these two months, but for most of the remainder of the year there is a moisture deficit. It is evident that summer crops will need frequent and copious irrigations, and that winter crops should be given some form of supplementary watering.

7. Summary and Conclusions.

The observations made in this chapter have revealed high summer temperatures and aridity, and an unreliable and unevenly distributed winter rainfall. Mild winters should encourage the growing of early vegetables, but the dessicating effect of the Ghibli is troublesome. Throughout most of the Jefara the yields of dryland crops are disappointing, and only the introduction of supplementary irrigation gives better returns. The adverse summer conditions can only be overcome by employing full irrigation, but it must be remembered that the water needs of plants are very high and therefore the demands on the groundwater reserves are substantial. The amount of water available for irrigation will be discussed in chapter 6.

The underlying theme of this chapter has been to try and show how climate is unfavourable to the farmer. It seems unlikely from the evidence given, that a stable agricultural economy can be developed without some form of irrigation. How much water is needed for irrigation? Climate can be used as an index of the water needs of crops and at this point it is useful to tabulate figures for lucerne, citrus, natural vegetation and potatoes. These have been calculated from the formula given by Blaney and Thornthwaite (3):-

Table 4.14 Irrigation requirements of selected crops

Crop	Consumptive Use (Potential evapo-(TRANSPIRATION)	Irrigation need (Consumptive use-precipitation)	Actual water needed from underground, with 60% efficiency of distribution
Lucerne	14,060	10,408	17,300
Citrus	9,930	6,278	11,000
Natural Vegetation	20,010	16,358	27,050
Potatoes			
Sept.-Nov.	3,210	3,102.6	5,140
Oct.-Dec.	2,705	2,501.6	4,160
Nov.-Jan.	1,815	1,565.8	2,600
Dec.-Feb.	1,682	1,463.7	2,439
Jan.-Mar.	1,918	1,782.4	2,970
Feb.-Apl.	2,765	2,692.7	4.480
Mar.-May	3,020	2,982.7	4.970
Apr.-June	3,675	3,660.3	6.100

Several important conclusions can be drawn from the above table. Lucerne is an annual field crop, which can be considered under full irrigation all the year. Assuming sprinkler irrigation is used, then this crop will need about 12,000-14,000 m3/ha. per annum (irrigation need of 10,408 plus an allowance for the inefficiency of the sprinkler). If canals, earth ditches and jedawl are used for irrigation, then at least ~~20~~15,000 m3/ha. will be needed. Citrus needs less water than lucerne. Potatoes need irrigating even when they are grown in the wettest period between December and February, although only about 2-3,000 m3/ha. are required, (perhaps 2-3 waterings). Cereals and olives also should doubtless benefit from an occasional irrigation. Much of the agricultural land on the Jefara is under olive trees, with intercultivation of field crops in the winter. The winter field crops need 2-3,000 m3 of water per ha. given as a supplement to the rainfall; the tree crops need an occasional irrigation in the summer. Such land is classed as semi-irrigated and needs about 4,000 m3/ha. per annum. Land which is under a field crop in the summer as well as the winter, is classed as fully irrigated and requires 12,000-14,000 m3 of water per ha.. The amount of water needed depends in large measure on the method of irrigation; the sprinkler is by far the most efficient means of distributing water (chapter 8) and with this method only about 2,000 m3/ha. need to be added to the 'irrigation need' given in table 4.14.

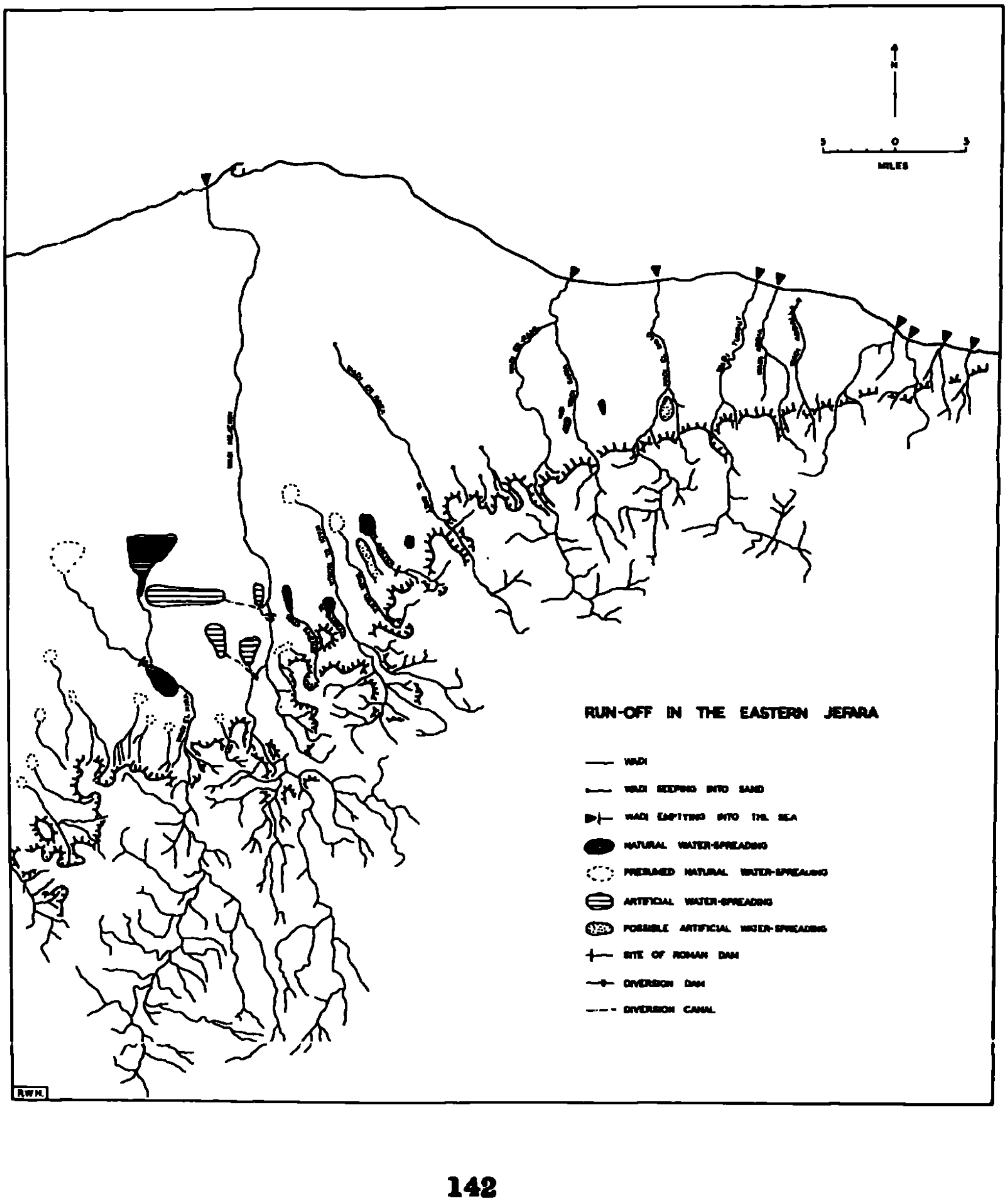
CHAPTER 5

Surface Water - a neglected resource.

1. Introduction.

Groundwater is being used very rapidly and yet at the same time surface water is running to waste and is doing considerable damage. Water is scarce in Northern Tripolitania and every effort should be made to ensure that all surface flow is utilised. Rainfall is seasonal, falling only in the winter months, and is often torrential; it is not surprising therefore that flow in the wadis indicated in fig. 2 is violent. The Americans refer to the short periods of wadi spate as 'flash floods'.

The amount of run-off on the Jefara is very limited because the whole plain is so pervious and flat that it acts like a giant sponge which sucks in the rainfall as soon as it reaches the ground. All the wadis flowing across the plain rise either in the Jebel or the Pre-Jebelic hills. As explained previously, nearly all those to the east of, and including the Mejenin, flow to the sea, but in the west they spread out at the foot of the Jebel and lose themselves in their own deltaic material and in the numerous areas of sand. The eastern wadis, particularly Raml, Turgut, Saria and Msid, are degrading their beds and tend to be incised in the plain, but from Wadi Er-Rbea westwards, the wadis are aggrading and easily flood. The eastern wadis discharge an estimated 5-10% of their catchment area rainfall to the sea and 6% underground. The western wadis lose about 15% of their water underground in the Inner Jefara and the rest


N
5 0 5
MILES
RUN-OFF IN THE EASTERN JEFARA
WADI
WADI SEEPING INTO SAND
WADI EMPTYING INTO THE SEA
NATURAL WATER-SPREADING
PRESUMED NATURAL WATER-SPREADING
ARTIFICIAL WATER-SPREADING
POSSIBLE ARTIFICIAL WATER-SPREADING
SITE OF ROMAN DAM
DIVERSION DAM
DIVERSION CANAL
RWH

to the atmosphere.

2. The nature of the catchment area.

The rainfall in the Jebel varies from under 150 mms. in the extreme west round Nalut to 300 mms. in the Gharian region and 250 mms. farther east. In the east the wadis are near the sea and because they have captured parts of the dip-slope drainage of the Jebel, they have large catchment areas. In the west the wadis are very small and with the low rainfall existing in that region, they only have very low discharges on to the plain. Most of the Jebel is composed of bare, denuded slopes, carved out of almost tabular Cretaceous sediments which are mainly limestones. At one time it used to be clothed with a woodland for Lang* has shown that between Nalut and Jaush for example, the communities of Haloxylon salicornicum, Calecotome intermedia and Periploca are relics of an open forest. The disappearance of the vegetation has left the soil and superficial material exposed to the raging torrents which cascade down the steep slopes. In the catchment areas shown in fig. 13, it is a depressing sight to see the think blanket of Quaternary material - the very lifeblood of the country - rapidly being washed away. In the west the amount of present day erosion is less because the rainfall is lower and most of the soil and superficial material has long since disappeared leaving the hills absolutely bare. The fact that the catchment areas are so eroded and devoid of vegetation means that much of

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* B/49.

the rainwater fails to sink into the Cretaceous sediments of the Jebel, instead, heavily charged with sediment, it bursts out violently on to the Jefara Plain. Plate 7 gives some idea of the turbidity of wadi water.

In the eastern Jefara, which is the best developed part of the plain, wadis wreak heavy damage to land and property, deposit tons of sediment, and carry large quantities of precious water out to sea. Along many of these wadis the locals have attempted to conserve some of the surface flow by building cisterns. These, although very commendable, only provide water for domestic use and are very small (see plate 10).

3. The quality of the water.

Quality is good, because water flowing across the surface of the land has little time to dissolve appreciable quantities of toxic minerals. The proportion of dissolved solids, particularly chlorides, is low and the water can be used for any purposes. The following figures, taken from C.O.T.H.A. (8 p.96) indicate the high quality of the water, thereby emphasising the need for its conservation.

Table 5.1 Quality of surface water

	Specific conduction	Dissolved solids, p.p.m.
Wadi Mejenin water	360	246
Mejenin cistern	539	358
Artificially spread water	360	246 (total salts 237)

The water, which has been stored in a cistern, is of slightly inferior quality.

4. Rainfall and flooding in the Eastern Jebel and Jefara with special emphasis on the Wadi Mejenin.

The amount of rainfall is so small and its distribution so seasonal that there is no perennial flow except from a few springs near the coast along some of the eastern wadis. C.O.T.H.A. quotes a formula taken from an article by L.A. Coutagnee in Revue de Météorologie 1935, $x=0.6\ (15+t)^2$ where t = average temperature in degrees centigrade and x = the rainfall required for perennial flow. If the temperature for Tripoli is taken as 20°C, then a rainfall of 735 mms. is needed to sustain a constant flow of surface water. To achieve De Martonne's aridity index of 20, which marks the boundary between a dry and humid climate, Tripoli would need a rainfall of 600 mms.; Tripoli actually has a rainfall of 368 mms. It is in the Jebel, however, where water can be concentrated in sufficient quantities, that seasonal flow can be expected. Whenever De Martonne's monthly aridity figure exceeds 20 for the Jebel stations, as it does in November, December, January and February, wadi flow is possible.

The mean rainfall in the eastern Jebel is around 250-300 mms., of which over 80% falls between October and March. Generally there is an average of 45 rainy days per year. 77% of these have amounts of less than 10 mms. and are not likely to cause floods; 14% (6 days) have over 10 mms. and could give a flood if the rain falls intensely during the night and over a large part of the catchment area, and 9% (4 days) have over 20 mms. which is almost certain to give a flood.

Rainy periods are more likely to give floods during the early part of the rainy season than later, because the first autumn rains are often the most intense and they fall on land which is partially impermeable due to the heat and evaporation of summer. An autumn rain of 15-20 mms. will cause a small flow in the Mejenin, but if 30 mms. fall in a night the Mejenin may even flow across the plain to Tripoli. Dr. Magazzini, the director of the Government Meteorological Service, has, however, known rainfalls of 50 mms. which have not produced a flood.

What happens to the rain that falls in the Jebel catchment area ? 3-4 floods of varying intensity can be expected in many of the eastern wadis during the winter season and C.O.T.H.A. estimates that 10% of the rain falling in the Mejenin catchment area (i.e. 30 mms.) flows in the wadi as it leaves the Jebel; of this about 5% reaches the sea. A higher percentage of water reaches the sea in the eastern wadis because they are shorter and have a steeper gradient; percentages there are roughly as follows:-

Run-off to the sea	10%
Infiltration	5%
Evaporation	85%

Of the rain falling in the catchment areas of the endoreic wadis up to 15% infiltrates underground in the Inner Jefara and the rest evaporates.

Today it takes less rainfall in the Jebel to give floods than it used to only a few decades ago. Before 1920, if 100 mms. of rain fell in a single storm in the catchment area of the Mejenin (a situation which only happens once in 25 years apparently), there would be a run-off of 7-8 mms. (5 million m3); if 100 mms. falls in the same area and period of time today there would be a run-off of 15 mms. (10 million m3.). Furthermore it is probable that each flood today now carries 4-5 times the amount of silt and sand per m3. of water than in the pre-1920 period. Conditions are certainly deteriorating in the catchment areas.

The Mejenin: This wadi has a catchment area in the Jebel of 650 sq. kilometres, which receives an average rainfall of 300 mms.. According to C.O.T.H.A. (6) the annual amount of rain falling on the catchment area is 195,000,000 m3., of which 13,000,000 is lost to infiltration (6.7%), 19,5000,000 flows from the Jebel and the rest evaporates. The Mejenin has the largest discharge of any of the wadis flowing from the Jebel.

The water flowing in the Mejenin from the Jebel is composed approximately of 2 floods of 6 million m3. lasting 3 days; 1 flood of 4 million m3. lasting 48 hours, and 1 flood of 2 million m3. lasting 24 hours. Dr. Magazzini has listed the recent rainfalls which have resulted in floods in the environs of Tripoli as follows:-

Table 5.2 Rainfall and Flooding

Locality	Dec. 1938	Dec. 1945	26-29 Apl. 1955	26-29 Dec. 1955	12-16 Mar. 1956
Gharian	81mms.(10 days)	100mms(6d)	41mms.	90mms.	33mms.
Tarhuna	90mms.(7 days)	60mms.(8d)	55mms.	93mms.	30mms.

In 1945 there was a very bad flood and the Mejenin flowed to the sea for 3 days, discharging about 5,000,000 m3. In 1953 the wadi flowed at Marabito Bridge (a few kilometres south of Gasr Ben Gashir), twice at 20-30 m3./sec. and once at 9 m3./sec., but no water reached Tripoli. In April 1955 another large flood struck Tripoli, the largest since 1945; in December of the same year there was another, but although the rainfall was higher in the Jebel, the flood was smaller because 6-8 hours flow was sent into the Amiot and Sidi Jilani diversion canals (evidence that the French scheme, which will be mentioned later, is having some effect on the flooding at Tripoli). Stewart (14) writes that in March 1956 there was a medium sized flood which reached Tripoli and broke away from its channel for about 12 hours. The total volume of water reaching the town was in the order of 3,000,000 m3., half of which flooded an area of 280 ha.. This flood he estimated left behind ½ million tons of silt and recharged the Quaternary aquifers with 1,000,000 m3.; of the remainder of the water two thirds approximately went out to sea and one third evaporated. There was serious flooding again in the outskirts of Tripoli in 1957/8 - see plates 5,6,7, and 8.

Until the great devastations of 1945, the floods were welcomed by the Tripolinos. Like the Nile in Egypt, the Mejenin floods had distinct advantages; they were small and gentle, they recharged Tripoli's aquifers, they irrigated land and deposited a fertile blanket of fine clay. Their character has now changed due to the activities of man and his animals in the catchment area. Today the floods represent something more than a loss of valuable water to the sea, because the Mejenin, unlike the smaller wadis in the east, threatens a town and valuable agricultural land. In the Inner Jefara there is up to 15,000,000 m3. of Mejenin flood water to be controlled annually, and the answer is not to try and divert some of it out to sea, for this would mean a loss of 5-6,000,000 m3.

5. Water and Soil Conservation in Roman Times.

Today the picture in much of Tripolitania is one of damaging floods, severe erosion, deposition of tons of sediment in downstream regions, and wastage of water. In Roman times, dry-land agriculture prospered and there were large exports of cereals to Rome. The Romans achieved this by conserving water and preventing soil erosion. By constructing fortified farms and other buildings along the line of the 'limes', the Romans were able to establish a balance between the sedentary cultivator, who tended trees and grew cereals, and the nomads. The latter along with their animals were kept away from the unstable slopes of the Jebel and the vegetation was not destroyed and the soil did not disappear.

The dangers of erosion and the scarcity of water were as acute in Roman times as they are today. To overcome these difficulties a series of small compact check dams were constructed in the eastern Jebel. These were built primarily to check the velocity of flow, but also to trap sediment and to store a little water. In addition to these, diversion dams were constructed along the wadis in the Inner Jefara wherever solid rock out-cropped; examples can be seen in Wadis el Hira, Mejenin, Hami and Aboter. The eastern Jefara and Jebel must have been almost like a miniature T.V.A. The Romans realised the power of wadi flow and repaired all dams and channels at the end of the rainy season.

6. The break-down of the Roman System.

It has been argued that the Romans did not fully appreciate local conditions; like the Americans in Oklahoma, they extended the 'sown' well into the 'steppe' and cultivated dry-land cereals in areas susceptible to wind and water erosion. The Romans did, however, understand the dangers of arable farming in a dry environment and furthermore there was nothing inherently wrong with their methods of conservation. The system which they introduced broke down and disappeared because dams which were damaged by floods, were not repaired and the process of their disintegration was of course cumulative. Political factors, in form of the Moslem invasions caused the decay of the North African civilisation. The first wave of Moslems did not disturb the Roman system for they brought with them citrus and henna and encouraged irrigation. The second Arab conquest, this time by the Hilal nomads, brought with it large numbers of sheep and goats and everything was subordinated to pasture. 'The trees, the garden, the forest and intensive cultivation, retreated everywhere and the climate deteriorated'.(4)

The Roman dams fell into disuse, erosion was accelerated in the Jebel; the Jefara, except the coastal oases zone, became almost a sea of sand; only the arrival of the European re-established the ascendancy of sedentary agriculture, but the appearance of the Italians in Libya augmented the amount of erosion because they took the best land on the Jefara Plain, forcing many of the locals to retreat to the hills and start ploughing and grazing the steep slopes. There seems little doubt that the Arabs brought about the destruction of the Roman efforts at water conservation, for even the great Arab historian, Ibn Khaldun refers to the Arab nomads as 'lawless destroyers and plunderers who ruined the settled and intricate civilisations of Yemen, of Persia, of Syria and of North Africa'.*

7. Water Spreading.

Having established that there are periodic floods in the eastern Jefara which result from heavy storms falling on the bare hills, the main problem in this chapter is to decide how to prevent these waters from flowing into the sea. This can be done to best advantage by water-spreading. However the problem just mentioned is closely allied to the much greater problem of conserving resources in the Jebel, for the more soil and vegetation there is on the hills the smaller and less violent the run-off and the easier it is to control it. The Jefara is well suited to water-spreading because it has very

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* Ibn Khaldun, 'The Muqaddimah - An Introduction to History' translated from Arabic by F. Rosenthal. Routledge and Kegan Paul.

pervious Quaternary sediments at the surface, gentle slopes averaging around 10%, and a geological structure which favours the recharge of aquifers upstream in the hydraulic gradient.

Water spreading work, which has been carried out widely in the U.S.A., consists of a series of earth and rock dikes in the wadis to show down the flow of water, reduce erosion, spread the diverted water over a large area and thereby increase the amount of infiltration and help to recharge the underground aquifers. The rock dikes are designed to bleed and to be overtopped by the water checked behind them. Wherever groundwater reserves are utilised for irrigation, artificial recharging by water-spreading is desirable if not essential, and provided that water is available for spreading, underground reserves of water should be depleted during the dry season. Experts of the United States Operations Mission have been working on water-spreading problems in Tripolitania for several years past. One of them, Davis (2) points out that during Roman times many wadis in Northern Tripolitania had their beds stabilised by rock dikes and terraces, and he considers that this network should be restored as soon as possible, so that cereals can be grown in wadi beds rather than in the present areas of shifting cultivation; these latter areas should be managed and improved for grazing. A programme has been initiated which consists of two types of water spreaders:-

a) Public work type involving earth and rock dikes in the major wadis.

b) Self help type, comprising community dikes in wadis, hillside terracing and cistern improvement.

Water spreading has many advantages. It helps to recharge the underground aquifers, it allows the harvest of crops in areas which are normally too arid for cultivation, it can help to overcome the problem of crop failures in drought years. Natural water-spreading is taking place in the eastern Jefara between Wadi Mejenin and Wadi Raml, where there are a series of endoreic wadis which rise in the Jebel and peter out in the Inner Jefara. Most of them rise where there is a rainfall of at least 250 mms., and working on the assumption that 15% of the water falling in the catchment area will flow out on to the plain and infiltrate, one can expect 375 m3/ha. to disappear underground each year. The F.A.O. Agricultural Report 1952 (5) evaluates the benefits of storing water in the eastern Jebel, particularly during drought years, in an area of 250 sq. kilometres between the Ben Gashir-Tarhuna road and Cussabat; the aim being of subsequently spreading the water to some specified locality on the Jefara Plain. In the agricultural year 1946/7 Tarhuna, which is the station taken as typical for the area, had 175.4 mms. of rainfall and in the following year 146.6 mms. If the rainfall had been conserved, in the first year with a 10% flow and a 50% efficiency of distribution, enough water would have been available to supply the needs of 1,248 ha. of dry-land cereals or olives, or 14,600 ha. with one supplementary irrigation of 300 m3/ha. and in the second year enough to supply the needs of 840 ha. of cereals or olives, or 1,203 ha. with one supplementary irrigation of 300 m3/ha. There is obviously some case for storing water for it would either allow the cultivation of more land in the Inner Jefara or safe-guard existing crops in drought years. In the two years being studied Ben Gashir had two months without rain in both winters; a supplementary irrigation of 300 m3/ha. would have saved many of the crops. The distribution of small quantities of wadi water for supplementary irrigation would probably be impracticable however.

