RECLAMATION OF SALT AFFECTED SOILS IN IRAQ

SOIL HYDROLOGICAL AND AGRICULTURAL STUDIES

RECLAMATION OF SALT AFFECTED SOILS IN IRAQ

SOIL HYDROLOGICAL AND AGRICULTURAL STUDIES

RECLAMATION OF SALT AFFECTED SOILS IN IRAQ

SOIL HYDROLOGICAL AND AGRICULTURAL STUDIES

P. J. DIELEMAN
editor

J. H. BOUMANS
W. C. HULSBOS
H. L. J. LINDENBERGH
P. M. VAN DER SLUIS
contributing authors

INTERNATIONAL INSTITUTE FOR LAND RECLAMATION AND IMPROVEMENT/ILRI
P.O. BOX 45 WAGENINGEN THE NETHERLANDS 1977

First published 1963
Third edition 1977

Contributing authors:

J. H. BOUMANS — Chief Soil Hydrologist,
Research Section, Land Improvement and Reclamation Company (Grontmij N.V.), de Bilt (Netherlands).
1953–1959: Chief Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board, Baghdad.

W. C. HULSBOS — Drainage and Irrigation Engineer,
International Land Development Consultants (Koninklijke Nederlandsche Heide Maatschappij), Arnhem (Neth.).
1957–1959: Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board Baghdad.

H. L. J. LINDENBERGH — Agricultural Economist,
Project Planning and Evaluation,
Government Service for Land and Water Use, Utrecht (Neth.).
1957–1959: Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board, Baghdad.

P. M. VAN DER SLUIS — Deputy Director,
International Land Development Consultants (Koninklijke Nederlandsche Heide Maatschappij), Arnhem (Neth.).
1955–1959: Chief Engineer Drainage, First Technical Section,
Development Board, Baghdad.

Editor:

P. J. DIELEMAN — Land and Water Use Specialist,
International Institute for Land Reclamation and Improvement.
1957–1958: Ass. Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board, Baghdad.

TABLE OF CONTENTS

Digging a drainage canal

PREFACE

This work is the fruit of the combined efforts of four authors, who during the period 1953–1959 were employed as foreign experts in the First Technical Section (subsequently in the Fourth Technical Section) of the Ministry of Development and Development Board of Iraq. One of their assignments was to report on the prospects and method of reclamation of salt affected areas.
A number of experimental fields were laid out with a view to understanding fully the behaviour of soil, salt and crop under given conditions of irrigation and drainage. The experience gained from these fields was regularly compiled in mimeographed reports which were distributed on a limited scale only. The significance of this research, however, warranted much wider publicity. One of the tasks of the International Institute for Land Reclamation and Improvement at Wageningen being to disseminate the knowledge and experience gained, this body therefore promoted the issue of the subject-matter discussed in the progress reports. The Institute is greatly indebted to the authors, who expressed their willingness to process and rearrange the contents of the progress reports so that they should become attuned to readers outside Iraq.

Rewriting the reports does not mean that the results obtained are applicable without further consideration to areas outside Iraq. As long as by reason of the complex nature of the problems and the lack of a quantitative understanding of a few critical factors, a mathematical description of the salt and water movement is beset with difficulties, opportunities of re-using results are limited.
The main object of rewriting the reports is to give the reader a clear picture of the interrelationship of salinity, irrigation, drainage and crops under the conditions prevailing in the Mesopotamian Plain of Central Iraq. By stating in full (as far as possible) the conditions and data of influence on the salt and water balance, an attempt has been made to facilitate the drawing of a parallel with the reader's own problems.

The first two chapters deal with the background of the experiments and conditions under which they took place. The experimental results are then discussed in chapters three to six. In chapters seven and eight the data obtained from the experiments provide the basis for a fundamental approach to the problem and systematic calculations of the water and salt balance.

Although the authors have not attempted to look on agricultural development (being part of more extensive development schemes) as a subject of discussion, they have found it difficult to disregard altogether certain important aspects of economic justification, organization and synchronization of reclamation projects. A few remarks have therefore been made on this subject in the final chapter.