The C.O.T.M.A. report suggests that the Mejenin water could be spread and used for the growing of dry-land crops such as cereals and olives. Assuming that these crops need 2,100 m3/ha. and that the efficiency of distribution of wadi water is 50%, then 4,200 m3 will be needed per hectare; the Mejenin, with a discharge of 15 million m3. in the Inner Jefara, occurring in 2-4 floods, could be used to develop 3,600 ha.

The Americans have constructed a rock dike in Wadi Beni Ulid (Plate 9). Although this is many kilometres away from the area at present under consideration, it is a region with a similar rainfall to that of the semi-arid Western Jefara. With water-spreading at least two crops of Bermuda grass, sometimes three, plus one of barley are possible. In 1955, for example, a good crop of grass was harvested after the first autumn rains; in the colder winter months the Bermuda grass was dormant and the barley matured and was harvested. If there is a spring rainfall in March or April as there was in 1956, another crop of Bermuda can be harvested. (2 & 3) Dikes increase the depth of moisture penetration from 18 to 36" and as long as a penetration of 24-30" can be achieved then cereals and forage can be grown.

8. <u>The difficulties of spreading the water of the eastern wadis which flow to the sea</u>.

As fig. 13 shows, the wadis immediately east and west of the Mejenin seem ideal for the development of water-spreading; the Mejenin has been partially dammed by the French and further work has recently been carried out by the Americans. The western wadis, which are all endoreic and spread themselves naturally, present no real problem. In the east are numerous wadis which are discharging to the sea each year, and C.O.T. H.A. (9) has made a study of these with a view to developing them for water spreading. Along the wadi Raml the land is not really favourable for water-spreading; in the upstream areas in the piedmont zone there is good land but the wadi is too incised, downstream spreading is impossible in the dune-lands. Like the Raml, the Wadi Saria is incised about 10 metres below the surface of the land at the foot of the Jebel, but further downstream about 8,000 m3. could be stored near the Sheep Ranch (6,000 m3. after evaporation). The Wadi Msid offers better prospects, for 9 kilometres south of Garabulli a canal could be built to take 60,000m3. of water to an area of about 300 ha. which is shown in fig. 13 . Upstream however it is too incised to be utilised. Wadis Abeter, Kerua and Sret are all endoreic and have inland deltas with natural water-spreading, but there is an area between wadis Milga and Abeter which could be used for artificial water-spreading.

In contrast to the eastern wadis, the el Hira, which has a catchment area almost as big as the Mejenin, is ideal for spreading and although the Italians constructed a 100 metre long dam, this place has been silted up and leaks, and the water is not being utilised to the full at the moment (13). Further west the Wadi Etel, with over 3,000 ha. of natural épandage, would seem to offer scope for development.

9. Conclusions.

In the western part of the Inner Jafara there is no need for artificial water-spreading because the wadis all spread themselves naturally. However, in this region, much of the water flows on to poor, hard and compacted land which has little agricultural value; to overcome this, weirs could be constructed to divert the water to better land. An attempt was made in 1951 to divert the water in a wadi near Tiji, to better soils but nothing has been tried since except the primitive constructions of the local population, one of which was seen at wadi Zigzau in Autumn 1957.

In the east there is an urgent need for a comprehensive plan for soil and water conservation, associated with reafforestation. A series of small check dams to slow down the flow of water in the eastern Jebel, must be built as quickly as possible, and at the same time trees must be planted and the grazing of animals prevented; in the Inner Jefara more diversion dams should be constructed. Because there is so much soil erosion all dams are clearly going to silt up very rapidly; this fact must be accepted at the outset and the under-employed local labour used for cleaning out purposes after each rainy season. Water which is diverted in the Inner Jefara can either be used for an expansion of cultivation in that area, or allowed to infiltrate 'in situ' or taken farther north to a place like Gasr Ben Gashir, and there used either as a supplementary irrigation or for the direct recharge of a falling water-table. In some areas of water-spreading it may be necessary to break up the fine clay layer which is sometimes evident at the surface.

The main advantage of water-spreading on the Jefara is that it encourages water to go underground and flow into a natural reservoir which is the most efficient available in an arid environment.

CHAPTER 6

Groundwater Resources

A. Introduction.

It would appear from chapter 4 that only by using full or partial irrigation can stable crop yields be obtained. At the present moment water for irrigation is only available underground, and any agricultural development is limited by the size of this reserve. It has already been established that the geological structure favours the accumulation of underground water and it now remains to determine whether water exists in large quantities and at the same time is of good quality. Is the amount of water sufficient to sustain the present rate of agricultural development and still allow for increased future demands?

Briefly reviewing the structure of the Jefara, it is evident that much of the plain is composed of Tertiary and Quaternary sediments which dip gently northwards; this is clearly shown in figs. 4b and 6b. Most of them are continental deposits of aeolian sands, alluvium, gravels, conglomerates and crusts, and are given the general name of Gefarico by Lipparini. Lying beneath the marine deposits of Miocene age are further continental deposits which are also referred to as Gefarico by Lipparini.

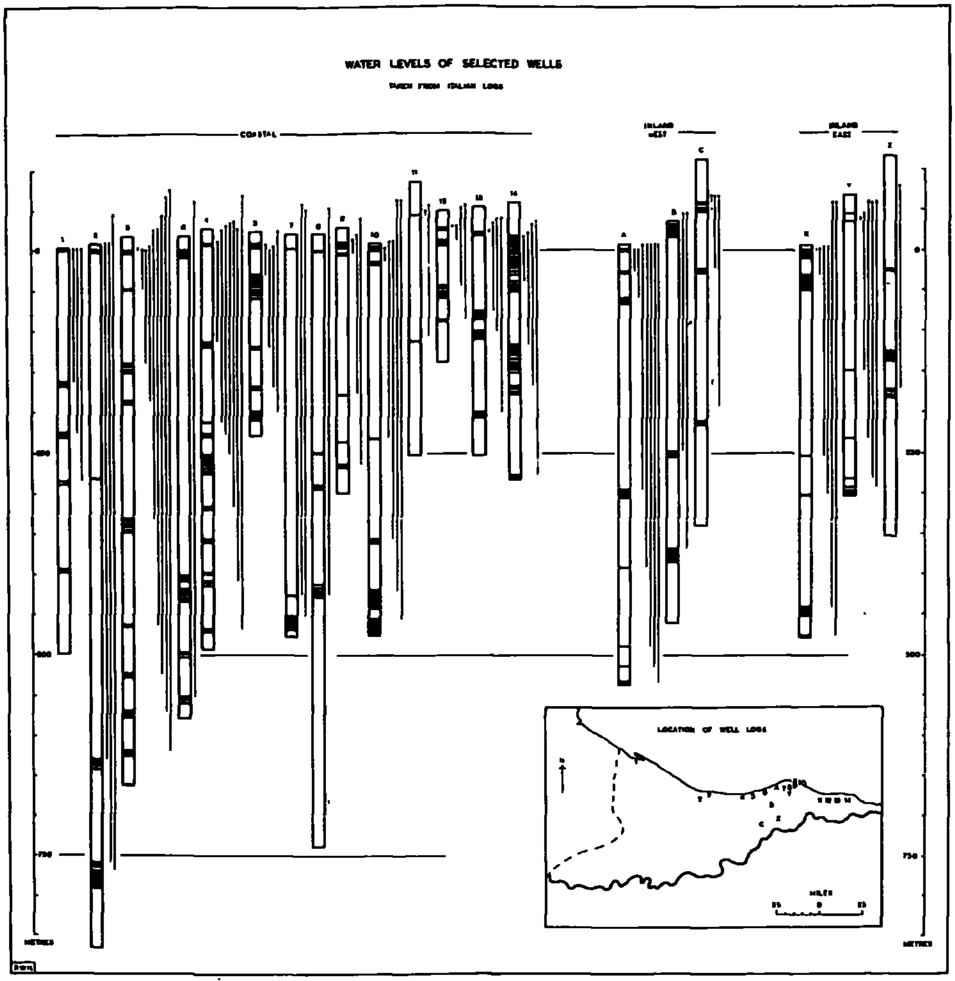
The geological section across the Jefara (fig. 4b) clearly shows the general structure; the sandy plain of the north made up of the Gefarico series and the Inner Jefara in the south, which is largely composed of Trias. The Inner Jefara is an interesting area largely because in many places it is disturbed by faulting.

Fig. 4b is a typical section where the Trias is upfaulted giving rise to low isolated hills which are surrounded by a mantle of superficial material; further to the west the Trias is covered in the southern part of the Inner Jefara by Jurassic and Lower Cretaceous rocks which give a line of small cuestas, but in the north it outcrops extensively; to the east around the Lejenin a part of the Triassic dome is downfaulted giving a basin-like structure which is filled with think beds of alluvium and gravel and is referred to as the Piedmont Plain (fig. 4a). The Inner Jefara is a very important area because wadi water collects in this zone after leaving the Jebel and much of it infiltrates underground to the Triassic substratum.

Fig. 6b is a diagrammatic section which is very simplified and not true to scale, but it adequately summarises the main aquifers beneath the Jefara. Within the Quaternary material are two main aquifers which are referred to as First or Phreatic and Second or deep Quaternary; being separated by a thin clay layer. In the Miocene strata there is a minor and a major aquifer; the first is in the Upper Tortonian Limestone and the second at the base of the Miocene in sands, gravels and sandstones of Langhian age.

Not every locality has this basic pattern of aquifers as the diagram of water-levels of selected wells indicates (fig. 14). The Italians drilled a number of wells before the last war primarily to investigate the possibilities of artesian water, and at the time of drilling, well logs were compiled giving the type of rock through which the bore was passing and the various water-

Figure 14.



see appendix Va

levels, with heads and capacities. The information recorded is summarised in Appendix **Vb** and fig. 14. It is obvious that recording was not standardised and that many static levels and yields are missing; furthermore no attempt was made to record fossils and date rocks. Despite these limitations the details are nevertheless valuable. Each well has numerous water-levels, many of which are under pressure to the extent of 50 metres; well no. 4 at Oliveti for instance, has nine aquifers with static levels varying from -18.55 to + 43 metres and capacities ranging from 1.86 m3/hr. to 138 m3/hr. The Quaternary material is very variable in composition with beds of sand or other water-bearing strata often being lenticular in shape; in one locality an aquifer may be thick and yield large amountsof water but elsewhere it may be thin and be of little value or even disappear altogether.

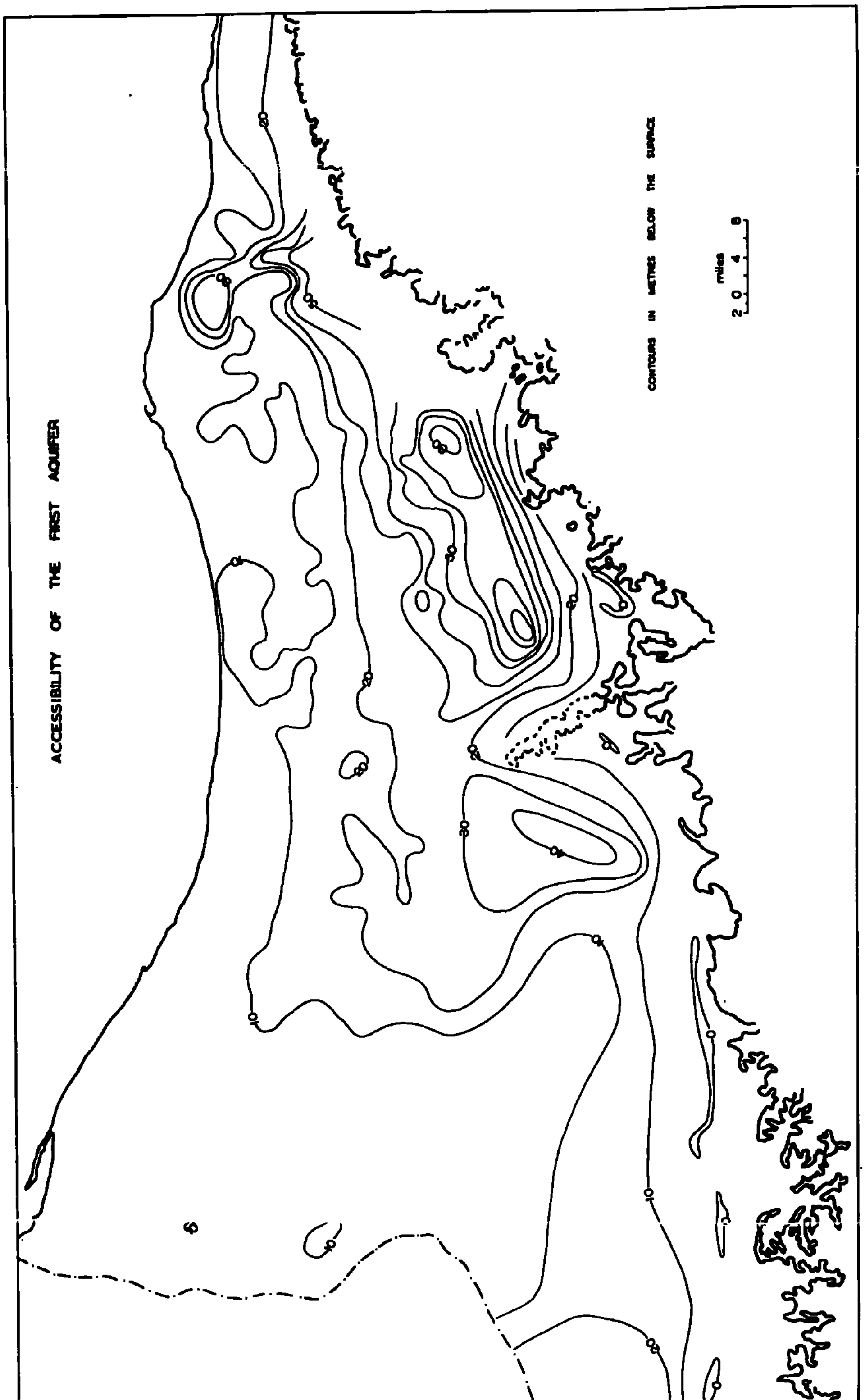
B.. Description and Location of Aquifers.

1. Quaternary Aquifers.

a) First or Phreatic water-table.

This is found throughout the Jefara Plain from the Tunisian border in the west to Ghanima in the east and it has been exploited for years by the sedentary Arab cultivator along the coast and the pastoral Arab in the interior. The fact that this was the only water-table used prior to the arrival of the Italians is a reflection of its accessibility. The average slope of the ground from the coast inland to the Jebel is about 0.3% as already stated, whereas the average slope of the first water-table is 0.2%. Therefore, the first aquifer will lie deeper in the Inner

Figure 13.


ACCESSIBILITY OF THE FIRST AQUIFER
CONTOURS IN METRES BELOW THE SURFACE
miles
2 0 4 8
N
20
30
10

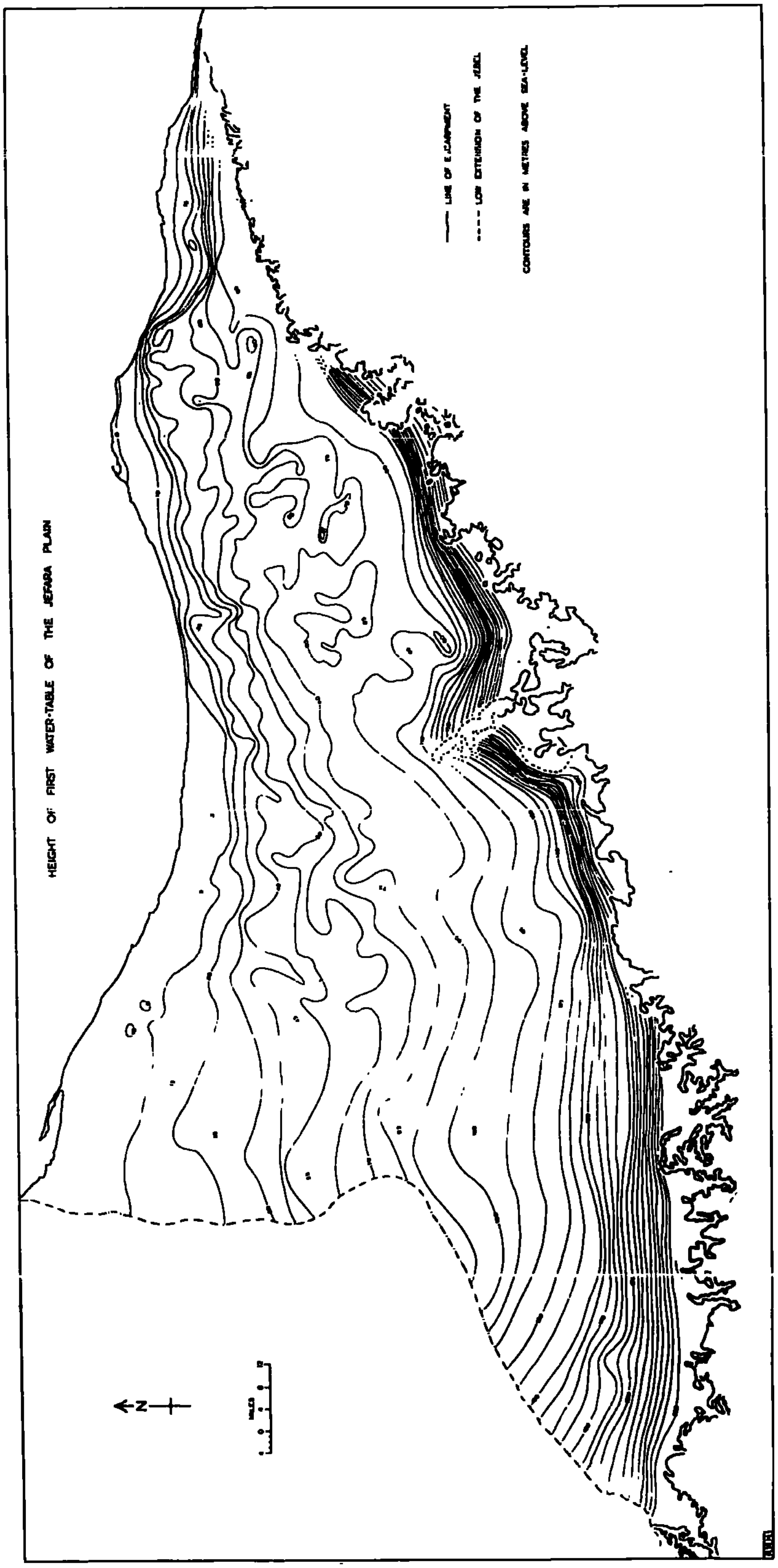
Jefara than along the coast. However, accessibility varies with the configuration of the land as well as distance from the sea. In order to illustrate this, a map of the accessibility of the first aquifer was drawn (fig. 15). This shows that along the coast, and in much of the Western Jefara, the first underground water is usually met less than 10 metres below the surface, examples being Bir Zigzau 2-3 metres, Pisida 0.8 metres, Mellaha and Tajiura 3-5 metres, Gargaresh 8.8 metres. In the west the water-table approaches and even appears at the surface in many places; the line of 'sebkh' parallel to the coast and those stretching inland are evidence of this, as is the spring line at the foot of the small cuestas. The Tripoli area is fortunate in having the first water-level readily accessible at 5-15 metres, but moving eastwards conditions change and the 20 metre iso-line is much nearer the coast; this deepening of the first water-table to the east is also brought out by well-logs 11, 12, 13 and 14. Moving south from Tripoli the same pattern is observed. Just south-east of the town for example there are high sand dunes which result in the water-table being 30 metres down; sections A,B,C, and X,Y,Z (Fig. 14) also indicate a deepening water-table to the south despite the fact that it is surprisingly shallow at Suani Ben Adem; at Azizia one has to go down 40 metres to find water. West of the El Menshar Hills the first aquifer is rarely more than 40 metres below the surface but in the Inner Jefara zone to the east it is always more than 50 metres deep and in places even 100 metres, particularly in the Piedmont Plain; even at Bir el

Ghnem almost on the eastern flanks of the El Menshar hills it is 92 metres. There is no water-table in the Inner Jefara which is related to the wadis because their flow is so small and irregular.

To summarise, the first water-table is near the surface along the coast from Tripoli westwards and also in much of the western Jefara, but elsewhere it is less accessible and is particularly deep in the Eastern Jefara towards the Jebel, where the local Arab is unable to reach it and instead has to build cisterns to collect run-off water (see fig. 7).

In order to understand the movement of water in this first water-table a map was drawn showing its height above sea-level (fig. 16). The information for this map was derived from numerous sources: the 1:100,000 War Office maps of the area, Italian well-logs, well-logs compiled by the Natural Resources Division of the Libyan American Joint Services, wells listed in the F.A.O. 1952 Report on Agriculture, questionnaires and personal observations; in most cases the altitude of the well and the depth of the water-table were known, so it was quite simple to work out the height of the water-table in relation to sea-level. In general the contour lines show a seaward gradient which is steep in the east and near the Jebel, but gentle in the west. Underground water flows at right-angles to the contours and down the gradient, so in the eastern Jefara it moves quickly to the sea but in the western Jefara, where the water-table is near the surface, the flow is very slow and it is not surprising that saline conditions soon develop. In the central part of the plain, however,

Figure 16.


HEIGHT OF FIRST WATER-TABLE OF THE JEFARA PLAIN
LINE OF ESCARPMENT
LOW EXTENSION OF THE JEBEL
CONTOURS ARE IN METRES ABOVE SEA-LEVEL
N
MILES

particularly between the Zawia-Bir el Ghnem road and the Wadi Megenin, certain irregularities appear in the contours: these are well marked and very significant. To the north-east of Azizia the water-table rises to 85 metres above sea-level and then descends in the south-east to 65 metres; to the west of Azizia it falls from 95 metres to 80 metres in the south; further to the east there is another depression in the contours south of Sidi Ben Naama and not far from the Jebel. The normal seaward gradient is interrupted and water moves southwards instead of northwards. It may be that there is some relationship between these anomalies and the Trias, high water-table altitudes occurring where there are Triassic outcrops and low ones where the Trias is fissured or faulted. The main depression of the contours to the south-east of Azizia is in the downfaulted Piedmont Plain. Water which flows seawards eventually springs out on the shoreline or under the sea, if under sufficient pressure; but what happens to the groundwater which flows to the inland 'basins'? It must disappear more deeply underground by additional percolation and certain parts of the Inner Jefara south of Tripoli can be considered definite zones of infiltration. This is one of the main facts bornein mind when a hypothesis for aquifer recharge is presented later in this chapter.

Impermeable Layer.

The phreatic water-table just considered, which is either one solid mass of water-bearing strata or several thinner water layers, depending on the nature of the deposits, occurs within the Quaternary Gefarico Series. However, in the Tripoli area the Gefarico is interrupted by a thin clay band which was deposited by a minor marine transgression in Tyrrhenian times (see chapter 1). The boundary of this impermeable layer starts in the west between Sabrata and Sorman, swings south of Azizia, then northwards just east of Ben Gashir, and finally eastwards to Gasr Garabulli and Gasr Khiar (see fig. 7). The first aquifer proceeds above the impermeable clays from Azizia and Suk Es Sebt and supplies the shallow wells in the Tripoli area.

b. Second or Deep Quaternary Aquifers.

This is found 20-25 metres below the first water-table, as indicated by well-log 11 at Tajiura for instance (fig. 14), and is in old Quaternary and even Pliocene deposits, the main aquifer being a 15-40 metre bed of sandy gravel. Sometimes the Upper Miocene rocks of Tortonian age are composed of limestones and sands and it is often difficult to distinguish between the deep Quaternary and the minor Miocene water-levels. Naturally the second water-table is less accessible than the first and is found 66 metres deep at Sabrata, 53 metres at Concessione Ingegnoli, 36 metres at Hashian, 36 metres at Gargaresh, 32 metres at Sidi Mesri, 32 metres at Ain Zara, 22 metres at Tajiura and 35 metres at Garabulli. Information given by numerous reports is often conflicting and not based on original work, and further research is needed before the exact relatiomship between the first and second water-levels can be thoroughly understood. The F.A.O. 1952 Report on Agriculture maintains that they are not independent and that pumping of one lowers the level of the other; 'Hydrologically speaking they constitute almost a single water-table flowing in a strata of varying permeability with a non-continuous strata between them' (F.A.C. 1952 p.167)*. There seems to be some truth in this generalisation for when the second aquifer is tapped in some places, its water is under pressure and rises to the static level of the water of the first water-table or perhaps a few centimetres above it, this is the case in well-logs 3, 5, 9, 10, X,Y,A.(fig. 14 and Appendix Vb). Northwards from Azizia and Suk Es-Sebt the second aquifer passes beneath the Tyrrhenian clay and gives Tripoli two freshwater layers, but in some areas the clay is extremely thin or absent so that the deeper aquifer cannot be differentiated and seems to be absent in well-logs 4, 6 and 8, Oliveti, Zanzur and Suani Ben Adem. Cederstrom (11) has carried out pumping work on the Mitchell Cotts farm at km. 24 on the Tripoli-Zawia road and is convinced that there is no connection between the first and second aquifers in this locality.

To summarise, in much of the area covered by the Tyrrhenian sea there is a second Quaternary water-level which was not exploited by the Arabs because of its greater depth. However, once this has been tapped the water rises to a static level much the same as that of the first water-table, therefore costs of raising the water are not unduly high.

2. <u>Artesian Aquifers</u>.

The Miocene deposits were laid down by a transgressive sea which invaded the Jefara almost as far south as Azizia - see

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* B/90.

fig. 2. As fig. 6a shows they dip to the north-west with their upper surface about 500 metres below sea-level near Tripoli, and at the same time they also thicken and widen westwards. It was stated earlier that there are two aquifers in the Miocene, one at the top and one at the bottom; in the western Jefara this is generally true but not in the east. Laurenti (24), Desio (18) and Archambault (5) divide the artesian water resources of the Jefara into two regions; and the information given in the summary table of artesian wells (Appendix Vc) and in the notes on the Italian well-logs (Appendix Vb) fits this division reasonably well:-

a) To the west of Tripoli and in particular between Sorman and Zanzur there appear to be two artesian levels. The first is usually found in arenaceous limestone up to 250 metres below sea-level and has a static level approximately +23 metres; examples are Pisida 228 metres below sea-level, Zuara 239, Oliveti 225 and Zanzur 234. The second level is usually more than 600 metres below sea-level, is found in the lower Miocene and has a static level of around +65 metres; it is deeper in the west as proved by the following examples: Ajelat 765 metres below sea-level, Sabrata 572, Zawia 532.

b) From Zanzur eastwards to Ghanima the Miocene deposits decrease in thickness and the two artesian aquifers of the west seem to merge into one, which is found at depths varying from 250-450 metres below sea-level. Water is found in a 50 metre thick complex of sand and limestone which is reported to the Lower Miocene, so that in the eastern area it is probably more correct to say that the upper artesian aquifer of the west disappears and the lower and more important aquifer persists. Heads of water average 63 metres above sea-level and the aquifer rises to the east as evidenced by the following depths below sea-level; Sidi Mesri 426, Tajiura 420, Es-Sbabil 210, El Guea 180 and Garabulli (Variani) 135 metres; it also rises to the south and at Suk es-Sebt is only 208 metres below sea-level.

Thus, there seems to be a general pattern of thick Miocene deposits along the west coast which have a major aquifer at considerable depth and another less important one nearer the surface, and thinner deposits in the east holding only one aquifer, which gradually rises in relation to sea-level. There are, however, variations which will not fit into this pattern particularly in the west where there are several small aquifers which have water under sufficient pressure to give a small flow at the surface, and also in more central areas where there seems to be more evidence of faulting in the Miocene (see fig. 6(a)).

C. <u>The potentialities of the various aquifers - yield and quality of water</u>.

1. <u>Yields</u>.

a) <u>Yields of First or Phreatic water-table</u>. The indigenous farmer makes good use of this shallow water layer and exploits it by dalu, wind pump and more recently small electric pump; Laurenti estimates the number of wells at 8,500 (25). The map of exploited water resources (figs. 17 and 18) shows the distribution of wells over the Jefara Plain and reveals an amazing concentration in the Tripoli-Tagiura oasis and in the oases farther west. In these areas the aquifer is particularly good and according to Shotton (37) will give yields ranging from 4.5 - 13.5 m3/hr., although the local farmer is content to draw 3-8 m3/hr., with his dalu and only irrigate a small area of $\frac{3}{4}$-1 ha. In relation to large scale irrigation, however, a yield of 13 m3/hr. is totally inadequate but higher yields could only be extracted from the first water-table by drastically reducing the density of wells in the areas of Arab garden cultivation; if electric pumps are installed in any quantity and an effort made to step up the capacity of the wells, water reserves will soon be exhausted. In certain parts of the Jefara the first water-table is almost as rich as the second and large-scale irrigation has been introduced by Italian and a few Arab farmers. In the El Maia region the water is only 2-6 metres below the surface and yields up to 20 m3/hr. are possible. In the Ben Gashir-Bir Longar area water is found at 19-25 metres and as the following table shows, yields of 30 and even 40 m3/hr. allow the irrigation of citrus, peanuts, lucerne and potatoes.

Table 6.1

Sample wells in the first aquifer in the Ben Gashir region

L.A.T.S. Natural Resources Division

Location & owner	Crops	elevation	Depth of well	Type	Water level below surf.	Date	Yield m3/hr	ha. irr.	Est. ann. discharge.
1.4kms.S.E. of Ben Gashir Aiad Lafi	Lucerne Peanuts Potatoes	-	36m.	Drilled	21m.	Nov. 1956	30	5½	145,800
1.3kms. S. of Ben Gashir Aiad Lafi	"	-	46m.	"	26.2m.	"	11	1	-
1.7kms.E.S.E. of Ben Gashir Petrillo Micheli	Oranges Peanuts Potatoes	77	47	"	18.4m.	"	40	6	15,200
1km. S. of Ben Gashir Petrillo Micheli	"	78	54	"	30.4m.	"	42	9	181,000
1.9kms. S. of Ben Gashir Auguliaro Dimaro	Lucerne Peanuts Potatoes	-	56	"	27.5	"	30	4	97,200
3.6kms. E. of Ben Gashir Haj Mohamed Addala	"	-	27	"	19.85	Jan. 1957	15	4	35,350
2.9kms. E. of Ben Gashir Hamed Addala	"	-	47	"	21.12	Feb. 1957	40	8	144,000

In the extreme east of the Jefara the first water-table is used occasionally by the Libyans at Garabulli and Gasr Khiar but rarely for irrigation. At Ghanima the water-table is deep and yields from the windpumps are low, 2-4 m3/hr. The low capacities of the wells in the eastern Jafara are more a result of the inaccessibility of the aquifer rather than the paucity of water stored in it.

In western coastal and central areas the amount of good quality water available is limited. Survey work carried out by the firm of Robert H. Ray in the Pisida area (37) shows that the groundwater is at 1-6 metres below the surface and lies at approximately sea-level; shotholes south of Sidi Ben Nur, Pisida and Zelten yielded freshwater but elsewhere the water was saline. The areas of freshwater are very limited and are usually found at slightly higher altitudes within sand dunes; only a few cubic metres an hour can be extracted because of the danger of salt water intrusion and water supplies are barely adequate for domestic requirements, without even considering irrigation.

In the west, at the foot of the Jebel, the water-table comes to the surface as a line of springs; this is the land of the semi-nomadic tribe known as the Siaan. This area was visited in June 1957 in connection with locust control and then in September 1957 with Dr. J.I. Clarke who was making a study of the Siaan people. Fig. 7 reveals small clusters of springs, a few kilometres north of the escarpment, which are found in the settlements of Tiji and Jaush. At Jaush Kebir there is a total of 18 springs of which only 7-8 are fully utilised; at Jaush Seghir only one spring out of 25 is clean and fully utilised. At Tiji the springs are better and 9-10 are used, one of which has been opened up by the government and provides the domestic water supply; one farmer is even copying the government scheme and has himself a small storage tank to conserve the meagre flow of water and thus grow a few irrigated crops. Between Tiji and Jaush there are a few more springs found along a small break of slope of about 10 metres. At Ain Battar there is a fair flow from springs, particularly a new one recently built by the Nazarat of Agriculture and water is lying in pools and running to waste. At wadi Lummazir about 9 springs are to be seen, although only one was in use in September 1957 since the rest had dried up.

In all these small settlements a little irrigation is practised but the only crops grown are sorghum (gseb in Arabic), pepper, melons and the date-Palm. Each spring is only sufficient to irrigate a few jedula, and those at Tiji do not flow at the rate of more than 7 cubic metres an hour. It would be possible to increase the flow of water by driving tunnels or trenches further into the break of slope which is the spring-line, thereby making sure of tapping the water-table, even when it is at its lowest at the end of the summer. Many of the present springs are choked with fallen earth and are useless and there seems to be little chance of development in this area because the water yields are so poor and the areas of good soil so few.

The springs farther east at Shakshiuk, Gasr El Haj, and Rabta have higher discharges, allowing more irrigation; palm trees are more numerous and at the last mentioned oasis there is enough water available for the State Tobacco Monopoly to authorise the planting of 5 hectares of tobacco in 1958 (not planted, however, because of the availability of the water but as a means of subsidising the local population). At the foot of the eastern Jebel beyond Bu Gheilan, springs are noticably absent although some may be found further south, such as that 4 kilometres north of Tarhuna which has a flow of about 152 m3/hr., but unfortunately disappears before reaching the plain.

The map of spring distribution shows that there are only two other areas of springs that have not been considered. In the extreme west there is a series of springs found in the escarpment at the foot of the Nalut limestone; these are small and only provide enough water for domestic requirements and the few tree crops amid the terraces on the lower slopes of the escarpment. Finally in the eastern coastal region several of the through flowing wadis have incised channels in the dune Jefara and near the coast they cut the first water-table giving a perennial flow of water to the sea. This wastage of water has not been measured and little if any is used for irrigation by the Libyan. There is perhaps scope for development here but the main difficulty is the fact that the water lies at the bottom of the wadi channel and needs lifting on to suitable agricultural land.

Our brief analysis of the capacity of the first water-table clearly indicates that only in the coastal oases and the Suani Ben Adem - Ben Gashir region is it sufficient to allow worthwhile irrigation. Elsewhere it barely meets domestic and stock requirements.

b) Yields from Second or Deep Quaternary Water-table

As we have seen this water-table is confined to an area within a 20-30 kilometres radius of Tripoli but because of its high yields it is of tremendous importance. The amount of water which can be extracted is generally 100-150 m3/hr., (well-log 10 at Tajiura gives 150 m3/hr. for example), although figures of 300 m3/hr. are not unknown. As the water is so abundant and of excellent quality both for agricultural and domestic uses it has formed the basis of much Italian agricultural development. Along the coast most of the farmers with large holdings favour the use of this deeper aquifer and many of the demographic farms such as those at Azzahra (Bianchi) each have up to 4 hectares of irrigated land and a well supplying 25 m3/hr., all dependent on the second aquifer. Theodorou[x] gives a table on page 52 of his report which clearly establishes the proportion of wells in the various aquifers on 70 Libyan and 70 Italian farms in the Zawia area:-

Wells	Libyan	Italian
First aquifer	174	26
Second aquifer	0	129
Artesian	0	2

The Libyan is content to tap the first and most accessible

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[x] B/96.

water-table, whereas the Italian takes most of his water from the second water-table except along the coast. Artesian wells are of little importance.

The wells which exploit the lower water-level are usually built in two stages; first there is an open well about a metre in diameter and about 15 metres deep, when there is a narrow tube-like hole, these are respectively called avampozzo and trivellazione by the Italians. At the base of the avampozzo 4-25 h.p. pumps are usually installed, and 5-10 hectares may be irrigated from one well. (For further details see chapter 8.)

The second water-table is the most important one on the Jefara. It is used extensively by large-scale commercial farming enterprises, by the Italian demographic farms, by the town of Tripoli for its domestic water-supply, by the Royal Air Force at Idris and also at the American air base, Wheelus Field. Laurenti (25) estimates there are 1,500 wells drawing on this reservoir of water: this is a pre-war figure and today there are probably almost 2,000 wells.

c) Yields from artesian aquifers.

Most of these aquifers have good yields and it is the quality of their water which has so far hindered their full exploitation. In the west the upper or minor aquifer gives moderate yields of 20-50 m3/hr., Pisida for example 30 m3/hr., and these can be raised to 100, 200 and even 300 m3/hr. by pumping, although the piezometric head may drop 8-10 metres.

The lower aquifer has slightly higher yields, averaging 60-250 m3/hr., Ajelat 120 m3/hr., Sabrata 100 m3/hr. and Olivetti (E.F.S) 270 m3/hr. (See Appendix VI)

The eastern artesian aquifers are far richer in water and the capacity of wells in this area is in the order of 300-350 m3/hr., both those at El Guea and Concessione Variani yield 300 m3/hr. Sub-artesian wells are found where the land is higher to the south and east of Tripoli; with pumping some of them will yield large quantities of water, as for example the well on the Micheli Concession at Azizia which has a pumped flow of 300 m3/hr.

2. Quality of underground water.

Underground water accumulates over a long period of time and it is not surprising that it often contains many salts and is of poor quality. The most harmful mineral substances which are found dissolved in the water are, in order of decreasing toxity: magnesium sulphate, magnesium chloride, sodium carbonate, sodium chloride and sodium sulphate; in order to ascertain the quality of the water it is necessary to know the total amount of dissolved solids present, particularly sodium chloride which is the most common of the salts. Using these as criteria plus the water's specific electrical conductance, which Thorne and Peterson* maintain is the best measure of the toxity of the salts present, the underground water of the Jefara Plain can be

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* Irrigated Soils, Philadelphia, 1949.

classified. This classification is derived partly from that quoted by I.E. Houk in his article 'Standards of Irrigation Water' in Irrigation Engineering, Denver, 1951, and partly from Marroni's pamphlet on the utilisation of saline water (28).

Table 6.2 Quality Classification of Underground Water

Class of water	Specific Conductance in micromhos at 25 C.	Dissolved solids p.p.m.	NaCl. p.p.m.
1. Good	Below 2,000	Below 1,400	Below 1,000
2. Fair	2 - 3,000	1,400 - 2,100	1 - 2,000
3. Poor to useless	Above 3,000	Above 2,100	Above 2,000

Class 1 water can be considered suitable for all crops, class 2 dangerous if used on certain sensitive crops such as citrus and tobacco, and class 3 can only be used for the irrigation of salt tolerant crops although some of the water may be too saline even for this. In evaluating the effect of a water on crops in a certain area, consideration should be given to the type of soil solution in that area; in chapter 3 it has been pointed out that a large number of the Jefaran soils are sandy, permeable and well drained, devoid of chloride and rich in calcium carbonate, thereby allowing the use of some poor quality water for successful irrigation.

a) Quality of water in the Quaternary deposits. All the water from the first and second aquifers in the area bounded by the Tyrrhenian deposits is of good quality, specific conductance is below 2,000 micromhos and total dissolved solids are usually less than 1,500 p.p.m. The quality of water in this area is not likely to deteriorate because the rainfall of the region is generally over 250 mms. and the groundwater is continually on the move especially at the present moment with the high rates of discharge for irrigation, however, overpumping along the coast may lead to the intrusion of sea-water. The second aquifer yields the best water on the whole Jefara and as already mentioned supplies the domestic piped water supply for Tripoli.

In other parts of the Jefara Plain the water in the first water-table is often of doubtful quality. In the western central areas water samples were taken by the Libyan American Joint Services in 1957 and analytical statements are available for El Wotia, Sidi Abdalla and El Hebilia:-

Table 6.3 Quality of water in wells at El Wotia, Sidi Abdalla and El Hebilia

Well	Specific Conductance micromhos at 25 C.	Total dissolved solids p.p.m.
El Wotia	5,900	6,078
Sidi Abdalla	5,000	5,610
El Hebilia	4,950	5,723

This water is obviously very saline, a poor class 3, and is unsuitable for irrigation, although it may be used for stock, particularly that at El Hebilia; it is typical of the water found in the western Jefara and most of the wells in this region are marked as saline on the 1:100,000 War Office maps.

Moving eastwards the situation does not change very much as the following figures for water at Bir el Ghnem illustrates:-

Table 6.4 Quality of water at Bir el Ghnem

Depth	Specific Conductance	Dissolved solids p.p.m.	NaCl. p.p.m.
71 metres	4,563	2,000	1,499
187 metres	6,435	7,123	4,500
187 metres (after pumping)	3,276	3,337	2,100

In this well, water of the first aquifer is found from 71-187 metres below the surface, its quality is poor both at 71 metres and at 187 metres but after pumping it improves and is only just in the class 3 category and therefore could be used for the irrigation of salt tolerant crops.

The quality of water in the Inner Jafara south of Tripoli shows a distinct improvement over that in the west, although even so a few wells contain water with a harmful amount of dissolved solids. In Annexe 1, p. 96 of the C.C.T.M.A. Report* the results of analyses made of water in the phreatic water-table are given:-

Table 6.5 Quality of water in the Inner Jefara (Piedmont Plain)

Well	Specific Conductance	Dissolved solids
Bir Freuan	3,515	2,527
Bir Baabsa	1,972	1,450
Bir Gurgi	2,465	1,610
Bir Jdid Dardur	1,633	1,070
Bir Es-Salalma	1,611	?
Bir Braga	2,935	?
Bir Ben Hammadi	3,675	?
Bir Soueme	674	?

* Sept. 1954 B/45.

Only two of the wells have class 3 water and even this is not terribly poor, the rest are divided up into four class 1 and two class 2 and all could be used for irrigation if sufficient quantity of water were available near the surface. This of course is not the case.

The quality of water in the extreme east of the Jefara is largely class 1 and 2 but, as we have seen already, is found too far below the surface to permit appreciable irrigation with the pumping equipment employed at present.

b) Quality of water in the Miocene deposits.

The summary table of artesian wells and the notes which accompany it, (Appendix Vd) can be used to determine the quality of the water in the Miocene strata. Most of the figures for temperature, specific conductance, and total dissolved solids are taken from American analyses 1953 (26), whereas those for sodium chloride are from Italian analyses (43); both sets of figures are sometimes suspect. It has already been noted that the artesian aquifers yield considerable quantities of water in some localities and it is depressing to find that this water is of such low quality that in many instances it has no agricultural value. Of the 44 wells listed, only fifteen are used (nos. 12,13,15,18,25,29,30,31,32,33,34,35,36, 37,38), and only a handful of these are fully exploited. The wells have been classified by the writer as follows:-

Table 6.6 Classification of artesian wells.

Class 1	No wells	
" 2	Three wells	Water suitable for the irrigation of all types of crops.
" 3 Good	Six wells	Generally water is suitable for the irrigation of all crops if drainage is good.
" 3 Moderate	Three wells	Water can be used to irrigate all but the most sensitive crops.
" 3 Fair	Thirteen wells	This water is suitable for irrigating salt tolerant crops or other crops, if it is first mixed with sweet water from a shallow aquifer.
" 3 Poor	Six wells	Water is of little use to agriculture and can only be used for irrigation of salt tolerant crops if mixed with sweet water and applied to a well drained soil.
" 3 Very poor	Four wells	Useless water, doubtful even for animals.

Unclassified wells - Nine.