It follows from the foregoing that not all aspects of the reclamation of salt-affected areas of Iraq have been dealt with in this paper; problems forming particularly the subject of experimental research have been treated only. This means that special attention has not been paid to the manner of setting out – chronologically – the various phases of the investigations with a view to arriving at a project design.

The plan of the present work leads easily to a certain overlapping of the subject-matter. An attempt has been made to reduce the overlapping without detracting from the readibility. Likewise, it proved to be very difficult to standardize all the technical expressions used. Misunderstanding could probably be avoided, however, by clearly restating the authors' intentions where necessary.

The publication of this book will place the compiled results of the research work carried out by authors and Iraqi engineers at the disposal of the Government of Iraq, its specialists and engineers and further of all those engaged in the reclamation of salt-affected soils. We are greatly indebted to the Iraqi Government for consenting to have it published in this form.

THE EDITOR

ACKNOWLEDGMENTS

The authors owe a debt of gratitude both to the Iraq Government and to Mr. K. F. Vernon, Head of the First Technical Section of the Development Board of the Government of Iraq, for his support and guidance during the initial stage of the experiments, to Messrs. Mahmud Hassan, Dr. Dhia Ahmed, Dr. Louya Tahsin Qadri for their support and interest during the subsequent stages of the experiments, to the Directorate General of Irrigation and its divisions at Kut al Hay and Hillah for their helpful co-operation, to the Irrigation and Drainage Laboratory at Tel Mohammed Baghdad for the analyses of the numerous soil and water samples, and finally to Mr. Nuri Majid, irrigation engineer, Mr. Abdullah A'rar, soil hydrologist, Messrs. Bakir Hassan, Abdul Razak Al-Sabty, Ayada Al-Hadithy, Ibrahim Al Samarai, Abdul Sattar Al Haj Abdullal, Hassan Moghrabi, Mohammed Qaddourah, Izzat Qaddourah, Karim Husseini and Mohammed Hassan Ibrahim, technical investigations supervisors, for their valuable co-operation in assembling and processing the experimental data.

1. GENERAL INTRODUCTION

1.1. SOME GENERAL FEATURES OF IRAQ

For background information and a better understanding of the following chapters a brief description of some general features of Iraq is given below.

— *Geographical situation*

Although the territory of Iraq extends between the parallels of 29° and 37° N., and between 39° and 48° E., the Mesopotamian plain in which the salinity problems are concentrated only extends between 30° and 34° N., and between 43° and 48° E. (Fig. 7).

— *Acreages*

Iraq includes an area of about 180 million mesharas (= 45 million hectares = 450.000 sq.km. = 175.000 sq.m.).
According to the Iraq Agricultural Magazine of January-February-March 1955, the area with rain-fed agriculture in the northern part of Iraq is approximately 16 million mesharas[1]) and the irrigable area approx. 32 million mesharas, together representing only 27 % of Iraqi territory. About 11 million mesharas are irrigated annually, but the same area lies fallow so that there is a potential expansion of irrigated agriculture of some 10 million mesharas.

— *Climate*

The Mesopotamian plain has a distinctly arid climate, as illustrated by the following graphs (Fig. 1, 2, 3).
The most characteristic feature of the climate is the long dry summer, from May to October, with very high temperatures. There is some rain in winter but normal agriculture requires an artificial water supply throughout the year. A detailed description of the climate of Iraq is given by WARTENA (1959).

[1]) meshara: local area unit, 2500 m^2.

— *Soils*

The soils in the Mesopotamian plain are all fluviatile; irrigation deposits and the sedimentation have been largely determined by the subsequent irrigation systems. Levee and basin soils are found as well as transitional soils. For a detailed description of the soil reference may be made to BURINGH (1960).