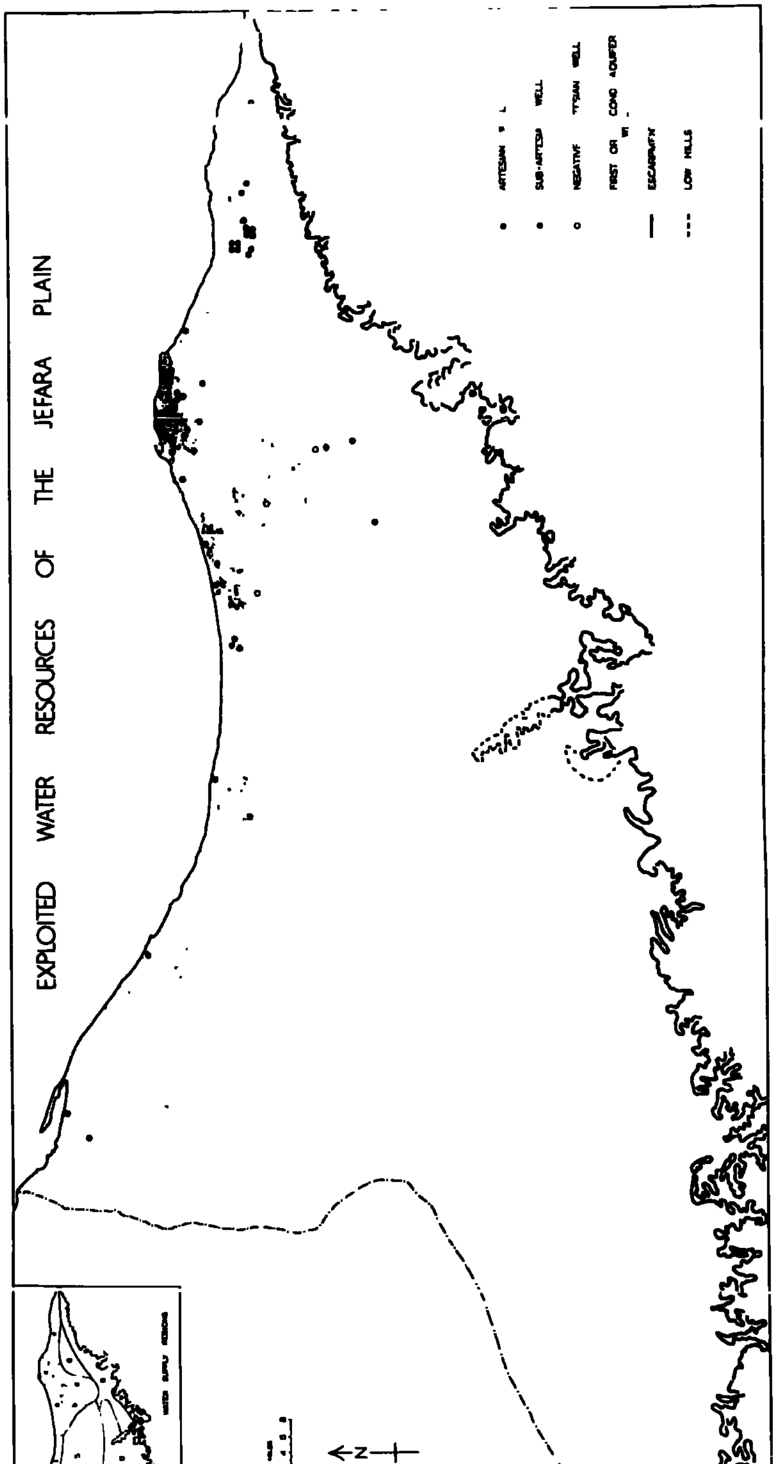
The quality of the artesian water is quite clearly superior in the eastern Jefara, particularly east of well no. 29 at Es-Sbabil. West of this well, the water in the upper and less important Miocene aquifer is better than that of the lower, but even so it is safer to mix it with sweet water before putting it on the land. On the southern and western fringes of the Tripoli oasis the quality of the water is above average for the western region, for instance at Gargaresh and Collina Verde, and further inland at Azizia.

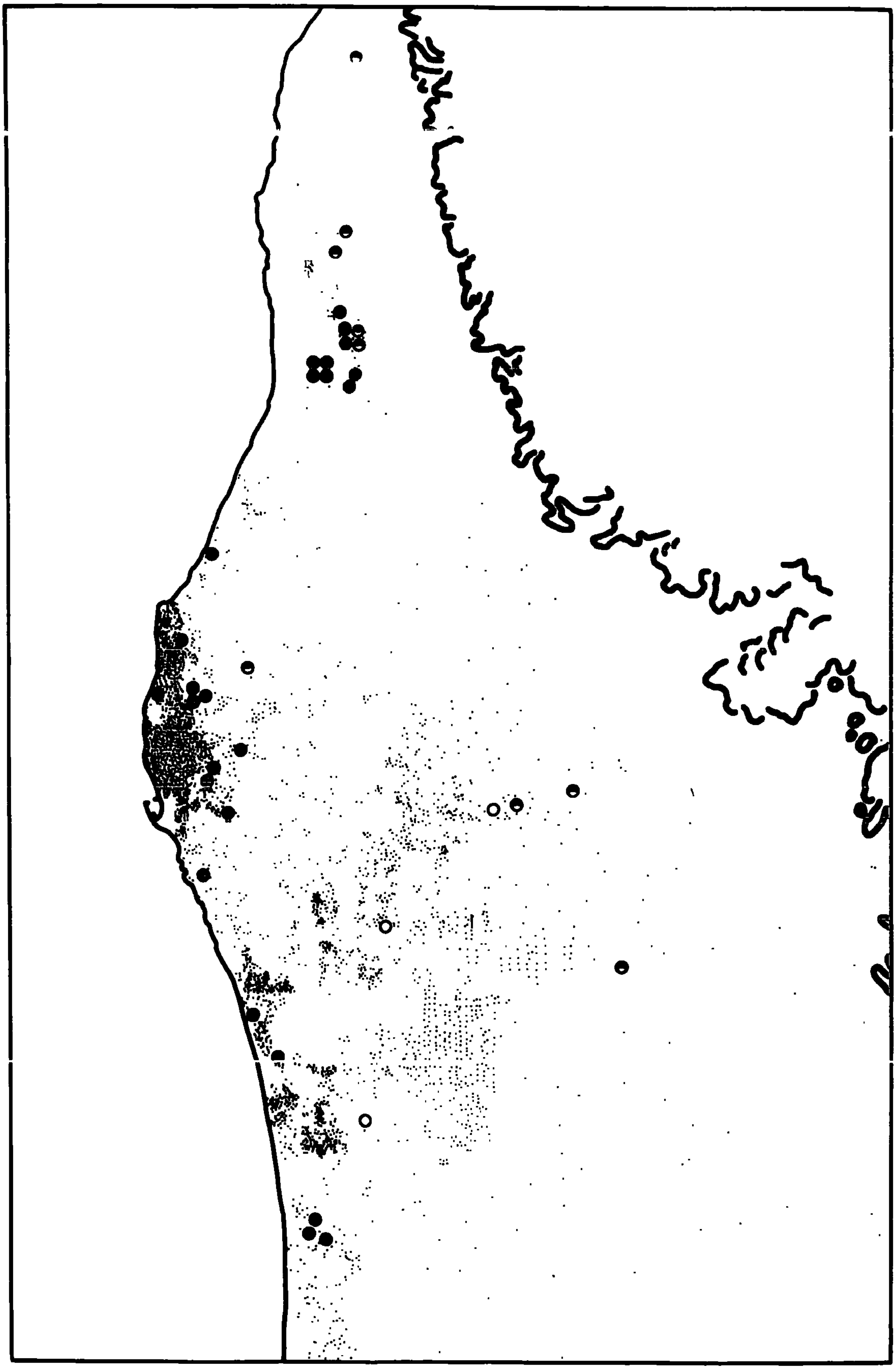
The temperature of the artesian water is always over 75F., but generally does not present any problem unless over 100F., as in wells nos. 6, 21 and 23, then the water must cool before being used. The existing low quality of the artesian water can be further aggravated by pumping, figures for conductance and dissolved solids often increase after a well has been used, as in the case of the first well drilled at the Government Sheep Ranch, Garabulli:-

	Conductance	Dissolved solids
Initially	2,358	1,993
After use	3,600	2,328

Generally speaking class 3 waters are unsuitable for irrigation in arid areas because of the danger of salt accumulation, but since it has already been pointed out that Jefaran soils are permeable and well-drained, and also rich in calcium, - particularly gypsum (calcium sulphate), the better quality class 3 waters may be used without detrimental effects. At El Guea and Garabulli Forage Farms class 3 Fair water is being used for irrigating lucerne with notable success; at the Variani farm (Garabulli) a class 3 Good water is being used for all purposes, even citrus, and the same applies at Es-Sbabil on the Ostuni farm and at Gargaresh, although at the latter the artesian water is mixed with water from a shallow aquifer.

Compared with the Quaternary aquifers, those in the Miocene yield poor quality water, but nevertheless this could be put to better use than it is at the moment, if the right methods are adopted, such as additional mixing of artesian water with sweet water and judicial choice of salt tolerant


EXPLOITED WATER RESOURCES OF THE JEFARA PLAIN
SUB-ARTESIAN WELL
LOW HILLS



crops. The example set by the five farms at Collina Verde, Es-Sbabil, Guea, Sheep Ranch and Variani, plus the results achieved with saline water in the Misurata area, which will be mentioned in a later section on the use of saline water, suggests that there is still scope for further exploitation of artesian resources.

D. Water Supply Regions of the Jefara Plain.

Having studied the various aquifers in turn, their locations, their yields and the quality of their water, it is now possible to put forward a tentative division of the Jefara Plain into water supply regions, but before doing so it is necessary to make a few observations on fig. 17. At the moment all water for irrigation comes from underground, and the water collected in cisterns is kept solely for domestic and stock requirements. Fig. 17 shows the distribution of first, second and artesian aquifer wells but unfortunately does not differentiate between the first two. The information used for compilation was taken largely from the War Office 1:100,000 maps, but when drawing the map it was realised that the density in the coastal oases was too low because these maps do not show every well. To get over this problem larger scale maps of 1:50,000 were employed but these do not cover all the western oases so that densities are too low from Zawia to Agelat.

In the Tripoli-Taijura region there is a remarkable concentration of wells with densities of 25, 30 and even 40 per square mile; these are mainly Arab wells in the first aquifer. The density of wells in the western coastal oases is slightly less and the area they cover slightly smaller; the large number of phreatic high yielding wells in the Ben Gashir-Suani Ben Adem-Fonduk Et-Togar area is evident, as is the concentration of second aquifer wells of the demographic farms in the Azzahra (Bianchi) district; in the eastern Jefara there are a few small groups of wells about 10 kilometres inland from the coast. Elsewhere the wells are very sparsely distributed except in the Dune Jefara south of the coast between Zawia and Zuara where they are about two miles apart.

Artesian wells are sprinkled along the coast, with just a few in the west a higher concentration round Tripoli and even more in the east round Garabulli where there are Government farms.

The following water supply regions (see fig. 17) are in a sense a summary of the information given so far in relation to water resources.

1. Western Coastal Region - phreatic water-table and the western artesian type with two aquifers:
   a) Pockets of freshwater in the dunes along the coast.
   b) Saline water at the surface (Sebkh).
   c) Western oases zone - freshwater is generally found in the areas of slightly higher land and overlies saline water; the water-table is always near the surface. More water is available here than in 1a, but is nevertheless still limited in amounts and discharges of more than a few cubic metres an hour are not possible without the intrusion of salt water.

2. Central part of the Western Jefara - although the water is never more than 10 metres below the surface the number of wells in this area is very small and most of them are saline and only used occasionally for stock.

3. Spring-line zone:-

   a) From Tiji eastwards to Gasr el Haj there are groups of springs with small flows of moderate quality water; these are found approximately along the base of the Jurassic rocks.

   b) East of the El Menshar Hills this spring-line is again evident from Rabta to Bu Gheilan, this time it is not so well marked because the springs have a very patchy distribution. Supplies of water are much the same as for 3a.

   c) This sub-region lies between 3a and the Jebel. In the north there are no wells worth mentioning and in the escarpment to the south there is a spring-line at the foot of the Nalut limestone.

4. Western Cistern Zone - this is an interesting area because although rainfall figures are low there is a large number of cisterns built to collect and store the surface water flow. Wadis do flow in this area because primitive diversion dams have been observed in Wadi Zigzau which is only a few kilometres to the east, but the amount of water involved must be small. However, wells and springs are absent so the local population undoubtedly has to conserve what little surface flow there is.

5. Western Dune Jefara - in the sandy lands to the south of the coast from Sorman to Zuara there is an even distribution of wells at approximately two mile intervals, water is of reasonable quality and generally less than 20 metres below the surface.
6. Inner Jefara around the El Mensher Hills - the water-table in this region is 30-40 metres down and wells are almost absent. The water is class 3 but may be available in reasonable quantities, for at Bir el Ghnem water is being brought to the surface from about 80 metres down to be used on the Government experimental farm.
7. Central and Eastern Jefara as delimited by the distribution of the Tyrrhenian deposits; found largely in the Dune Jefara and having two Quaternary water-tables in places:
   a) Gargaresh-Sabrata region. The first water-table is found everywhere and is exploited in the oases by the garden cultivator; in some localities it yields large amounts of water and the Italians have made use of it (Ricotti Citrus orchards for example Farm Study No. 2); occasionally the second water-table provides water for irrigation. At greater depth the Miocene strata still has two aquifers.
   b) The Azzahra (Bianchi) region and the area immediately to the west where the second water-table is extremely rich.
   c) Tripoli-Taijura region which has a high yielding second water-table and also a valuable first water-table; this region is also part of the eastern artesian type with only

one main aquifer.

d) Suani Ben Adem, Azizia and Ben Gashir region which has a rich first water-table, occasionally a second water-table and a few sub-artesian wells.

e) Eastern region - here the eastern artesian type with one aquifer provides more water for irrigation than the two quaternary water-tables. There is a limited number of wells exploiting the first aquifer which is at least 20 metres down in most areas and sometimes even more, the second aquifer has a very patchy distribution and is only tapped sporadically. In the east there are a few springs in the channels of deeper wadis, not far from the coast.

8. Eastern Duneland: This is a region very much like 5 with a uniform sprinkling of wells in sandy land, but which exploit the first water-table at a greater depth of 30-40 metres. There are no cisterns.

9. Zone of deep phreatic water, where wells are scarcely evident and surface water flow is collected in numerous cisterns.

E. Overpumping and the recharge of aquifers.

Underground water is a limited resource and great care should be exercised when exploiting it. In water supply region no. 7 irrigated farming has developed very rapidly since the last war and cash crops such as groundnuts, potatoes and citrus, all high water consumers, have grown in importance: the demands on the groundwater reserves have increased and consequently the water level in Quaternary wells has dropped seriously in the last 20 years.

The Natural Resources Division of the Libyan American Joint Services has made an extensive survey of the Quaternary wells in the Tripoli, Ben Gashir and Suani Ben Adem areas (12). Here there are some 750 wells which are discharging an average of 570,000 m3/day, enough water for a city of a million people according to Cederstrom, and each well has a pump with a diesel or electric motor of up to 20 h.p. It is estimated that the 570,000 m3/day represent about 80% of the discharge of the area. Concumption of water is probably considerably higher than this at the moment because Cederstrom mentions in his Terminal Report (12) of July 1957 that 125 new wells were planned in the Ben Gashir district alone.

1. Evidence of Overpumping. Wherever useful quantities of good quality Quaternary water exist, irrigation is increasing, and it is quite clear that in certain areas water levels are dropping alarmingly. Cederstrom quotes a drop of 15 metres at Ben Gashir and 5 metres at Ain Zara, Mazzochi* remarks that in the intensely irrigated coastal zone the water-table has dropped 6-8 metres since 1936 and Lewis in his End of Tour Report[e] gives evidence from his groundwater investigation programme of overpumping along the coast associated with a falling water-table and salt water intrusion. There are two main areas where the fall in the Quaternary water-tables is

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* F.A.O. Horticulturalist.

e B/91

dangerous: the Ben Gashir-Suani Ben Adem area and the Azzahra area.

Broc in his book 'Orcharding in Tripolitania'* states that in the Suani Ben Adem area the first water-table was at the surface 20 years ago and that duck could be hunted there; a few years later it was found 3.5 metres down and it is now 6 metres below the surface. On the De Marchi Concession which is about 1 km. west of the 16 kms. stone on the Tripoli-Suani Ben Adem road, the initial static level of the first water-table stood at 3 metres below the ground surface but by October 1951 it had fallen to 10 metres below the surface. However, the fall in the first water-table is most marked in the Ben Gashir region and even now equilibrium has not been achieved. Between 1940 and 1951 the water levels in wells west of kilometres 25-27 on the Tripoli-Tarhuna road dropped 4 metres, an average of 0.35 metres annually, and this has occurred in most wells within a 15 kilimetres radius. (34 p.169)

In the Azzahra (Bianchi) region there are about 500 wells on the demographic farms each extracting 100-200 m3. a day from the second Quaternary aquifer, plus about 20 other wells mainly being used by the Libyans. Irrigation increases and the water-table declines 0.2 - 0.4 metres a year; the F.A.O. Report (34) gives figures for the period 1938-1951 which show this decline, and answers to questionnaires put out to farmers in this same area all indicate the same trend in more recent years. (Farm Studies 27-31).

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* B/94

Table 6.7 Declining Water-table at Azzahra

Depth of water below ground-level in metres (34)

	1939	1947	1950	1951
Bianchi, farm 150	11.1	13.2	13.9	14.5
	1939	1948	1950	
Bianchi, farm 55	14.5	17.5	17.9	

2. The significance of declining water-levels in wells. What does the decline of water levels in wells really mean ? Two possible interpretations are given by Cederstrom (12) and Solignac (40).

Cederstrom is very pessimestic about the water supply situation of the Jefara Plain, he thinks that rates of discharge are dangerously high and probably exceed the amount of local and surrounding area recharge; the cones of depletion around exploited wells expand in order to establish an equilibrium between inflow and outflow and they do this at the expense of neighbouring undeveloped areas where the water-table in turn is subsequently lowered. He thinks the problem is one of a general lowering of the water-table, which is going to become more disastrous because 'the Italian water law has been disregarded and desert Arabs are beginning to install heavy pumps as fast as the more cosmopolitan Arab and the European'.

Solignac is more optimistic about the present exploitation of the water resources of the Jefara Plain, and although he only paid a short visit of a few weeks to Libya in order to investigate the need for an emergency water law, he makes one or two useful theoretical observations. At the outset he is convinced that groundwater reserves are not being impoverished and discharge does not exceed recharge over a wide area, neither is he worried about the 3-4 metres drawdown in the Bianchi, Giordani and Micca area or the 6 metre drawdown in the Ben Gashir area. His optimism is based on the following reasoning:-

The number of wells in the area studied in detail by Cederstrom is not excessive - there are reputed to be something like 750 in a quadrangle 30 x 30 kms., that is 90,000 ha. Even allowing for the fact that only about 32,000 ha. are actually cultivated and only 22,320 are irrigated, the number is still not high. Experiments carried out by Viali show that the radius of the influence of a well on the water-table is only 200-250 metres, an area of 13 ha.; if this is the case then the 22,320 ha. of irrigated land should be able to support more than 1,700 wells instead of 700. Viali's experiments were carried out at Micca where the first water-table was found 10 metres below the surface; after pumping for some time the static level settled down at -18 metres and when another well was sunk 250 metres away the water-table was still found at its original level of -10 metres; at 250 metres distance the main body of the water-table was not affected.

There are thus two conflicting views on the state of the underground reserves; Cederstrom thinks the water-table is falling over wide areas and Solignac maintains that falling water levels in wells are merely cones of depletion which are having no real effect on the general level of the water-table. Solignac's argument does not take into account the very slow rates of percolation of the underground water in much of the Jefara region and it is quite possible that cones of depletion may affect the water levels in unexploited areas over a long period of time. Lewis (26), however, propounds a similar argument that declining water-levels only represent local overpumping with associated cones of depletion, because during his stay in Tripolitania he could detect no perceptible decline of the upper surface of the first water-table down the hydraulic gradient from an intensely irrigated area.

There seems to be some grounds for arguing that the groundwater reserves, although probably over-exploited in certain areas, are not as near exhaustion as Cederstrom would have us believe. The real crux of the problem is the rate of natural recharge of the underground aquifers.

3. <u>Origins of the underground water beneath the Jefara Plain</u>.

Some writers and research workers regard the underground water resources of this area as fossilized remnants of a former more pluvial period, probably Pleistocene, while others think that ~~it was~~ they were trapped 'in situ' when the deposits in which they are found were laid down; neither of these hypotheses seems convincing however.

<u>The first and second water layers</u> - It is sometimes argued

that very little of the rain which falls on the plain manages to percolate far enough underground to feed the Quaternary aquifers; this can soon be disproved, because without pumping the static water level in a well will fluctuate from season to season and year to year; the connection between rainfall amounts and the height of the water-table cannot be denied. Two wells have been observed by the Natural Resources Division of the Libyan American Joint Services, one at Ben Gashir and one further south in the Wadi Mejenin zone. In the latter the higher maximum is in March, then there is a drawdown until the end of April, and then a rise to a lower maximum (0.4 - 0.45 metres lower) sometime in May, followed by another fall. At Ben Gashir the higher maximum occurs likewise in March, but the lower is in December. Both wells have their highest static levels after the winter rains, but the next highest follows the spring rains in the Mejenin well and the autumn rains in the Ben Gashir well, obviously related to the rainfall distribution pattern, for in the north of the Jefara there is more rain in Autumn than Spring and in the south it is the other way round. There is always a time lag between the time of maximum rainfall and highest water level because the rate of movement of underground water is determined by the permeability of the strata; percolation rates are often slow in the Quaternary sediments and sometimes the water has to travel some distance, for instance, the wells at Giordani are fed by water which flows from the high first water-table region to the south around

El Maamoura and Ras el Ambat.

Most reports written since the last war agree that the Quaternary aquifers are being recharged continually by rain fall, either directly or indirectly; in the Dune Jefara and the coastal areas the rainfall soon infiltrates through the loose sandy soil; in the Inner Jefara water from the mountain wadis spreads out and percolates underground subsequently to move northwards. In the greater Tripoli area Cederstrom (12) estimates that 15-20 millimetres of rainfall per annum penetrates to the first water-table. Archambault (5) points out that infiltration of wadi water in the Inner Jefara at the foot of the Jebel is encouraged by the very pervious nature of the coarse alluvial fans (cônes de déjection) which the wadis themselves have deposited there. He also notes that east of Bu Gheilan there is a noticeable absence of springs at the foot of the escarpment, and he attributes this to the eastward movement of the underground water in the Cretaceous sediments of the Jebel, which are themselves in fact dipping in the same direction; as these waters move eastwards there may be some leakage northwards into the Quaternary and Miocene sediments of the Jefara.