Fig. 1. Temperatures at Baghdad Airport
----- mean maximum daily temperature
—— mean daily temperature
--- mean minimum daily temperature

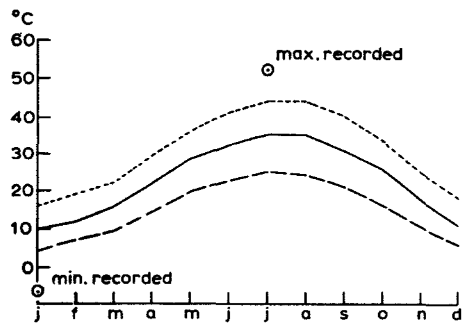


Fig. 2. Average depth of monthly rainfall at Baghdad Airport

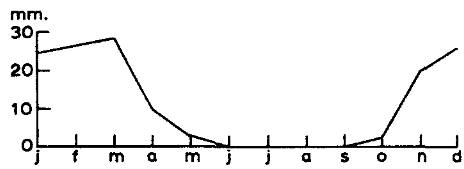
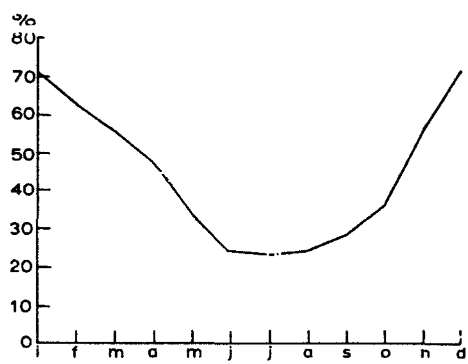


Fig. 3. Monthly average relative air humidity at Baghdad Airport



A striking feature is the very high content of calcium carbonate: 25 % to 30 % of lime is quite common and less than 20 % is rare. As may be expected under the prevailing climatic conditions, the organic matter content is low to very low. The chemical composition of the soils as a whole is determined by the salinization, described in chapters 3–5.

— *Irrigation water*

The only source of irrigation water for the Mesopotamian plain are the Euphrates and Tigris rivers with their tributaries. Both the Euphrates and Tigris rise in Turkey and are partly fed by melting snow.
The rivers are best characterized by the following graphs (Fig. 4, 5, 6).

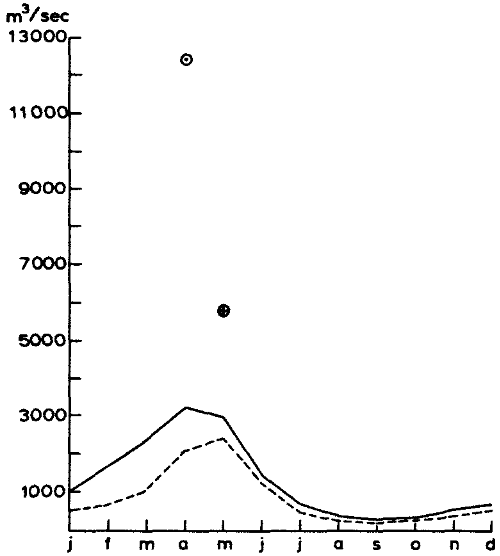


Fig. 4. Average monthly discharges for
—— Tigris river at Samarra
----- Euphrates river at Hit
⊙ max. flood recorded for Tigris at Samarra
⊕ max. flood recorded for Euphrates at Hit

These graphs clearly show that both rivers have a distinct flood period. For many years the Iraq government has been trying to harness the two rivers by building dams and barrages, and by 1959 substantial progress had already been achieved in this field, thus – as a collateral benefit – making more water available for the irrigation of summer crops.

— *Irrigation system*

The irrigation system in Iraq is primarily based on gravity supply, although in some of the higher lands, mostly levee soils, pump irrigation has developed fairly rapidly in recent years.

All main barrages and diversion dams, as well as main feeders, main and secondary canals with all auxiliary structures, are government-built, controlled, operated and maintained.
This means that the government also controls the irrigation duties. For the purpose of illustration it can be said that under the present agricultural system the winter irrigation

duty at the head regulator is approx. 1 m³/sec. per 12,000 mesharas of gross area actually cultivated (or about 3 mm/day for the gross cultivated area).
The water distribution in the fields is entirely left to the farmers and/or landowners.