<u>The artesian aquifers</u>. These as yet have not been exploited sufficiently to give a decline in piezometric heads or yields, but it is worthwhile to make a cursory study of their recharge in order to establish their hydrological cycle. Professor Vinassa Regny (36) was one of the first to speculate as to

the origins of the artesian water. He suggested that it was plutonic and the result of volcanic action but although there is evidence of vulcanicity in the fractured central parts of the Triassic dome and in the Jebel, this suggestion seems highly improbable. Desio's theories appear much more convincing (16, 17 and 18) and are supported by the writer's own research. Basically the Italian considers that the artesian water derives from rainfall as in the case of the other two aquifers in the Quaternary material. The infiltration zones have already been located on the map of the upper surface of the first water-table (fig. 16), and water disappears here into the Miocene strata and then flows northwards within it to the coast; here it is under pressure which roughly corresponds to the height of the first water-table above sea-level in the infiltration zones. These are found along or a little to the south of the southern limits of the Miocene deposits where the latter are near the surface; some water must also enter the Miocene via the upfaulted areas of Triassic Muschelkalk limestone. Water takes a long time to move through the Tertiary rocks and the artesian water which flows today fell as rain many, many years ago.

It has now been established that the underground reserves of water are in all probability being continually replenished by annual precipitation; Ahmed is more dogmatic and maintains that 'rainfall is sufficient to maintain all water-tables' (3 p.27). He also argues that assuming an average rainfall for the Jefara Plain and Jebel of 200 mms. a year, a vast quantity of water seeps into the sub-soil even allowing for high rates of evaporation, though in fact to result in a continual wastage of water from littoral and sub-marine springs: the total amount of groundwater used for irrigation (80 million m3) is only a small part of that which is accumulating each year (3 p.40). It does appear from the evidence available that water levels in both the first and second aquifer wells are falling and that this may subsequently lead to a general lowering of the water-tables over a wide area. However, this process does not represent the exhaustion of an irreplacable reserve because, as we have seen, recharge continues every year from rainfall, and in chapter 4 it was noted that over a long period water-tables will remain static. There is no need for undue alarm in areas of falling water-tables because some reduction in consumption would soon give equilibrium between discharge and recharge; this could probably be best achieved by a reduced density of wells. In unexploited areas which have adequate supplies of good water there is no reason why irrigation should not be expanded.

4. Dangers of salt water intrusion.

In many respects a falling water-table is more dangerous with regard to the possibilities of salt water intrusion than as evidence of depleted water reserves. It has already been emphasised that in much of the Western Jefara the Quaternary water is already saline and all along the coast of the

Jefara much of the artesian water is poor. Every effort must be made to see that there is no deterioration of the quality of underground water.

The two main areas which are susceptible to salt water intrusion if there is overpumping, are water supply regions 1 a and c and the coastal zone of water supply regions 7 a and c. In regions 1 a and c there are only limited pockets of freshwater overlying brackish water; these will constantly yield a small amount of water if carefully exploited, but any well that is overpumped soon becomes unusable. However, it is in the coastal zones of water supply regions 7 a and c that the danger is really threatening because, unlike the western coastal zone, large farms with intensive irrigation are found very near to the sea; overpumping here means that the denser sea-water gradually moves inland.

Fortunately a detailed study has been made of one particular case of salt water intrusion (11). About 23 kilometres west of Tripoli along the Zawia road there is the Ricotti-Prina citrus orchard, where there are some 100 ha. of land devoted to oranges, lemons and tangerines; some parts of the farm have been under these tree crops for more than fifteen years and have been irrigated all this time from the first aquifer. The Ricotti orchard is situated between the coast road and the sea. A few years ago Concessione Ingegnoli, which lies immediately south of the coast road, was purchased by Società Agricoltura Libica (S.A.L. - a cover name for Mitchell Cotts), and the new owners quickly rehabilitated the old wells on the farm and built new ones so that the irrigation of extensive areas of peanuts, potatoes and early vegetables would be possible. Soon after the wells on the Concessione Ingegnoli began to operate Ricotti alleged that the water-level in his wells dropped and at the same time the quality of the water in them deteriorated. The question was asked whether the increased demands for water were interfering with the hydraulic gradient with the result that sea-water was moving inland. (For more details about each farm see farm studies 1 and 2).

Fig. 16 shows that there is a steady slope of the first water-table towards the coast; despite this, however, there is some intrusion of sea-water inland at depth due to its greater density. If a cone of depletion expands sufficiently to reach the freshwater-saltwater boundary the normal hydraulic gradient is reversed and salt-water flows into the depleted area. This has in fact happened at the Ricotti farm but since it takes years for salt-water to penetrate half a kilometre northwards it would appear that the recent pumping on the neighbouring farm has no real connection with the problem.

Cederstrom carried out pumping tests and analyses on the two farms in March, 1956. The wells at the Ricotti farm are in the first aquifer and water is about 17 metres below the surface and rarely more than 6 metres below sea-level; in contrast the wells on the other farm are in the second aquifer and the water is found 14-30 metres below sea-level. The quality of water in the Ricotti wells as represented by the sodium chloride content is 177, 145, 120, 100, 300, 200 and 385 parts per million, the last three figures coming from the wells nearest the sea. During pumping tests a combined discharge of up to 200 m3/hr. from certain of the Ingegnoli wells had no effect on the water-levels in the Ricotti wells, thereby proving that there is no hydraulic connection between the first and second aquifers. There has obviously been continuous overpumping on the Italian concession for many years and a cone of depletion has grown until it has reached the salt-water freshwater boundary a few kilometres to the north.

This intrusion of sea-water is likely to occur anywhere along the coast of the Jefara Plain where the Quaternary aquifers are heavily pumped, and the only way to overcome this problem is by the careful control of future exploitation and by a reduction of water consumption on farms of the Ricotti type.

E. Summary and conclusions.

The study of the groundwater resources has revealed that within the boundary of the Tyrrhenian deposits there is a surpricing amount of water present in the Quaternary material. This has been realised by the local agriculturalists and as a result there has been a tremendous increase in irrigation in post-war years and cash crops are now being produced even by former subsistence-type Arab farmers. Demands for water have naturally grown and the water-table is falling noticeably in some districts and here there is very little scope for the further development of irrigation on most of the farms. At the present moment the discharge from wells is exceeding inflow and there is no sign of an equilibrium being established, but the water reserves are not fossilized remnants of the Pleistocene pluvial period so there is no cause for immediate alarm. If after another ten years or so the water-table has dropped still further and yields from wells begin to decline with consequent higher cost for raising the water, then some action must be taken to curtail consumption so that the aquifers can replenish themselves. Within the confines of the Tyrrhenian deposits certain undeveloped areas could be exploited for an extension of irrigated farming, such as west of Azzahra and the dune zone immediately south of Tripoli; however, the sand in these areas will take many years to fix.

Elsewhere on the Jefara the Quaternary water is either inaccessible or too saline and the artesian wells, which often have large capacities, generally yield a poor quality water. Development away from the core region of the Jefara largely depends on finding a cheap means of raising the deep Quaternary water in the east and making better use of the higher quality class 3 waters from phreatic and artesian sources.

H. Greene[x], in his book 'Using Salty Land', emphasises that the use of saline water on permeable well drained land is not as

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[x] F.A.O. Agriculture Studies No. 3 - Section on Irrigation.

dangerous as in areas of heavy soil; there is less chance of water-logging and the leaching of salts is easier if good quality water is available. When a calcium clay soil is irrigated with water of high sodium content the sodium tends to take the place of the calcium and the soil becomes saline; this can be corrected by the application of calcium sulphate (gypsum) which is plentiful in Northern Tripolitania. It would seem that there are distinct possibilities of utilising some of the class 3 water of the Jefara and this view is substantiated by experiences with such water in the Misurata region in the east.

The use of brackish water at the Italian settlement of Crispi, south of Misurata, is described by Marroni (28). In the eastern part of Tripolitania, particularly round Misurata and to the south, most of the underground water is of poor quality, both from Quaternary and artesian sources, and the farmer is forced to use it if he wants to irrigate; for instance at Misurata phreatic water with a sodium chloride content of 2,000-3,000 p.p.m. is being used for irrigation purposes. At the Ente settlement of Crispi poor quality artesian water is being used, and the following two wells are typical:

	Parts per million	
	Total solids	Chlorides
Well no. 3 Crispi	2,392	1,100
Well no. 2 Crispi	2,524	1,368

It is interesting to study the policy adopted by Ente at Crispi since, as has already been stated, one of the means of expanding irrigation on the Jefara is by the increased use of saline water.

At the outset the agency decided that only semi-irrigation should be practised and crops with their whole life-cycle in the summer should be excluded, furthermore only crops with some degree of salt tolerance should be cultivated. On a 10 ha. holding, olives were planted well apart at 15 x 30 metres (almost dry cultivation spacing), leaving space for 4 ha. of cereals, 4 ha. of pulses (beans and vetches), 0.5 ha. of lucerne, 0.5 ha. of spring-summer grasses (sorghum and gseb) and a small area for industrial and horticultural crops. With only one fifth of the farm irrigated and the land resting for periods of up to three years results have been most encouraging. Some crops such as lucerne suffer if irrigated with the artesian water during the early phases of germination, but this problem can be overcome by sowing during the rainy season. Olives and date palms have done well but the fruit trees, particularly citrus, are disappointing; wheat, barley, pulses, sorghum and gseb seem to thrive; tomatoes, asparagus and cabbage succeed in some areas; tobacco, potatoes and groundnuts are not at all happy with the brackish water.

On the Jefara there is scope for development along these lines. The soils are suitable because it is possible '...... to use the brackish water on those soils which are permeable and rich in Ca CO_3, and where the groundwater level lies deep, as the excess salts can easily sink to the sub-soil' (41 p.18); furthermore freshwater is available for mixing on many localities. Careful selection of salt-tolerant crops from the table given in chapter 3 should give worthwhile results. Pantanelli once remarked that 'more extensive ultilisation of brackish water will be a strong weapon for land reclamation and settlement in Mediterranean countries' (28). And what applies to the Mediterranean as a whole also applies to the Tripolitanian Jefara.

SECTION III

WATER UTILIZATION

CHAPTER 7

Water Consumption

A considerable amount of underground water is used every year but no attempt has been made to estimate the actual quantity involved. Most of the water pumped from below the surface is used by the agriculturalist, Wheelus Field Air Base and the town of Tripoli.

A. Estimate of the present consumption of water.

The largest water consumer on the Jefara is the farmer who irrigates his land. In 1956 Lury (2) estimated that there were 13,628 ha. of irrigated land on the Jefara Plain; today this figure has probably increased to about 15,000 ha.. Ahmed* concludes, from his study of the consumption of electricity, that in a normal year 12,000 m3 are required for the full irrigation of one hectare of land, and in a drought year 14,000 m3. If we take 14,000 ha. as the present area of irrigated land and assume that it is all under full irrigation (a doubtful assumption as some of this land may only be semi-irrigated), then the amount of water used on the Jefara Plain is about 168,000,000 m3 per annum. This represents a maximum estimate.

The town of Tripoli, with a population of 130,000 people, is another large consumer of water. This comes from underground and is pumped from three localities:-ɵ

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* Ahmed, A.A., B/84.

ɵ Information supplied by Signore Fumagalli of the Municipio.

1. Fournaci - here there are six wells having a total hourly capacity of 1,200 m3. Each well is about 50 metres deep, has two electric pumps, only one of which is usually operated at one time, and draws all its water from the second aquifer. In January 1958 15,010 m3 were pumped every 24 hours making a monthly total of 434,500 m3.
2. Bu Meliana - here there are two wells having an hourly capacity of 320 m3. One well has an electric pump of 80 m3/hr. capacity, and the other, two electric pumps of m3/hr. each. The output per 24 hours in January 1958 was 6,600 m3 and the total for the month 17,760 m3. Water from Fournaci and Bu Meliana is stored in two water tanks; one at Dalra with a capacity of 2,000 m3, and one in the old city with a capacity of 1,800 m3; it is then fed into the mains.
3. At Bab Ben Gashir there are two wells, which like those previously mentioned, are about 50 metres deep and have an 'avampozzo' of 14 metres. The maximum total capacity of these wells is 80 m3 an hour. This is all used locally and is not fed into the general mains.

In 1957, 10,374,726 m3 were pumped from the second aquifer to supply the domestic and industrial needs of Tripoli. This of course does not include water raised from the many wells in the Old City.

Wheelus Field consumes a large quantity of water in supplying the high luxury demands of the United States Air Force. It is difficult to obtain precise information either from the Air Base itself or from the many American water experts working in Libya. Agnese N. Lockwood, in her book 'Libya-building a desert economy'* quotes the amount of water used as 1 to 1.5 million gallons daily, that is 1,379,000 to 2,070,000 m3 per year. Since these figures relate to 1956 it is probably safe to assume that the present consumption of water at Wheelus Field is in the order of 2,000,000 m3 per year.

The British army barracks in Tripoli take all their water from the municipal town supply, but the Royal Air Force at Idris, twenty miles south of Tripoli, has its own pumping installations. There are five wells altogether on the camp but at the moment only three are used. The actual station itself is supplied by two wells which are pumped on alternate days from 7 a.m. until midnight, each being pumped seventeen hours in forty-eight. The wells are about 120 metres deep and water is found at 35 metres below the surface; they are each fitted with electric submersible pumps with maximum capacities of 21 m3/hr.. 75 m3 are usually pumped per 24 hour period. Away from the camp are the married quarters, where one well usually supplies about 46 m3 of water per day. The whole camp is therefore using about 121 m3 per 24 hours, making a yearly total of nearly 45,000 m3. This is a minimum consumption figure because the information was collected in the winter when the demand for water was at its lowest.

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* International Conciliation, Carnegie Endowment for International Peace, March 1957.

The biggest problem is to try to assess the domestic consumption of water for the rest of the Jefara. This is extremely difficult. The population of the whole Jefara is approximately as follows:-*

Table 7.1 Estimated population of the Jefara Plain

Tripoli and Western Province	383,504
Tiji Mudiria	2,747
Jaush Mudiria	2,680
Gasr Khiar Mudiria	11,986
Parts of the Inner Jefara with population included in Central and Eastern Provinces	3,000
Total	393,917

The population of the whole Jefara can be taken as 400,000 and since Tripoli's water consumption has already been considered, 130,000 can be subtracted leaving approximately 270,000 people on the rest of the Jefara. The problem is now to decide how much water is used per head of the population, and the figures for Tripoli cannot be used because they include water used for industrial purposes. The F.A.O. Report on Agriculture, 1952[e] describes how the town of Zuara, with a population of about 8,000, has two wells which together supply a daily total of 195 m3.. 70,175 m3 are used in a whole year working out at 8.77 m3 per head (that is 5.37 gallons per head per day). This seems a

* General Population Census of the U.K. of Libya, 1954.

e B/90 p. 190.

reasonable figure for people living in the towns and villages along the coast, but is probably too high for the inland areas; in the latter areas, however, there are a large number of sheep and goats all of which need water, so that the figure calculated from the F.A.O. Report will suffice. The total domestic consumption for the whole Jefara Plain, exclusive of Tripoli, is therefore approximately 2,370,000 m3 per year.

A maximum estimate in round figures of the present consumption of water is probably as follows:-

Table 7.2 Estimated Water Consumption on the Jefara Plain.

Irrigation	150,000,000 m3 per year
Tripoli City	10,500,000
Wheelus Field	2,000,000
Royal Air Force	50,000
Domestic - Jefara	2,250,000
Total	164,800,000

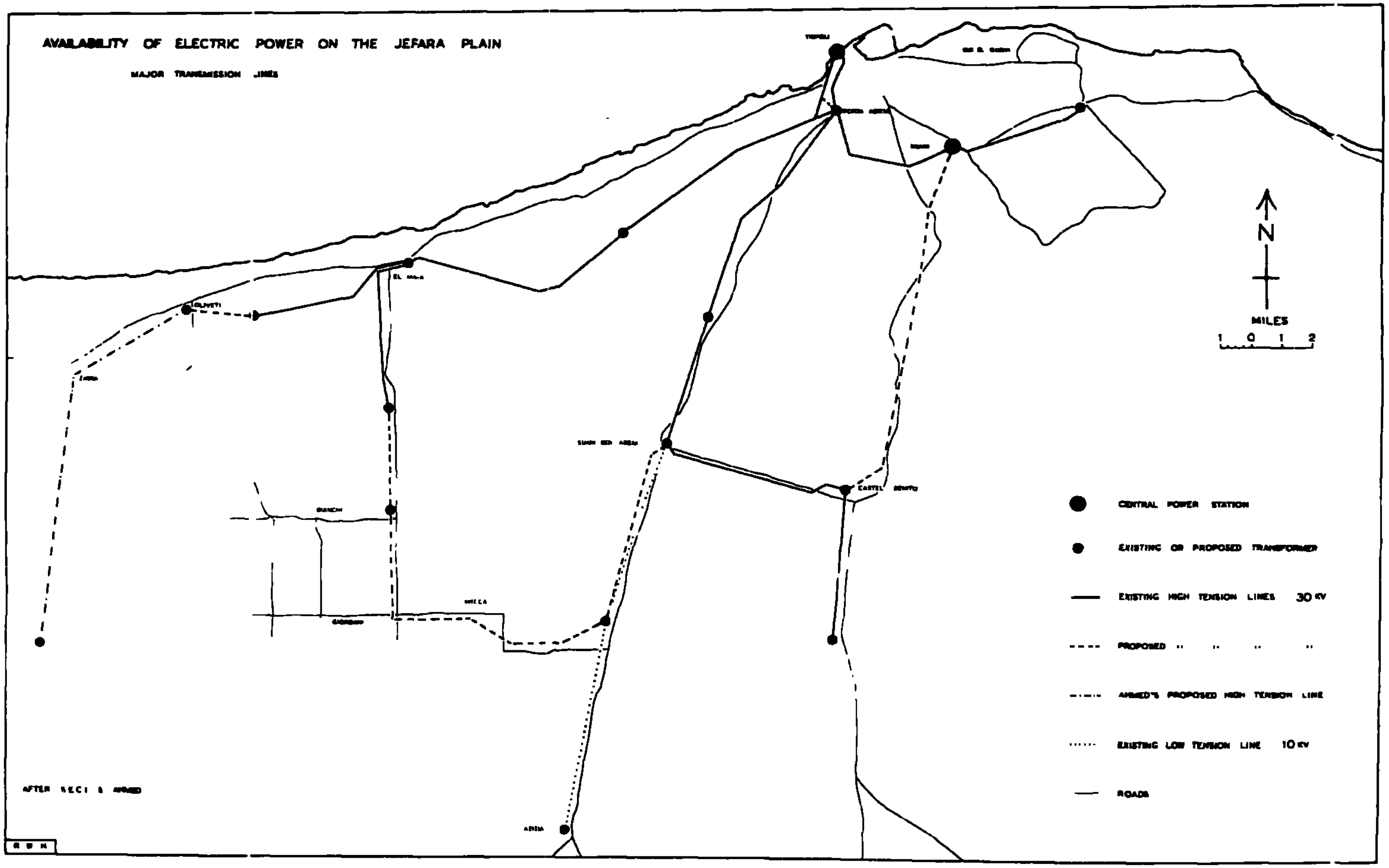
91.5% of all water consumed is for irrigation, 6.1% for Tripoli City, 1.22% for Wheelus Field, 0.34% for the R.A.F. and 2.2% for domestic purposes outside Tripoli. Note that Wheelus is using almost as much water as the rest of the domestic consumers, and one fifth of the amount used by Tripoli City.

B. The location of the most heavily irrigated lands.

Electricity is the main source of power utilised for driving pumps and the Tripoli Electricity Undertaking (formerly S.E.C.I.) tries to encourage the farmer to use electricity by offering him a low tariff. The following are the reigning prices in February

AVAILABILITY OF ELECTRIC POWER ON THE JEFARA PLAIN

MAJOR TRANSMISSION LINES



1958:-

Table 7.3 T.E.U. Electricity Tariff.
Price mms./unit.

Type of Consumer	Outside Tripoli	Tripoli
Electric Light	29	27
Domestic Power	29	27
Industrial Power	23	23
Agricultural Power	8	8

The farmer can buy his electricity for irrigation far cheaper than any other customer.

Fig. 19 shows the main transmission lines on the Jefara. Since they are found in water supply regions 7a, b, c, and d where good quality groundwater is readily accessible their presence encourages irrigation.

It is difficult to establish the actual present distribution pattern of irrigation equipment because the necessary information is not available. However, farmers are eligible to apply for customs free diesel oil and to obtain this they have to fill in forms giving details of the machinery on their farms. These forms are held by the Nazara of Agriculture, and it proved impossible either to see them or have them analysed or translated. Fortunately Lury (2) studied the 1955 forms and produced a few interesting and very valuable figures, which will suffice to give an idea of the irrigation equipment in private ownership only a few years ago:

Table 7.4 Distribution of pumping equipment by province, 1955.

Equipment	Tripolitania	Trip. & West	Eastern	Central
Motor) diesel	215	199	16	-
Electric) diesel	150	143	7	-
Petrol machines	23	22	1	-

These 1955 figures indicate a distribution pattern which is still the same today. Tripoli and Western Provinces have 92.5% of Tripolitania's motor pumps, and 95.3% of the electric generators; Eastern Province has very few motor pumps and none are listed for Central Province. It is quite clear that irrigated farming is confined almost entirely to the Jefara Plain. Most of the pumps are medium sized, 5-20 h.p., although the largest is over 70 h.p.; most of the generators are also 5-20 h.p.,but there are a few at all sizes up to 130 h.p.

How are the pumps distributed ? The following table gives the number of motor pumps and generators by locality in 1955, with the underlined figures indicating areas where irrigation is most intense, i.e. Bianchi, Collina Verde, Gasr Ben Gashir, Oliveti, Sorman, Suani Ben Adem, Zanzur, Zawia and Tajiura. Most of the areas listed lie within the bounds of the Tyrrhenian deposits and the electricity grid.

Table 7.5 Distribution of pumps and generators by locality, 1955.