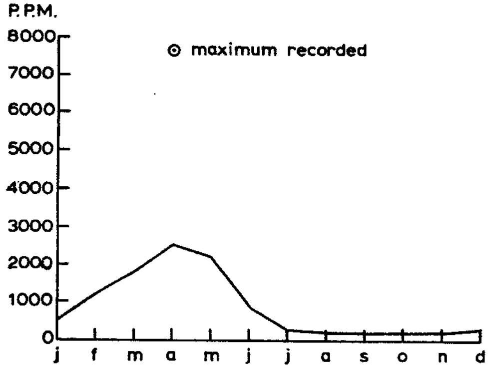


Fig. 5. Average silt content of Tigris river at Baghdad

Fig. 6. Average total dissolved salts of Tigris river at Baghdad

— *Crops*

The main winter crop in the delta area is barley, wheat only being cultivated on the non-saline or slightly saline soils.
Date palms are grown on the non-saline, higher river and canal levee soils. The cultivation of summer crops is restricted. Crops growing in summer include cotton, sesame, peas, lentils, beans and other vegetables. In the lower areas with a better spring and/or summer water supply there is a considerable amount of rice-growing.
The low to very low crop yields are mainly due to the high salt content of the soils. For instance, barley yields from 100–300 kg per meshara, an average of 120–150 kg per meshara being quite common.

1.2. SALINITY IN ANCIENT TIMES

It is a well-known fact that the civilisations that previously flourished in the territory of present-day Iraq are among the oldest and most renowned in the world. Agriculture was always one of the foundation pillars of these civilisations and many ancient historians claim to have seen the magnificent crops with their own eyes. As the present salinity situation in Iraq is fairly bad (see 1.3), this has led to speculation as to whether salinity was known in ancient times. Under the auspices of the Iraq Government the Directorate General of Antiquities, Baghdad, together with the Orienta Institute of the University of Chicago, carried out a number of investigations in this connection. An examination of tax records, which gave information on crop yields and the ratio of wheat/barley acreages, led to the following conclusions: –

1. There was no major occurrence of salinity in ancient times and crop yields stood at a high level; for instance, in 2400 B.C. cereals yielded up to 2500 litres per hectare (= approx. 500 kg/meshara).
2. No traces or records were found of artificial drainage, so that it must be concluded that there were no artificial drainage facilities.
3. The first salinity records encountered about 2400 B.C. relate to the present area of Gharraf in East Iraq (Fig. 7). This salinity may well have been caused by intensive irrigation and a rising water table.
4. The area did not recover from this onset of salinity and this phenomena may well have contributed to the decay of the Sumerian Empire, coinciding with this onset.
5. There was a salinity onset in Northern Babylonia around 100 B.C. but it was much less severe and the area recovered. The recovery was very probably due to a deeper water table.
6. Although there may be some fossile marine salt deposits, the genesis of soil salinity in Iraq as a whole must be attributed to the salt content of the irrigation water, however slight this may be. Owing to the high evaporation, caused by the arid climate, this salt accumulates in the soil over the years and the situation becomes more severe with a high water table, when capillary action may cause the evaporation to continue even after the actual irrigation has ceased.

Summarizing, it can be said that salinity was not a severe problem in ancient times, so that the present salinity in Iraq is most probably due to the accumulation of salt from irrigation water over the years.

1.3. SALINITY AT THE PRESENT DAY

There is practically no salinity in the rain-fed area of Northern Iraq, but it is very pronounced in the irrigated area of Central and Southern Iraq. The degree of salinization varies, some areas being only slightly saline, others being highly to extremely saline. This variation may be due to various causes, as differences in irrigation practices, differences in soils and occurrence of natural drainage. In this connection it should be noted that until very recently no artificial drainage facilities existed.

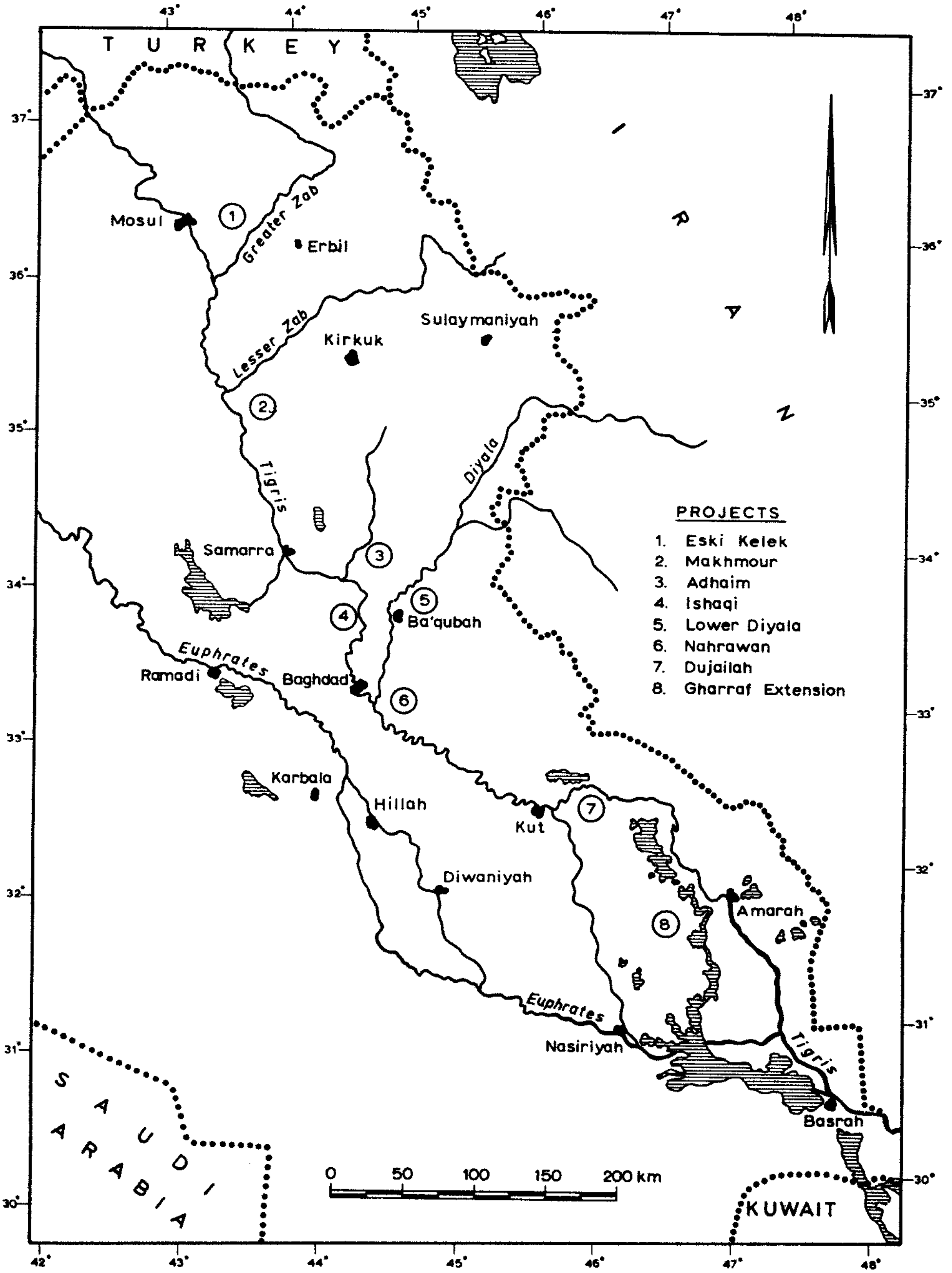


Fig. 7. Map of part of Iraq with some projects

As illustrated below, the amount of salt brought to the fields by normal irrigation practices may be enormous.

A moderate irrigation depth of 300 mm with an average salt content of 400 ppm brings on to the field 300 kg of pure salt per meshara, and if there is no natural or artificial drainage this salt remains in the soil and increases over the years to enormous quantities. It has been estimated that the total quantity of salts present in the upper 5 m of the soil of the area suitable for crop production in the Central and Southern parts of Iraq (amounts to 1 milliard (10^9) metric tons over an area of 150,000 sq.kms (DUJAILAH EXPERIMENTS 6, 1959).