Locality	Motor Pumps	Electric Generators
Ajelat	-	-
Ain Zara	5	4
Azizia	4	2
Bianchi	16	43
Collina Verde	18	-

Gasr Ben Gashir	14	28
Garabulli	8	6
Oliveti	13	3
Giordani	2	12
Gurji	9	6
Sabrata	7	1
Sorman	20	7
Suani Ben Adem	19	4
Suq el Jiumaa	2	9
Tajiura	20	9
Tripoli	1	1
Zawia	19	-
Zuara	1	-

C. Increasing Consumption of Water.

The Government's general agricultural policy seems to be one of encouragement for the irrigating farmer. It has already been pointed out that a low electricity rate exists for the agricultural consumer, and a further incentive for the expansion of irrigated cultivation is the fact that irrigation equipment can either be imported without payment of duty or, if payment is necessary, at a very low rate. The following are the amendments of the 1952 Customs Tariff:- (3)

Tariff No. 265 Machinery, apparatus and detached parts used for artificial rain installation — Customs Duty Nil.

Tariff No. 266 Pumps for liquids (Jet, centrifugal, rotary, pressure and others)- and detached parts thereof --Customs Duty Ad Valorem 2%.

Machinery producing and generating electrical current, electric motors and detached parts thereof, including electric pumps — Customs Duty Ad Valorem 2%.

i. There are no figures available which show how the consumption of water is increasing, and this can only be inferred by indirect means. The Tripoli Electricity Undertaking supplied the following figures which give the number of agricultural motors in Tripolitania which use electricity:-

Table 7.6 Number of electric motors in Tripolitania 1951 to 1957

1951	1,095
1952	1,105
1953	1,222
1954	1,256
1955	1,334
1956	1,369
1957	1,410

Numbers steadily increase each year.

ii. The sale of electricity to the farmers by the T.E.U. has shown a general increase in the period 1951-57.

Table 7.7 Sale of Electricity for agricultural motors. K.W.h.

User							
Various	6,431393	6,425545	6,817863	7,703279	8,780877	9,052731	8,572668
INPS							
Oliveti	605160	595440	642600	743010	795240	624240	873600
Bianchi	1,893920	1,918960	1,910320	3,173556	3,382167	2,791200	2,732400
ENTE							
Oliveti	227520	237120	264480	333600	407520	480960	518765
Azizia	118800	99000	131400	147600	167400	187800	224700
Total	9 , 276793	9,276065	9,766663	12,101075	13,533204	13,336934	12,922133

The two Oliveti settlements and Azizia have been using increasing amounts of electricity each year as the area under irrigation has been steadily expanded; elsewhere and at Bianchi the installation of irrigation equipment seems to have reached a peak and the consumption of electricity has declined slightly and now appears to vary with the rainfall.

iii. It is quite clear that more water is used in drought years, particularly in the spring and Ahmed[x] is the only person who attempts to measure this. He compares the amount of electricity used per day per hectare in a drought year, 1947, with that used in an average year, 1949; his figures are for the INPS settlements in the Bianchi area. In March 1949 the daily consumption of electricity was 2.2 K.W.h. per ha. as opposed to 4.4 K.W.h. in 1947 (expressed in terms of water - 20 and 40 m3/ha. respectively). The water given in February 1949 was 8 m3/ha. and February 1947 12 m3/ha.

iv. Another means of establishing the extent of the expansion in irrigation is by studying the loans made available by the various financing houses in Tripoli. Money is loaned for the purchase of irrigation equipment by the Libyan Finance Corporation, the Agricultural Bank, the National Bank of Libya, other private banks, and plus, of course, the moneylender. No information could be obtained from the Agricultural Bank because when the records of loans are compiled no attempt is made to differentiate between the nature of the loans. On the other hand, the Libyan Finance Corporation produces an annual report (1) in which details are given of the type, number and value of loans. Of the money loaned by the Libyan Finance Corporation for

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x B/84, 1952.

the development of irrigation, about 60% is for motor pumps, 30% for pipes and low pressure sprinklers, and 10% for oddments. Loans are usually for 3-5 years and at 5.5-6% interest. The Corporation started its first financial year 31st March 1953, and for the first four years of its operation until 31st March 1956, over £L30,000 were loaned each year.

Table 7.8 Summary of loans made by the Libyan Finance Corporation.

Year	No. of loans	Value
1953/4	28	£L36,520
1954/5	21	£L32,875
1955/6	27	£L45,143
1956/7	32	£L40,180
Total	108	£L154,718

The figures for 1955/6 include six loans, total value £L7,268, for the installation of irrigation equipment at the Maamoura settlement. The amount of investment in irrigation is considerable and according to Dottore Carlo Barberis the Director-General of the Corporation, enough money was loaned in the three financial years 1953/4 - 1955/6 to convert a thousand hectares to irrigation.

Other than the National Bank of Libya there are seven banks in Libya: Bank Misr, Crédit Foncier, Banco di Sicilia, Banco di Napoli, British Bank of the Middle East and Barclays D.C.O. In 1957 all banks, except Bank Misr, loaned money for the purpose of agricultural development, and records of these transactions were despatched monthly to the National Bank of Libya for its record files. Bank Managers were naturally reticent about divulging the details of their loans, so the records of the National Bank had to be studied. These records are very general and the details given are limited to the following three headings:

1) Loans for citrus groves and/or fruit.
2) Loans on or for livestock.
3) Loans on or for agricultural bodies.

The loans for agricultural bodies include money set aside for the development of farms, particularly with regard to irrigation. In the year 1957 they are as follows:-

Table 7.9 Loans made by private banks 1957.

Bank.	Total amount loaned	No. of customers	Av. amount per customer
Crédit Foncier	£L89,123	46	£L1,940
Banco di Sicilia	£L1,154,702	481	£L2,390
Bank Misr	-	-	-
Banco di Napoli	£L745,635	274	£L2,710
Banco di Roma	£L4,096,339	940	£L4,348
British Bank of the Middle East	£L776,733	47	£L16,070
Barclays D.C.O.	£L873,290	286	£L3,050
Total	£L7,735,822		

In 1957 nearly £L8 millions were loaned by the private banks. Some of this money was used as an advance on crops but most of it was invested in irrigation equipment. The

British Bank of the Middle East, with an average loan per customer of £L16,070, would appear to have financed several large scale irrigation projects.

v. The continuing expansion of irrigation can also be proved by the sales of irrigation equipment. Two firms predominate, F.R.E.I. and Consorzio Agrario, and both were visited by the writer to obtain details for 1956 and 1957. The sales season usually runs from November until May when irrigation is least required; each firm surveys its customer's farm, advises on the type of equipment required and then installs it if requested. The installation of equipment during the last few years has been largely geared to groundnut production.

In the period January 1956 to February 1957, F.R.E.I. sold 7,748 six metre lengths of movable quick coupling sprinkler pipes: a total length of 46,488 metres which is almost 50 kilometres. In the same period 27,834 metres of concrete and asbestos mains pipes were sold. The same firm has several pumping units which it offers for sale: a 2½ h.p. diesel with a centrifugal pump, a 5 h.p. diesel with a centrifugal pump, and a 10 h.p. diesel generator with an electric pump. In 1956 and 1957 a total of 1,200 units were sold.

The information gleaned from Consorzio is more detailed and also points to brisk sales of irrigation equipment.

Table 7.10 Sales of selected types of irrigation equipment by Consorzio, 1957.

Nature of Equipment	Amount	Value	Amount	Value
1) Electric centrifugal pumps 2-7 h.p.	295 units	£L12,334.105	197 units	£L8,998.715
2) Diesel engine pumps for pushing water along irrigation pipes 6:8 h.p.	22 "	£L1,005.705	40 units	£L1,464.870
3) Generators from 5 Kvampere to 16 Kvampere	55 "	£13,555.815	61 units	£L12,784
4) Diesel engines for well pumps, usually 4:8 h.p. although up to 36 h.p. sold	107 "	£L20,898.7	133 units	£L23,723
5) Zinc pipes, diameter 80, 100 and 120 mms. (5 m. length).	34,419 metres	£L27,144.88	33,374 metres	£L27,359
6) Asbestos pipes, diameter 100, 125, 150 and 175 mms.	25,746 metres	£L18,240	14,577 metres	£L11,355.909
7) Sales of spares and accessories		£L5-6,000		£L5-6,000

In 1956 approximately £98,179.205 worth of equipment was sold by Consorzio and in 1957 the value dropped slightly to £L90,685.494. 1956 was a bumper year for the groundnut and this led many small farms to increase their irrigated area, hence the high sales of small electric pumps. In 1957 there was an increase in the sale of diesel pumps and diesel generators indicating that the area of irrigated land has been stabilised within the limits of the electricity grid but that expansion is still continuing elsewhere where sufficient water is available.

Many farmers seem to have installed their underground distribution pipes in 1956 and then bought their surface pipes the next year.

D. Summary and Conclusions.

It is clear that there has been an accelerated expansion of irrigation in Tripolitania during the last few years, which has taken place largely on the Jefara Plain. There are signs, however, of changes in this trend and one can expect less capital investment in irrigation during the next few years. Slower expansion will be the result of three main factors: lack of rotation almost to the point of monocultivation of groundnuts, resulting in disease, poor quality nuts and low yields; increased competition on the world markets from other groundnut producers, particularly from countries whose governments are subsidising exports; and finally a declining water-table in many parts of the Jefara which is raising the cost of production, already at a high level.

It is difficult to assess the amount of water either falling as precipitation on the Jefara or flowing on to it from the Jebel. By averaging the rainfall for the stations Zuara, Tripoli, Garabulli, Gasr Ben Gashir, Azizia, Bir el Ghnem and Tiji, it would seem that approximately 2,350 m3/ha. falls over the whole plain, a total of around 47,000,000 m3. ~~The estimate of the amount of water used for irrigation is high and is nearly three~~

A considerable quantity of water flows on to the Jefara from the Jebel but it is impossible to estimate the amount without knowing the rainfall and the areas of the wadi catchment basins; it is unlikely however that more than 100,000,000 m3. of water leave the Jebel during a rainy season. One can estimate therefore that the plain receives in total about 4,800,000,000 m3. per average rainy season, of this possibly 10% disappears underground (probably 15% in endoreic areas) - a total recharge for aquifers of 480,000,000 m3.

It was shown in table 7.2 that total water consumption on the Jefara Plain is about 165,000,000 m3. per annum, well under half the total recharge. This does seem to suggest that there is no cause for alarm, but it must be borne in mind that although there is a theoretical surplus of water accumulating underground much of it is in unexploited western areas where water soon becomes saline. Where intense irrigation is localised within the limits of the Tyrrhenian deposits, consumption of water may at least equal if no exceed recharge.

CHAPTER 8

Methods of Raising and Distributing Water.

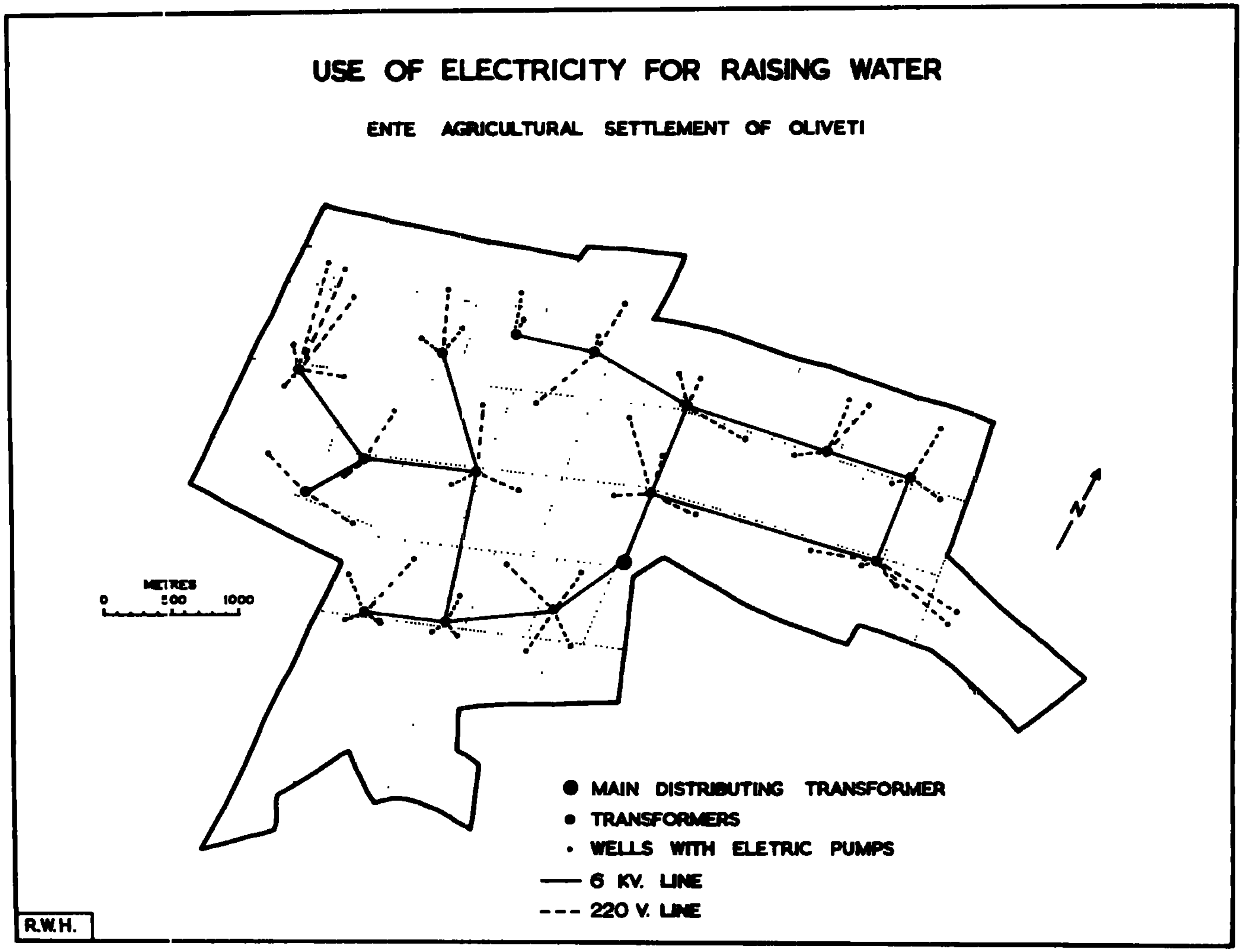
A. Introduction

Methods of raising and distributing water in Tripolitania are varied, depending on such factors as size and location of farms, the extent of the irrigated area, capital available and the attitude of the farmer. It is important to know how the water is lifted from the underground reservoirs, because the type of pumping equipment employed determines how much water is likely to be used; as will be shown later the dalu is capable of raising much less water per hour than the electric pump. It is also important to know which method of irrigation is the most popular. The sprinkler seems to be ideally suited to the Jefaran environment, and concomitant with the expansion of irrigation in the last few years has been widespread introduction of this technique.

With the exception of a few springs (see fig. 7) all irrigation water used on the Jefara Plain has to be pumped from wells. The main types of wells built to exploit underground water are shown in fig. 6b. Along the coast are the littoral phreatic wells which tap the water of the first aquifer a few metres below the surface; further inland are other wells which draw on water from the same aquifer which may be up to 80 metres deep. Below the Tyrrhenian clay layer there is the second aquifer which is usually 20 to 30 metres below the surface; sometimes the water in this aquifer is under pressure and rises to the static level of the water in the first squifer, but in many cases it has to be pumped. Artesian wells flow at the surface but the sub-artesian wells generally have to be pumped from a depth of up to 40 and 50 metres.

Before the arrival of the Italians, the Arabs were content to take water from the first aquifer by means of the dalu and occasionally the Persian Wheel. The Italians started an intensive search for water and the second and artesian aquifers were soon discovered. At the outset, however, the Italians established dry farming and on many of the large concessions the wind pumps which were installed, were sufficient. The Libyans soon appreciated the value of the wind-pump and many were introduced on their small farms, particularly away from the coast where the first aquifer is deeper. Gradually the Italians realised that the deeper water reserves were quite extensive and that potentially at least they could form the basis of a semi, if not fully, irrigated agriculture. More mechanical pumps were imported into the country and a small power station was constructed by S.E.C.I. Many of the demographic farms already had electricity and electric pumps when the farmer moved in (see fig. 20). The trend towards more emphasis on irrigation started in the late 1930's, and has been accentuated since the end of the 1939/45 war particularly in the last five years. Today mechanical pumps abound everywhere both on Italian and Libyan hawāza farms; there are electric, diesel-electric, diesel and petrol pumps. Even on the small sanīya farms which are located within the grid system, the farmers are introducing small electric centrifugal pumps. In the agricultural year 1952/3 Theodorou*

* B/96 p.57.


USE OF ELECTRICITY FOR RAISING WATER
ENTE AGRICULTURAL SETTLEMENT OF OLIVETI
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MAIN DISTRIBUTING TRANSFORMER
TRANSFORMERS
WELLS WITH ELETRIC PUMPS
6 KV. LINE
220 V. LINE
R.W.H.

found that only 9% of the Italian farms, in contrast to 99% of Libyan farms in the Zawia area, were without pumps. Today most of the remaining Italian farmers will have installed mechanical pumps and some of the Libyan farmers will have discarded the dalu in favour of some sort of mechanical lifting device.

B. The Main Types of Mechanical Pumps Available.

Piston pumps are declining in importance and most pumps in use throughout the world today have a rotating impeller. This is built into a casing which is designed to direct the water through and away from the impeller. The shape of the impeller and its enclosing case determines the classification of centrifugal, mixed flow and axial flow (propeller pump). Mixed flow pumps have the upward thrust of axial flow and the outward thrust of centrifugal flow.

Table 8.1 Classification of pumps.

Type	Suction head	Type of impeller	Total Head	Capacity
Centrifugal	Medium	Enclosed	high + 3m.	Low-medium
Mixed flow	Low-Medium	Semi-enclosed	medium 2-8m.	Medium-high
Axial (Propeller)	Low	Open	Low - 3m.	High

Centrifugal pumps with enclosed impellers are capable of high speeds and are generally able to lift small quantities of water to considerable height. Since a large number of Jefaran wells have a total head above 8 metres, most pumps installed are of the centrifugal type.

C. Methods of raising water on the Jefara Plain.

1. The Dalu - The dalu is the traditional method of raising water in Tripolitania. Along the coast there are shallow masonry

wells of 3 metres diameter, which have lifts not exceeding 9-10 metres; inland there are similar but deeper wells which are used for the watering of stock. Skin buckets are used to raise water from both the wells, but along the coast they are of the self-emptying type, whereas those inland are a simple bag-shape. The self-emptying dalu is ingenious and effective in its own small way, and its distinct and fascinating characteristics can be best studied among the palm trees of the sanīya farms of the coastal oases. Only no. 43 of the farm studies has a dalu.

Plate 1 shows the structure of a Libyan well in the coastal zone. At the top of the well are two masonry pillars (sometimes these are wood) which support a pulley in a wooden framework over the centre of the well. The large wooden pulley wheel takes the main rope which is attached to the leather bucket. At the discharge side of the well is a roller which is positioned approximately in line with the base of the pillars. The secondary rope which is attached to the spout of the dalu, travels over this roller. The dalu itself is funnel shaped with a narrow spout-like tube at its base; it is open at both ends. When it is dropped into the well it soon fills with water and is then ready to be lifted. In order to prevent the loss of water during the lifting operation, the spout, which is very flexible, is pulled up tightly alongside the main body of the dalu until its mouth is above the top of the bucket. When the dalu reaches the top of the well the bucket part continues upwards to stop just short of the pulley wheel, while the spout is pulled down and out towards the point of discharge by the secondary rope which is running over the roller. When the dalu is fully raised the spout is trailing downwards to the side of the well, so the water automatically discharges into the canal or hollowed palm trunk which leads it to the storage tank. The two ropes, the main one attached to the bucket part of the dalu, and the secondary one attached to the spout, are pulled by an animal that walks backwards and forwards on an inclined plain which usually disappears into a pit. A minimum of one man and an animal is needed, although some wells have two dalus which can be operated at the same time and then more animals and men are required. The animals used are bullocks, cows, camels, and sometimes donkeys. The top of the well and the storage tank are found on artificially raised ground so that water can be distributed round the farm by gravity flow.

The capacity of the actual dalu is small, somewhere between 0.09 m3 and 0.2 m3, and the whole process of raising water is very laborious. The dalus easily wear out and two to three have to be bought each year.

Several research workers have estimated the amount of water that can be raised by a dalu per hour. On page 40 of his report, Lewis* lists 36 wells which have an average depth of 12.5 metres. The average depth of water in these wells is

* Lewis, R.H.: 'Irrigated Land-Use and Irrigation Report'. L.A.T.A.S. Libya.

2.9 metres and their average discharge is 2.6 m3/hr., the latter probably derived from figures which range from 2.5 - 4 m3/hr.. Prinzi and Negretti (11) suggest that the dalu can raise 3.6 m3/hr. It seems reasonable to assume therefore that dalus generally raise 2.5 - 3.6 m3/hr.

By raising water with the dalu the farmer imposes obvious limitations on the size of his irrigated area. Lucerne for example needs at least 10,000 m3/ha. of water per year, even allowing for natural rainfall (see chapter 4): this works out at about 28m3 per day. Even if a farmer works 10 hours a day he will only raise 25-35 m3., sufficient water for only one hectare. Most farmers raise water for a few hours in the morning before 10 a.m. and then again in the evening, but rarely do they spend more than six hours at this task. In the middle of the summer it is doubtful if the average dalu irrigates more than ½ ha. of land; Theodorou reckons ¼ ha. and farm study no. 43 shows 0.3 ha.

The dalu clearly has a very low capacity and only a very small patch of land can be irrigated if this method of raising water is used. The Libyan farmer in the coastal oasis zone can buy a small electric pump of 1-2 h.p. for a modest sum, and with this he can raise up to 10 m3 of water an hour compared with the dalu's meagre 2-3 m3/hr. Even if the dalu operator works all day and all night he can only raise a total of 72 m3/hr. With the dalu there is always the danger that the farmer will grow too large an area of an irrigated plant or tree crop, with the result that there is too little water given at each irrigation; furthermore with the dalu the farmer can only exploit the first aquifer, and as long as this method of raising water is retained, no change of cropping can be expected. However, it is necessary to point out that despite the extreme density of wells in the coastal zone , particularly in the Suq el Jiumaa and Tajiura districts (see fig. 17), the water-table has been stable for many years and there is no evidence of over exploitation. The widespread introduction of small electric pumps in this area would soon exhaust the limited reserves of the first aquifer.