The salinity data for a few project areas are summarized in table 1. The data were taken from surveys carried out by the Government Agencies and Consulting Engineering Firms. The salinity is given as the average electrical conductivity of the saturation extract (EC_e) of the upper 50 to 100 cm of the soil. The location of projects is shown in Fig. 7.

TABLE 1. Some data on the salinity of Iraq soils

Project	Km²	Latitude[1])	Percentage of project area[2]) with		Meteorological data[3])		
			$EC_e > 8$	$EC_e > 16$	rain mm	temp.°C	station
Eski Kelek	130	36.05	0.4	0.2	382	19.4	Mosul
Makhmour North			1	0			
Makhmour South	2500	35.25	7	1	380	22.0	Kirkuk
Lower Diyalah	4300	33.45	37	17			
Adhaim left	1350	34.15	54	19			
Adhaim right	605	34.15	64	25			
Ishaqi	975	33.50	49	23	140	22.6	Baghdad
Nahrawan	430	33.15	81	62			
Dujailah	1000	32.25	86	–	132	24.1	Hai
Gharraf extension	1660	31.50	85	61	120	23.8	Nasiryah

1) Approximate latitude of centre of project.
2) EC_e values for the upper 0.5–1.0 m of the soil profile.
3) Rainfall and temperature, yearly averages. Mosul 1923–'52; Kirkuk 1938–'52; Baghdad 1937–'52; Hai 1940–'52; Nasiryah 1940–'52; (CLIMATIC MEANS, 1954).

The table shows that there is no salinity problem in the Northern districts of Iraq. These have little irrigation and the rainfall, although erratic, is sufficient to cause some leaching during winter. The salinity of the soils increases towards the south where irrigated agriculture becomes more prominent owing to the decreasing rainfall. The salt problem is most serious below Baghdad (latitude 33°20′), where the valleys of the Euphrates and Tigris widen to form a single vast, broad plain. These valley soils have been irrigated since early Babylonian times. Owing to the very slight slope of the river plains and the very low rainfall, natural drainage or leaching was of no importance. As a result, the salts from the irrigation water of some millennia have accumulated in the topsoil.

1.4. RECLAMATION WORK BEFORE 1950

During the period from 1927 to 1929 the first reclamation experiments were carried out by STRACHAN in the Saklawiyah area. These succeeded in temporarily removing the salts from the root zone of the soil and good rice crops were grown as well as barley and wheat crops during the subsequent shitwi season. But as a reclamation project the experiment was doomed even before it began owing to the wrong choice of site and lay-out. The failure to study the water table was critical (HAWKINS, 1945).
STRACHAN's main conclusion was that it proved possible to remove the salts from a highly saline soil, and to grow crops on the leached soils. Moreover, he indicated that the salts should not be leached in summer, but preferably in winter. The value of this conclusion is not diminished by the fact that the washed plots rapidly became saline again owing to the extensive seepage from a recently excavated irrigation supply canal and a high water table. It merely proved that the experiment did not succeed in keeping the salt out of the soil once it had been leached. But no quantitative conclusion on the rate of salt removal or water use for salt removal could be drawn from his experiments.
It was not until 1944 that a second attempt was made by TURCAN and HAWKINS to reclaim saline soils.

In this year ATKINSON, Director-General of Irrigation, wrote:

'It was perfectly clear that as there is more fertile land available in Iraq than there is water to irrigate, consideration for the future demanded that the fertility and production of the irrigated areas must be improved, and must be maintained at a high level if the country is to survive and to provide for an increasing population and that land drainage and the most economical possible use of water were matters of vital concern.'

It seems that before this could be written it was necessary to overcome a considerable amount of misunderstanding on land drainage and its need and possibilities. Moreover, the special wartime conditions prevented reclamation problems from being studied as thoroughly as they deserved.
The reclamation was approached experimentally and resulted in a report on 'A project for drainage and reclaiming land adjoining the Aqqar Quf', the first comprehensive report of this kind produced in Iraq (TURCAN, 1945). The site selected for the experiments was also in the Saklawiyah area, on saline soils with a shallow water table.
The gross area comprised 64 mesharas of land and was bordered by two collector drains excavated to a minimum depth of 1.25 m with a distance apart of 400 m.
For the leaching trials plots were formed by digging 90 cm deep field drains at distances apart of 50 m and 100 m. The basins were kept continuously inundated with an average depth of 10–15 cm of water. Washing was begun on 5-2-1945 and water supplied almost continuously until 29-4-1945 at the rate of 1 m^3/sec. for 1200 mesharas. A total water depth of 2 m over the gross area was supplied. The results of this experiment, as given by TURCAN, can be summarized as follows:

1. Over the whole area with mixed drain spacing, the subsoil run-off factor, i.e. the percentage of irrigation water removed by field drains, was 34.4. The inner drains were 3.5 times as effective as the outer drains. In the central portion of the plots the run-off was about 54 %.
2. An average of 1.1 per cent (dry weight basis) of chlorides was removed from the top 3 feet of soil. From a depth of 3 to 6 feet the percentage removed was calculated to be 0.4. On the 14 mesharas washed this amounts to 606 tons of chloride, which is equivalent to 1000 tons of NaCl, removed from the soil to a depth of 6 feet.

3. The amount of chloride ion removed by the field drains was calculated to be 140 tons, which was considered low compared to the 606 tons removed from the surface layers.
4. In the first samples taken after washing the average chloride ion content of the soil was approximately 0.10 % at a depth of 6" and approximately 0.20 % at a depth of from 2'6" to 3". However, on 5-7-1945 four more samples were taken at different sites. Two samples at 20° cm contained an average of 0.011 % of chloride and two at 60 cm depth 0.078 % and 0.004 %. Probably the first sampling struck some of the more saline portions of the soil. Two further samples taken at different sites on 1-8-1945 at the root zone gave 0.01 % and 0.007 % of chloride ion.

The work of TURCAN and HAWKINS should be considered very valuable. It showed a proper understanding of the salt problem and under difficult conditions and among people who generally regarded their efforts with scepticism, they succeeded in completing their experiment and concluded that the salt land of Iraq could be converted to good soil capable of producing excellent crops where previously it had only been possible to obtain marginal yields or none at all. It is unfortunate that this work was not continued as additional valuable information could have been assembled which was badly needed at the time in other parts of the country where irrigation schemes were under way (Dujailah). As regards the details of their work and some of their conclusions the following observations can be made (these are partly based on the knowledge obtained from our later work): –

1. The results of the soil sampling show that no reliable average value was obtained, but the data given indicate that the leaching was successful. A salt content of 0.011 % of chloride ion, based on dry weight of soil, at a depth of 20 cm, is extremely low and unlikely to occur.
2. Approximately 30 kgs of salts per square m were removed to a soil depth of 6 feet by an irrigation application of 200 cm and with an average depth of drainage water of 69 cm (34.4 %). This is in fairly good agreement with our later experiments.
3. It was to be expected that only 140 tons of the 606 tons chloride ion leached downwards from the upper 6' of soil would be removed by the drains. The amount of salt removed is proportionate to the depth of drainage water and its salt content and is not directly related to the amounts of salt washed down in the upper part of the soil profile.
4. The conclusion that the inner drains were 3.5 times as effective as the outer drains is inaccurate. The discharge of the inside drains was probably 3.5 times that of the outside drains; this must be due to boundary effects, as the percolation water of the outside plots mostly passed below the drains and, as stated in the report, it probably moved through the deep subsoil to the broad Khor[1]) south and west of the plots. It would therefore have been better to make a separate evaluation of the results of the central part of the area.
5. One may question the statement in the report that the permeability of all soils improved as washing proceeded as no results of permeability measurements are given. This conclusion is probably based on the observation that the drain discharge increased as the washing proceeded. This was also reported by T.A.M.S. (1957). In later experiments, however, no such an increase could be demonstrated.
6. The recommendation that washing should be continuous to be more effective and that the plots should never be dry throughout the leaching period does not agree with later experiments (DUJAILAH EXP. 4, 1957) But it is possible that the difference in soil texture, especially in relation to the sensitivity for shrinkage upon drying, is responsible for the different results; the Dujailah soil did not shrink appreciably and few cracks appeared during drying.