2. <u>The wind pump.</u> The 1949 Foreign Office Working Party Report stated that there were over 249 wind-pumps in Tripolitania and it is reasonable to assume that about 200 were on the Jefara Plain. Today numbers are declining rapidly but the wind-pump is unlikely to disappear for many years to come. In the early days of Italian development the wind-pump was a common feature of the landscape, especially before a generating plant was installed in Tripoli, and even now is widely used in areas beyond the limits of the grid-system. Most of the dry hawāza farms are scrapping the wind-pump, but on the small Libyan farms away from the coast which have been developed over the last 20-30 years, it is still invaluable because it allows the farmer to raise as much water as his coastal counterpart does with the dalu, but from a much greater depth.

Most of the pumps on the Jefara are of the windmill type. The rotary movement of the sails is converted into a vertical movement which in turn motivates a piston; the piston creates a vacuum and water is drawn up from below. Ahmed[x] states that a modern oil bath wind-pump starts to rotate with a wind velocity of 7 m.p.h. and any speed above this can be utilised for pumping. However, his studies of wind velocities in the period 1924/34 shows that the average velocity is between 9 and 20 m.p.h. and this he considers unfavourable. Today Consorzio Agrario has a small stock of Italian made wind-pumps but sales are very low. The following table gives an idea of the capacities of selected wind-pumps with a wind speed of 15-18 m.p.h.

Table 8.2 Capacities of selected wind-pumps sold by Consorzio Agrario in M3.

Lift	.... Diameter of windmill in metres						
	2.0	2.4	3.0	3.65	4.25	4.85	5.3
8 metres	1.6	2.5	3.3	-	-	-	-
22 metres	0.45	0.75	1.2	2.1	3.0	4.0	4.1
40 metres	-	0.3	0.5	1.0	1.5	2.2	2.6

The amount of water that can be raised by a wind-pump is very small unless a very large windmill is used (18 metres diameter) and strong winds are frequent and steady. The pumps listed above represent a good cross-section of those sold by Consorzio, and the table shows that one can rarely expect to raise more than 3-4 m3/hr.

Two demographic settlements on the Jefara were established with wind pumps: Fonduk Et Togar and Ghanima. Both of these will be discussed in more detail elsewhere but it is important

x B/34 p.105

to make a brief reference to them at this point. Fonduk is situated within the bounds of the Tyrrhenian deposits where abundant water reserves lie below the surface; these having been untouched until quite recently. All the farmers now own their farms, and being aware of the underground water available, they are naturally eager to dispense with the wind-pumps and install electric pumps in their place. Reference to the farm studies shows that farms 38 and 40 can only irrigate 2 ha. of land because their wind-pumps can only raise 5 m3/hr. In contrast farm 39 has a 5.5 h.p. electric pump with a capacity of 28 m3/hr. and 12 ha. of land can be irrigated. At Ghanima several farmers often share one wind-pump so there is no possibility of irrigation.

Unless several are installed side by side, and a large storage tank constructed, the wind-pump has such a low capacity that it is of little value to the irrigator. It is likely to be retained on dry farms where only a small domestic supply of water is required and on small semi-irrigated farms away from the electricity grid (as at Bir Langar). Probably the greatest disadvantage of the wind-pump is its unreliability: its operation depends on the vagaries of the wind.

3. <u>Mechanical Pumps and Power Units</u>. It should be remembered that a pump must be capable of lifting water from the lowest pumping level in the well to the highest point to which water is required on the farm, and at the same time overcome hydraulic friction in the pipes and perhaps even supply water at

sufficient pressure for sprinkler irrigation. When the Italians tapped the first aquifer near the coast, pumps could be placed at the surface, but with the exploitation of the deeper aquifers this was not possible because suction lift is limited, and pumps have to be sited not more than 5-6 metres above the water. Most of the deeper wells in the second aquifer, as at Azzahra, and inland in the first aquifer, as at Gasr Ben Gashir, have a masonry well 1.0 to 3.5 metres in diameter and 20 to 30 metres deep. This part of the well is usually excavated to about one metre above the water-table and is called the 'avampozzo' by the Italians. Below the avampozzo a tube of 100-200 mms. diameter is drilled for several metres into the water bearing strata; this the Italians refer to as the 'trivellazione'. Many of the farm studies give information on the depth of the trivellazione and avampozzo (see for instance farms on the ENTE settlement of Jiuddaim). Plate 18 shows a well under construction at Gasr Ben Gashir. On the Jefara Plain most pumps are of the centrifugal type and are placed at the bottom of the avampozzo, and sometimes even submerged; they are of all sizes but usually in the range 5-25 h.p. Two types of power are used to drive these pumps: electric motors and the internal combustion engine. The former power has many advantages; with a turn of a switch water is supplied at a constant rate, speed can easily be increased to maintain the same discharge with a greater lift, and the electric motor needs little maintenance and in fact no attention during its operation. The latter form of power has many disadvantages; because of the danger of fumes the engine cannot be sited in the avampozzo and therefore a long rotating transmission shaft is necessary, and furthermore, fuel and maintenance costs are high. The internal combustion engine is, however, independent of the electricity grid and it is essential to remember that many parts of the Jefara are without this facility.

The water-lifting units offered for sale by F.R.E.I. give an idea of the equipment that is being installed. They are as follows:-

i. Electric pumps.

a) Submersible - These are popular on the large irrigated farms particularly those with their own grid system and generating plant (Farm Studies 1 and 3). An electric motor and a centrifugal pump are coupled together in a tube-like casing and are then submerged below the pumped static level of water in the well, no attention being needed for many years. Five sizes of pumps are sold, from 7 to 20 h.p.; they have capacities of 15-42 m3/hr. with lifts of 15-140 metres. The minimum diameter of well to take these is 230 millimetres.

b) For fixing at the base of the avampozzo two ranges of electric centrifugal pumps are supplied: 0.4-1.7 h.p. which will raise 1.2-8.4 m3/hr. with lifts of 11.5-55.5 metres, and 1.7-5.5 h.p. pumps which will raise 2.4-21 m3/hr. with lifts of 14.5-85 metres. An example of the small type of pump is mentioned in farm study 45, and of a larger type in farm study 30.

ii. Diesel pumps.

a) Where the water-table is near the surface in the coastal oases areas which lie outside the Tripoli grid, a small diesel pump is valuable. F.R.E.I. sell a 2½ h.p. Petter diesel engine which is coaxially coupled to an Austrian centrifugal pump. This has a capacity of 27 m3/hr. and a total lift of about 34 metres. It can be used for irrigating small areas of 1-1½ ha. An example of this unit is seen in farm studies 14 and 42.

b) Where the water-table is deeper or more water is required a 5 h.p. Petter diesel is coupled to a German Reiz pump. This has a capacity of 72 m3/hr. and total lifts of 45-50 metres.

iii. Diesel Electric Pumps. These are generally employed when the lift is over 50 metres. F.R.E.I. offers a 10 h.p. diesel generator (7½ KvA) which can lift 30 m3 of water 75 metres and discharge it at pressure of about 2 atmospheres.

From the information given above and from observations made on many Jefaran farms it is possible to draw several conclusions about the suitability of the varying types of pumping units. Whenever the grid is available, the electric pump is the most efficient, submersible if the water is very deep but otherwise the normal electric motor and pump in the avampozzo. In areas where electricity is not available, because the electric pump is so efficient (80%), a diesel generator with electric pump gives better results than a straight-forward diesel or petrol engined pump. If there is a group of wells on a farm outside the grid, then a localised power system is the most efficient (as on farms 1 and 3 of the Farm Studies).

The mechanical pump has opened new vistas for the agriculturalist. If for instance a pump with a 40 m3/hr. capacity is worked for 7 hours a day, the total annual amount raised is 64,800 m3 -- sufficient for about 6 ha. of lucerne. A 10 h.p. diesel or 7 h.p. electric pump will raise this amount. Further information on how much land is irrigated by given pumps can be gained from the Farm Studies. The dalu and wind-pump cannot compete with these powered means of raising water.

D. Irrigation Techniques.

Few arid areas in the world rely entirely on groundwater to supply the needs of irrigation. It is important to realise that large heads of water, as exist in the diversion canals of Imperial Valley of U.S.A. and along the Euphrates in Irak, are not encountered on the Tripolitanian Jefara; instead there is a small flow of water from numerous wells. This is one of the many factors which has encouraged the widespread introduction of sprinkler irrigation.

1) Traditional method of irrigation. For many years, probably ever since the Arabs first arrived in North Africa, the land on the coastal sanīya farms has been irrigated by flooding. Each field is divided into squares or rectangles known as 'jedawl' (singular 'jedula', which are flat but have banked edges. The water that has been raised by a dalu is collected in a storage tank, and when sufficient head is available, irrigation

commences, the water flowing along earth ditches (swagi in Arabic, sing. sagia) to the jedawl (see plate 11). On most of the saniya farms the sagia ditches are 80-100 metres in length for each well; they are usually dug out of the soil but sometimes they may be concrete (see plates 2 and 16). Most of the Libyan farmers who use the windpump to raise water, also irrigate by the jedula system. Sometimes, as is shown in plate 13, each jedula has a series of furrows within it; this would appear to be related to the type of crop grown, since it is usually associated with cereals or perhaps potatoes. American extension workers have been desperately trying to introduce the furrow-line system in place of the jedawl. The jedawl method of distributing water is barely 60% efficient.

2) Gravity Irrigation on the Hawāza farms. Where gravity irrigation is still retained on the present and former Italian Concessions, there is a network of canals, plus furrows and corrugations for the field crops and usually jedawl for tree crops which are irrigated. Water is led to the fields by main and secondary distributory canals, both of which are generally made of sections of pre-cast concrete. Plate 30 shows an example of Italian gravity irrigation of artichokes; in this particular instance the water was taken to the field by underground pipe and then brought to the surface by a hydrant, subsequently to be led on to the land in simple earth ditches hoed out by the Libyan labourers. Citrus trees are usually irrigated by flooding and around each tree there is either a square or

circular shaped depression (see plate 14). The squared system used in the Italian citrus orchards has been introduced from Sicily. Ricotti (see farm study 2) uses the Sicilian method of irrigation for his old orchard and hopes to introduce the American furrow system for his new orchard, although at the moment the latter area is irrigated with sprinklers.

In addition to the loss of water to evaporation, there is the serious problem of water leaking from badly repaired sections of the concrete canals, plus the fact that water is lost from earth ditches and from flooding. Ahmed[*] claims that if concrete pipes and canals are neglected then 10-20% of water may be lost in transit. U.N.E.S.C.O. claims that with unlined canals in sandy soils the loss of water per 24 hours, in m3 per sq. metre of water covered surface, is 0.45 to 0.533 i.e. 182.5 m3 per sq. metre of water covered surface per year; furthermore by using the flooding method of irrigation on very permeable soils there may be up to a 25% seepage of water below the root zone. Losses from seepage are also encouraged by the fact that most of the canals carry a small volume of water at a slow velocity - about 0.4 m3/sec. to o.9 m3/sec.

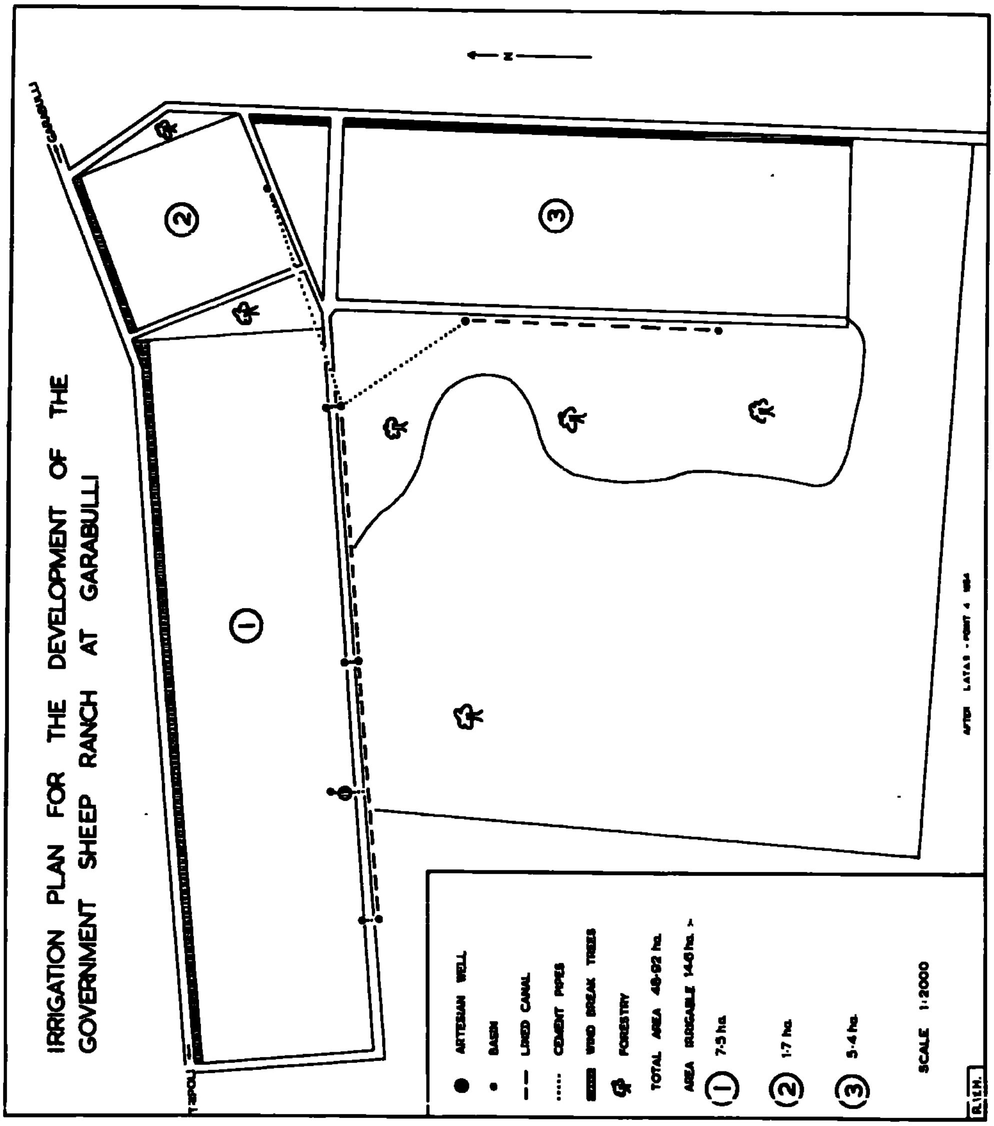
3) <u>American system of lined canals and syphons</u>. The development of new government farms has been largely financed by American money and supervised by American technicians. The main farms are at El Guea, Garabulli and Bir el Ghnem, and all except the last one take their water from artesian aquifers. The artesian wells have some of the highest discharges of any wells

* Ahmed A.A. B/84.

on the Jefara Plain and some average 300 m3/hr. At Bir el Ghnem the phreatic water-table is deep but water is plentiful and a considerable quantity is stored on the surface in a large tank. With these big heads of water (by Libyan standards) the Americans decided to develop a system of lined canals, such as are used in many drier parts of the United States. In the initial stages of developing the new government farms the land had to be cleared, levelled and then gently graded, this being done at considerable expense. Major distribution canals were constructed throughout each famm, with gradients of 0.5 to 1.5 metres per 1,000 metres, and capacities of 200 m3/hr. In some cases lined lateral canals were also constructed 50 metres apart and with capacities of 150 m3/hr. (see plate 12). The crop land is ploughed into furrows or corrugations, and water is transferred to them from the canals by means of syphons (see plate 15). Fig. 21 shows the initial plan for the development of the Garabulli Sheep Ranch. Water is taken round the farm by lined canal and cement pipes and feeds into basins; from these basins it flows along lateral lined or earth canals, then to be put into furrows by syphons.

At the outset the main difficulty of establishing the new farms was to discover a cheap means of building effective canals, because the normal raw materials and equipment needed for their manufacture are scarce in Libya, and hence expensive. The Americans developed a 'low cost mixture' for lining canals composed of 75% caliche, 15% gypsum, 5% cement and 5% sand; this is plastered on the walls of the canals and after a day

Figure 21.


IRRIGATION PLAN FOR THE DEVELOPMENT OF THE
GOVERNMENT SHEEP RANCH AT GARABULLI
GARABULLI
ARTESIAN WELL
BASIN
LINED CANAL
CEMENT PIPES
WIND BREAK TREES
FORESTRY
TOTAL AREA 48·92 ha.
AREA IRRIGABLE 14·6 ha. >
1 7·5 ha.
2 1·7 ha.
3 5·4 ha.
SCALE 1:2000

or so is sprayed with a layer of bitumen.

Although this method of irrigation looks very impressive it is not really suitable in Libya and it is doubtful if any of the larger private farms will adopt it. It has several serious disadvantages:-

i. Land needs extensive levelling before development is possible, and this is expensive.

ii. Only a few wells, mainly artesian, have large enough discharges to supply the head of water necessary for flow along the main canals.

iii. The control of water in the canals and through the syphons is more complicated for the labourer than looking after sprinklers.

iv. The canals may be cheap in cost but at the same time they are cheap in quality; they soon break down and need frequent attention, and furthermore they are constantly filling with sand.

v. Irrigation of this type has to be an integral part of a well planned scheme and when completed it lacks flexibility. Canals often lie idle.

vi. Evaporation from the water flowing in the large open canals is considerable.

4) Sprinkler Irrigation. Once constructed, canals remain permanently 'in situ' but the sprinkler has a mobility which is one of the most important points in its favour. The expansion of irrigation on the Tripolitanian Jefara has been conjoined with the introduction of sprinkler irrigation, and there are few

areas in the world today where this artificial rain method holds such an important place in irrigated agriculture as it does in this part of Tripolitania. (The editor, writing about the sprinkler in the editorial of World Crops (5 p.205), remarks: 'This system has been mainly used on small properties with market garden or orchard crops, but its application to annual field crops has hitherto not made much progress'. In Tripolitania, however, the sprinkler is widely used for the irrigation of field crops.)

Much of the equipment used is of Austrian manufacture, and most of the farms with a few hectares of irrigated land appear to manage with 200 metres of mains pipes and 1,200 metres of movable pipes. The quick coupling movable pipes are usually in 6 metre lengths and have a diameter of 89 mms.; a ½" screw-in nipple is fitted to each one. The mains pipes have a larger diameter of 108 mms. and they are generally made of asbestos or concrete. Each sprinkler covers a circular area of 2½-3 metres radius and supplies 1.8 m^3/hr. of water at a pressure of 1-1½ atmospheres; these low pressure sprinklers are more economical and better adapted to Tripolitanian soils.

Most of the electric pumps have sufficient lift to pump water from the well directly into the sprinklers, but some farmers, however, collect the water in storage tanks and then employ surface pumps to push it into sprinklers (see farm study no. 3). There is scope for further investigation of the use of artesian water directly in sprinklers (plate 4). For examples of sprinkler irrigation consult plates 17,19, and 20.

E. Methods of storing water.

There are two main methods of storing water in use on the Jefara Plain: the storage tank (Arabic - Jiabia) and the cistern. The former only stores water for a few hours, the latter for several months.

Storage tank. Today many of these can be seen on the Jefara Plain on all types of farms (plate 2 for example), but many of them are not used; they vary in size from a few m3 to 300 m3. Whenever the capacity of a pump is limited to a few cubic metres per hour, then discharge is too low for direct irrigation because most of the water would be lost in transit to the land. However, if water is pumped several hours and then stored there is sufficient available to allow a high rate of flow along the canals. Storage tanks are therefore essential for the dalu and the wind-pump, but not for an electric or diesel pump, a small diversion basin of a few m3 capacity will suffice. Also farmers using sprinkler irrigation and pumping water directly from the well into the pipes do not need any storage facilities. It would appear that only with the more primitive gravity methods of irrigation is the storage tank necessary, but this is not quite true because certain farms with large areas of irrigated land are finding it necessary to store water. Some of these farms have such an extensive area of land under irrigation that sufficient water cannot be pumped during the day to supply irrigation requirements, and in order to avoid irrigation at night, water has to be pumped during the hours of darkness and stored. Farmer no. 3 of the Farm Studies, although employing storage tanks has such a large irrigated area that he has to irrigate continually, even during the night.

Cisterns. The Romans were probably the pioneers of the cistern in Tripolitania and many constructions are still evident today and even in use. As fig. 7 shows cisterns are concentrated at the foot of the Jebel, particularly along wadis, where the first water-table is deep; the major concentration being from Yefren to Ghanima. Stone or earth walls are built on slopes where there is run-off following rains, and water is channelled into sedimentation basins and then into cisterns of a few m3 capacity. Some cisterns are located in a wadi bottom, a good example of which is shown in plate 10. This cistern has a small hole at the top which is plugged and padlocked. Cisterns keep the water cool and clean and there is little evaporation, but they have many disadvantages and they never provide the main water supply of any settlement. Water taken from them is used for domestic consumption and for watering stock, but rarely for irrigation because the quantity stored is so small. Much larger cisterns would be needed to store water for irrigation but prospects of these being built are small because of the problem of leakage. Since cisterns depend on the rainfall for their supply of water they fail to help during the critical drought periods. Numbers are not likely to be increased but many are in the process of being cleaned. They have little agricultural significance.

F. Conclusions.

Sprinkler irrigation will continue to increase in importance in the future because in the Jefara region it has many advantages over the gravity flow system:-

1) Sprinklers give a more even distribution of water (see plate 17). However, since each sprinkler irrigates a circular shaped area, overlapping is necessary if a piece of land is to be completely watered, certain areas receiving twice the amount of water. Farrows of England now claim to have overcome this problem with rainers which can irrigate in squares.

2) With sprinklers the rate of application of water can be adjusted to suit the infiltration rates of the soil, thereby avoiding puddling, leaching, erosion and disturbance of the top soil, which often result from applying water by the other methods. Dr. H. Martin argues that in order to avoid disease in groundnuts water must not stand on the land, hence his remark 'l'irragazione a pioggia e preferibile all' irrigazione per scorrimento'.[*]

3) Sprinkler irrigation can be used on the undulating Dune Jefara with ease, and no levelling is necessary.

4) With sprinkler irrigation there is no need for a network of canals and ditches. Dr. Mazzocchi[⊖], the F.A.O.

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[*] Malattie ed insetti nocivi all'arachide in Libia; F.A.O. Tripoli, 1956, p.13.

[⊖] Personal communication.

horticulturalist, maintains that the canals and jedawl at Sidi Mesri have to be rebuilt every 2-3 months. This is the case on any farm that has this system of irrigation, and the labour necessary for rebuilding is often difficult to find, for usually men are working in the Inner or Dune Jefara when they are needed. It is argued that frequent cultivation between a crop will reduce evaporation, but if the land is broken up by canals and jedawl, such cultivation is impossible

5) Soluble fertilizers can be applied to the land through sprinklers.

6) Dry soil can be irrigated and made fit for cultivation much more easily with the sprinkler method than any other (see plate 4).

7) Sprinkler irrigation saves water. A.G. Lownde estimates that 'spray irrigation is probably four times more efficient in water use than flood irrigation'.* Mazzocchi considers that with canals and jedawl, citrus need irrigating every 12-14 days with 800 m3/ha., a total of 12-14,000 m3/ha. per year; in contrast with sprinklers an irrigation of 400 m3/ha. is needed every 10 days, a total of only 9,000 m3/ha. Reference to farm study no. 30 shows how less water is given to groundnuts when sprinkler irrigation is used.

Sprinklers are ideal for farms which have 3-5 ha. of irrigated land devoted to field and vegetable crops between trees (see plates 19 and 20), and it is not surprising therefore that nearly every farm on the irrigated Italian demographic

* Symposium on 'Water in Agriculture' Australian Institute of Agricultural Science and Men of the Land Society (5 p.209).

settlements ~~have~~ has installed this method of irrigation. A considerable number of Italian and Libyan hawāza farmers have abandoned gravity irrigation, and even many of those who still retain canals express the desire to install sprinklers (see farm studies 7,8,9,10,11 and 28). All the specialised commercial farms, with the exception of a few small citrus orchards, rely on sprinkler irrigation. It has even been suggested by W.T. Harris that artificial rain irrigation could well be introduced on the sanīya farms in the Suq El Jiuma'a area; this would permit the use of animal drawn tools for planting, cultivation and harvesting of crops.[e] It may have been more satisfactory if sprinkler irrigation had been installed at the Wadi Caam settlement scheme, instead of the large American canal system.

It is argued by some experts that sprinkler irrigation requires greater capital outlay and higher payment for labour and that with this method too little water is applied to effect deep penetration, with the result that root development is limited and salt tends to accumulate within the root zone; furthermore, that soils sometimes seal over with the impact of water drops and that evaporation rates are high. The popularity of the sprinkler method in Tripolitania challenges the validity of these arguments; few farmers find fault with it and some, such as Gargour, enthusiastically praise it (see farm study no.3).

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e Terminal Report - Feb. 1955 - June 1957. Extension Adviser, U.S.O.M.

CHAPTER 9

Irrigation Costs.

A. Introduction.

Throughout this thesis the need for irrigation and the advantages that its adoption can bring, are constantly stressed, but there is little reference to the cost of irrigation, which is one of the most important factors to be considered. How much does it cost to buy a pump, or to install sprinkler irrigation ? The application of water to crops only increases production costs, and it has been shown elsewhere that water costs make up 17-20% of total production costs in the case of groundnuts and 30% in the case of barley. Because all the water has to come from underground it is necessarily expensive, and the irrigator has to bear the capital outlay for pumping and irrigation equipment, plus overhead charges such as interest and depreciation, and operation costs. Capital outlay per hectare on the Jefara Plain is probably one of the highest in the world, and it would appear that the Jefara is a marginal area for irrigated cultivation as well as dryland cultivation, with only high income crops being profitable.

B. The cost of selected irrigation equipment sold by Consorzio Agrario.

All types of equipment are sold by this co-operative. If a Libyan, who owns a saniya farm in the coastal oases zone, decides to replace his dalu, he can buy a small 1½ h.p. Italian electric pump which is capable of delivering 10 m3/hr., with lifts such as are encountered in the dalu wells. Such a pump, which can be bought for £L20 on an instalment or crop-payment basis, is suitable for irrigating about 1 ha. of land. Having installed the pump, the farmer retains the jedula method of irrigation, and the cost of lifting the water and then putting it on the land depends on the amount of electricity used, the cost of which is probably less than that necessary to feed two bullocks, which would be needed to raise a similar amount of water with the dalu. For a small outlay therefore and with no higher operating costs, the dalu can be replaced, and it is not surprising that many of the saniya farms are making the change.

The larger electric pumps of about 6 h.p. such as are found on many of the demographic farms have a capacity of 30 m3/hr. and cost about £L140. However, if sprinkler irrigation is to be installed one of these electric pumps is sometimes insufficient to both raise the water and distribute it round the pipes. To overcome this Consorzio sells an Austrian diesel pump in the range 5-10 h.p., which costs £L180 and has a capacity of 40 m3/hr. The approximate cost of the pump, plus the rest of the sprinkler equipment necessary in relation to its capacity (this includes 200-250 metres of zinc pipes at 75-95 piastres per 5 metre length depending on diameter, underground asbestos pipes at 44-67 piastres, and sprinkler nozzles and joints, which are needed every 5 metres, 35 and 50 piastres respectively) is £L500-£L600.

Small 5 k.w.h. generators, which are used in diesel electric installations, are sold at £L450.

C. Approximate cost of developing 12 ha. of land for sprinkler irrigation.

The Libyan Finance Corporation, which has loaned a large amount of money for irrigation development, has investigated irrigation costs in order to ensure that their loans are used to the best advantage. From the equipment point of view, 12 ha. is considered the optimum area to develop for sprinkler irrigation.* With such an area the capacity of the well is fully utilised and the sprinkler equipment is constantly in use.

Table 9.1 Cost of developing 12 ha. for sprinkler irrigation.

Well	£L400
Motor (sometimes two)	£L200
Generator	£L300
Pump	£L100
Underground pipes	£L250
Movable pipes	£L300
Total	£L1,550

In the table above, a diesel generator is included, but if the T.E.U. grid is available, then only an electric pump needs to be bought and costs are lower. Generally the cost of equipment works out at £L100-£L120 per hectare. It is much more economic to develop a larger area for irrigation, as reference to the capital outlay for the ENTE settlements of Oliveti and Fonduk illustrates (6). An enormous amount of money was spent on developing irrigation on these farms and the capital costs for water installations per hectare at Oliveti (see fig. 20 for lay-out) were £L222 and at Fonduk £L500 (these are pre-war costs and in present day terms would be higher). On these two settlements the ratio of irrigated land to each well was too small since

* Personal communication, 1957. Dottore Carlo Barberis, Director-General, Libyan Finance Corporation.

only an average of three hectares were intended to be irrigated on Oliveti farms and only 1 ha. on Fonduk farms. Today, now that all farms are in private ownership, the area of irrigated land is being expanded.

D. Cost of developing Government Farms.

Two irrigation techniques have been associated with the expansion of the irrigated area on the Jefara Plain: on private farms the sprinkler and on Government farms gravity irrigation with low-cost canals (see chapter 8). The development costs of certain of the Government farms are given in the Terminal Report of Lewis (3):-

Table 9.2 Cost of irrigation development on Government Farms at Garabulli and Bir el Ghnem.

Garabulli	£L	Bir el Ghnem	£L
Land levelling	720	Well and casing	1,950
Irrigated structure	657	Pump and motor	3,000
Lined canals	1,113	Pump house	250
Misc. expenses	235	Storage reservoir	1,800
		Irrigation development	2,200
Total	2,725		8,220

An artesian well drilled by the Italians, was already flowing when the Americans started their work at Garabulli, so that the expense of a drilling rig was avoided. Nevertheless the total cost of development was £L2,275, averaging out at £L136 per hectare. At Bir el Ghnem, where 25 ha. were developed, costs were far higher and amounted to £L329 per hectare.

The new Government seed multiplication farm at El Guea may prove even more expensive than Bir el Ghnem, for at the time of writing his report, Lewis stated that 7 ha. of land had been developed for gravity irrigation and 6 ha. for sprinkler irrigation, at a cost of £L13,000, i.e. £L1,000 per ha. The cost of developing the Government farms certainly seems high.

E. Comparison of irrigation costs with different methods of raising water.

It is very difficult to compare costs of raising water because of the problems of equating conditions under which the various methods operate. However, it is possible to draw a few general conclusions.

Prinzi and Negretti (5) were the first workers to try and assess the cost of raising water. Their figures bear little relationship to present day costs but they still have a relative value, because they show what are considered the cheapest way of raising water.

Method	Cost per m3 in Lira
Dalu	0.22
Wind pump	0.22
Motor Pump	0.10
Electric pump	0.14

The fuel and electric pumps have the advantage.

Ahmed (1) considers that irrigation should be based on the use of electricity, and in order to back up this argument he made a detailed study of the costs of raising water, so as to show that electricity is the cheapest form of power. The results of his work can be summarised thus:-

Table 9.3 Cost of raising irrigation water (Ahmed)

Dalu	7.5	M.A.L.	Electric pump	1.0	M.A.L.
Wind pump	1.4	"	Electric pump (localised grid)	0.85	"
Diesel-Electric	1.3	"			
Diesel	1.1	"	Artesian	0.33	"

Artesian water is obviously the cheapest, although electric pumps, driven by power from a local generating plant, are capable of raising water at a low cost. Comparing the capital costs per well for each of the different methods, the localised grid is the most expensive at 695,000 M.A.L., then diesel-electric at 670,000 M.A.L., then the direct diesel at 600,000, and the electric pump driven from the T.E.U. grid at 370,000. The cost of wind-pump installation, which one would expect to be low, amounts to 370,000 M.A.L., nearly as much as the electric pump. Ahmed does not give any figures for the artesian well or the dalu; the former will be fairly high but the latter will be low.

Bologna's estimates are the most recent available (2). He bases his calculations on a theoretical area of groundnuts, which he assumes are given 22 waterings, each of 800 m3/ha., making a total amount of 17,600 m3/ha. and a daily rate of about 133 m3/ha. His costs for the dalu are 41.7 milliemes per cubic metre, and for the diesel-electric pump 8.1-8.5 milliemes per cubic metre. If the Government establishes a series of small farms associated with a settlement scheme, he maintains that the construction of a small generating plant will allow water to be raised by small electric pumps at a cost of 5.55 milliemes per cubic metre.

In his general report prepared for the F.A.O. (4), Molenaar compares the dalu with an electric pump and finds that if 1,000 m3 are raised the cost of raising water by dalu is $0.00173 per m3. and by centrifugal pump $0.0028 per m3.; however, if the electric pump raises 5,000 m3 then one cubic metre costs only $0.000148.

All the costs quoted from the above sources include capital costs. Details concerning the cost of water is given in some of the farm studies, but normally these are only operating costs, since the farmer tends to disregard or forget money that is used on capital expenditure. On most of the concession farms, which have 6-8 h.p. electric pumps, the cost of water seems to be about 2 milliemes per cubic metre; costs on other farms appear to fluctuate between 2.5 and 5 milliemes per cubic metre. Many farmers do not differentiate between the cost of water at the well head and the cost of water on the land; farmer 29, however, is an exception, and his water costs 2.8 milliemes at the well head and 5 milliemes in the sprinkler. It is interesting to note that on the two farms 38 and 40 which have wind-pumps, water is reported to cost 5 milliemes per cubic metre.

Both farms 1 and 3 have their own generating plants, although they could take their power from the T.E.U. grid. The managers argue that with their own generating plant they are independent and at the same time their power is a little cheaper, if anything, than that supplied by the Undertaking. Confining our attention to farm no. 1, it is seen that ten wells are in operation at present with the possibility of three more being built in the near future. The power plant, which was installed at a cost of £L23,000, consists of two 275 h.p. diesel generators. Electricity is distributed round the farm by a high tension grid of 3,000 volts, and then reduced to 380 volts at each well by a transformer; each well has a 35 h.p. submersible pump which is used to raise

60 m3/hr. Twenty hours running of the generating plant takes 1,000 litres of oil at a cost of £L20, and during its operation it needs attention, for which the labour costs £L2. The electricity produced is sufficient for 6 wells, and during the 20 hours they raise 7,200 m3.; four men are needed to attend to the sprinklers at each well and they have to be paid at least £L5. Total operational costs are therefore £L27 for 7,200 m3 and the cost per cubic metre of water on the land is 3.7 milliemes.

It would appear reasonable to assume that in running costs it takes 3-5 milliemes to raise one cubic metre of water and apply it to the crop. 100 m3 therefore cost from 30-35 piastres, and for a crop like citrus, which needs something like 10,000 m3/ha. water costs are £L30-£L50 per ha.

F. Conclusions.

From the point of view of cost the dalu and the wind pump are the least attractive means of raising water, and electric pumps seem to be the cheapest particularly if they are located on a farm which has many wells and its own generating plant. Of the methods of distributing water on the land the sprinkler is the most economical. For an area of 12 ha. the movable surface pipes and the underground distribution pipes of the sprinkler system cost about £L550, but the land levelling and lined canals of 12 ha. of a Government Farm cost £L1,080, about 90% more (cost calculated from 20 ha. at the Government farm at Garabulli i.e. $\frac{1,800 \times 12}{20.}$).

The capital outlay for the canal system of irrigation which is practised on many farms, is probably low because the pre-cast canals which are utilised are faily cheap and also because many earth ditches are used. Operational and maintenance costs, however, are high and the loss of water is great, so in the long run this method is probably more expensive than sprinklers.

Although capital outlay per ha. is high and is usually more than £L100 this is not really important; what is important is the relationship between the water costs incurred with the growing of the crop and the price that is likely to be received for that crop. High income crops should be grown and should be given heavy applications of fertilizers and manure to ensure that yields are good.

Once irrigation equipment has been installed it should be given maximum use so as to derive maximum returns on the capital invested. Semi-irrigation requires only one third of the water needed for full irrigation, but at half, not a third of the cost; capital costs of semi-irrigation are about 60% of those for full irrigation. The less frequently irrigation equipment is used, the more expensive it becomes. Once a farmer turns to irrigated cultivation he is encouraged to grow crops all the year round and water as many as possible in order to obtain high yields.

Plate 1

Traditional Libyan Well

This type of well is found in the 'saniya' (small garden) farms in the coastal oases. The 'dalu', a peculiarly shaped, self-emptying skin bucket is attached to the rope seen dangling in the well, filled with water and then hauled to the surface by a cow which is harnessed to the rope lying on the ground. This method of raising water can only be used where the water-table is not more than a few metres below the surface and even then discharges are rarely more than 3 m3/hr.

Plate 2

Rehabilitated Well and Storage Tank

Some wells, which at one time were allowed to fall into a state of disrepair, are now being brought back into use as irrigated farming becomes more popular. A small electrically driven centrifugal pump has been installed at the base of the 'Avampozzo' and the shallow storage tank of about 50 m3 capacity has been restored: sufficient water is raised to irrigate 2-3 hectares. In the foreground is a badly damaged cement irrigation canal.

Plate 3

An Artesian Well on the El Guea Forage Farm

There is much good quality class 3 artesian water beneath the Eastern Jefara and at the El Guea Government Forage Farm this water is being used to irrigate lucerne with good results. The Libyan in the photograph is demonstrating how the water flows from the well to supply three gravity irrigation canals. The tamarix hedge along the track shelters the farm from the hot sandy winds.

Plate 4

Sprinkler Irrigation at El Guea

One of the artesian wells on the El Guea Farm is used for sprinkler irrigation. The water is under sufficient pressure to be used directly in low pressure sprinklers and pumps are therefore eliminated. Although construction costs are high, operation costs are low. In this photograph fallow land is being irrigated prior to ploughing.

Plate 5

A Subsiding Wadi Megenin at Gasr Ben Gashir

Despite valiant efforts during the last few years to divert the Wadi Megenin into basins in the Inner Jefara, it has repeatedly flowed to the sea and much valuable water has been lost. From this photograph it is not difficult to visualise the wadi when it is in full spate.

Plate 6

Flooded Olive Groves near Tripoli

In a country as arid as Libya, one would not expect to see land under water, but nearly every year scenes like this are evident during the winter season. Provided the water does not do any damage and does not remain on the land for a long time, it has two beneficial effects; firstly it deposits very find clay-like alluvium which helps to make the sandy soil heavier; secondly some water infiltrates underground to recharge the phreatic aquifer.

Plate 7

Wadi Floods and Communications

Few bridges exist on the Jefara Plain and roads and tracks are soon cut when a wadi is in full spate. This track across the Megenin, a few kilometres south of Tripoli, was impassable when the flow of water was at its peak. Every time a wadi flows, roads are damaged and in this photograph parts of the foundations are on the point of being washed away. The water is very turbid and carries much material which is either deposited on the land or washed out to sea. After the Wadi Megenin has subsided bulldozers are called out to clear the roads of silt and the sea just west of Tripoli is a reddy brown colour over many square kilometres.

Plate 8

The Power of the Wadi in Spate

The flow of water in the Eastern Jefaran wadis is often considerable and as a result does untold damage to land, property and limb. After heavy rains have fallen in the Jebel, 'flash floods' tear across the plain washing everything before them. In the winter of 1957/8 the car shown in the photograph, was picked up by one such sudden flood and was eventually left propped against a tree. The floods are of short duration but very intense.

Plate 9

Rock Dike at Beni Ulid

In Wadi Beni Ulid a rock dike, financed and designed largely by the Americans, has been built to check the seasonal flow of water in the winter. This construction, by checking the velocity of flow and thereby encouraging infiltration, conserves water that would otherwise be lost. There is an urgent need for rock dikes of this type in the eastern Jefara and Jebel, where precious water is allowed to flow to the sea.

Plate 10

Libyan Cistern

This cistern, sited in a wadi bed, is typical of those found in the inner zone of the Eastern Jefara where the phreatic water-table is inaccessible. The top is about 5' across and is plugged with an old piece of palm trunk, which incidentally is padlocked. When watering stock the plug is taken out, and water, which is raised in a skin bucket, is poured into the hole to the right of the plug, eventually finishing in the trough at the base of the cistern.

Plate 11

"Jedula" - Irrigation Squares in the Coastal Oasis Zone

The coastal oasis zone stretching from Ajelat to Tajiura is characterised by a profusion of date palms and fruit trees, with interplantings of herbaceous crops such as potatoes, groundnuts, maize, millet, water melons, pepper, tobacco and lucerne. As shown in the photograph, the land is sub-divided into squares which are supplied with irrigation water from the well in the palm trees. The water is distributed by earth channels and losses through seepage are considerable.

Plate 12

American System of Gravity Irrigation at the Garabulli Sheep Ranch

It has been discovered that "caliche" (calcified sand) can be used to make low-cost cement canals and that by spraying these with bitumen, seepage can be avoided. This system of irrigation has therefore been adopted on the new government farms. There seem to be three main disadvantages: flowing water has to be transferred from the canal to the crop; evaporation is encouraged; and finally the canals soon disintegrate and therefore need constant attention.

Plate 13

Furrow Irrigation on a Small Inland Libyan Farm

Although the Libyan usually divides his land into 'Jedawl' for irrigation, he sometimes uses a series of short furrows, particularly for vegetables and small grains. In this photograph the main channel lies on the right with subsidiary channels at right-angles. The very sandy soil is easily moved with a hoe and channels can soon be blocked or opened. The efficiency of water distribution by this method is very low.

Plate 14

Jedula Irrigation Pattern in an Italian Citrus Orchard

Citrus trees need irrigation in all but a few of the winter months, and the flooding method with squares, brought over from Sicily and southern Italy, has been retained on many farms despite the competition of sprinklers. The use of squares, ridges and furrows in the very sandy soil is only possible where there is a continuous drought over a long period of the year; heavy rain soon destroys them.

Plate 15

Using Syphons to Irrigate Lucerne

All the new government farms on the Jefara Plain - El Guea, Garabulli and Bir El Ghnem- have a network of irrigation canals of American design. One of the difficulties of this method of irrigation is the transfer of water from canal to furrow; this is overcome by the use of syphons. The water is dammed in the canal by a canvas obstruction which can be seen in the extreme foreground; the baskets lying aroung are used at the furrow end of the syphon to prevent soil wash. In this photograph too much water has been allowed into the canal and flooding has resulted. Labourers need constant supervision with this method of irrigation.

Plate 16

Raised Libyan Irrigation Canals

This photograph was taken on an inland Libyan farm near the Wadi Megenin, south-east of Gasr Ben Gashir. This farm was established before the last war and the trees are bigger than those in plate 29 (young maize plants). Beyond the canals and amid the fruit trees is a winter crop of broad beans. The canals, which have been placed on earth banks to permit the gravity flow of water over the whole farm, are made of cement; they are in a poor state of repair and much water is lost through seepage.

Plate 17

Distribution of water by Sprinkler

The development of irrigated farming over the last decade and a half has been largely the result of private enterprise and has been made possible only by the widespread introduction of sprinkler irrigation. This close-up photograph of a sprinkler has been deliberately taken at a slow shutter speed to accentuate the falling drops of water. The sprinkler gives a more even distribution of water than any other method of irrigation.

Plate 18

Sinking of a New Well

Many new wells are either under construction or planned, particularly in the Gasr Ben Gashir area. This team of Libyan workers has already dug the 'avampozzo' and at the moment is engaged in drilling the 'trivellazione'. A pump will be placed at the bottom of the 'Avampozzo', water will be raised from the first aquifer, and peanuts and winter cereals will soon be growing between the olives in the background.

Plate 19

Sprinkler Irrigation of Barley

Ever since the early days of colonisation the Italians, practising dry-land cultivation, have grown winter cereals between olive trees. Barley, needing the least moisture of all the winter crops, is here being irrigated on an Italian concession farm just south of Gasr Ben Gashir. The spray is often blown by the wind and in this picture the olive tree in the foreground is deriving some benefit from the irrigation.

Plate 20

Sprinkler Irrigation of Potatoes

The potato has become an important winter crop during the last few years and on some farms is now grown for export. Having higher water requirements than cereals, it is rarely grown without irrigation. Sprinklers are here in operation on a Libyan farm, formerly an Italian concession, south of Gasr Ben Gashir. This method of irrigation is easily adapted to inter-cropping of the type shown in this and the above photographs.