The leaching trial was followed by a summer cultivation on 50 % of the area. As soon as the soil was dry enough it was ploughed and sown with mash and lubia. Legumes were selected to add nitrogen to the soil and also for green manure since the crop could be ploughed in at the end of the summer season. The crops were grown without applying any further irrigation water. There were two reasons for adopting this programme (TURCAN, 1945), viz.: –

[1]) swampy area.

1. To study the resalinization of a recently washed plot with saline subsoil water some two metres below ground level, and surrounded by salty land under the influence of evaporation.
2. To see whether the soil contained sufficient capillary moisture in the root zone to support a leguminous crop such as mash and lubia through the summer. Since summer water is scarce, it was important to know whether a green manure could grow during the summer season following leaching with little or no supplemental irrigation.

The ideas developed here are very interesting. There are three considerations, viz.: the danger of resalinization after leaching, the need of restoring the leached plant nutrients, especially nitrogen, and in connection with this, the desirability of growing a leguminous crop after leaching. Most of the seedlings had died or were in a stunted condition by the beginning of July. The wilting of the plants was found to be due to lack of moisture. The chloride ion figures were still low. TURCAN remarks that the top foot of soil rapidly lost its moisture under the influence of the hot summer winds, and he thinks that if the seedling can succeed in pushing its roots down below this dangerous zone there may be sufficient residual moisture to maintain growth throughout the growing period in this type of soil. The solution would be either to plant a little earlier in the season or to apply light irrigation, two or three weeks after sowing, to enable the seedlings to extend their roots deep enough into the subsoil before the arrival of the hot winds. It is to be doubted, however, whether summer growth would be possible without a regular water supply, even if the crop was sown early.

There was hardly any resalinization during the summer cropping period, when the water table was more than 2 m below the surface. No soil samples were taken, but barley and wheat (winter crops) were sown after giving only 3 days of water to clear local concentrations of salt. This observation, as well as the rapid drying of the soil during summer, was confirmed by later experiments.

Although TURCAN did not succeed either in establishing the relationship between salinity and the amount of leaching water required to obtain a given salinity level, or in determining such drainage criteria as the run-off and drainspacing and -depth required, the results obtained are interesting. They were discussed in detail because the line of thought is in complete agreement with ideas on reclamation as developed in Dujailah.

1.5. RECLAMATION EXPERIMENTS SINCE 1950

After the second world war, especially after the establishment of the former Development Board in 1950, there was a sudden increase in interest in agricultural problems and many consultant engineering firms were instructed to carry out irrigation and drainage projects and to collect the information required for the planning of a project. Generally speaking their instructions made no provision for the establishment of drainage standards by setting up experimental farms and undertaking elaborate and time-consuming research work.

The experiments required for gaining information on such drainage standards, as

drainage modulus, drainage depth, rate of removal of salts and crop response to leaching and drainage, had to be undertaken by the Government departments.
The First Technical Section of the Development Board was responsible, among other things, for the design and the implementation of a drainage programme, which included the selection of suitable drainage requirements, reclamation methods, etc. In order to implement a research programme, various experimental fields were laid down, the most important being in the Dujailah project area. No justification is needed for laying down experimental fields when it is remembered that neither in Iraq nor in any of the neighbouring countries with comparable soil and climatic conditions has any systematic research been undertaken into reclamation possibilities and techniques.
The Dujailah Land Settlement Area covering 400,000 mesharas, is located south of Kut al Amara. The unfortunate history of this Land Settlement project has been described in detail by HASSAN MOHAMMAD ALI (1955) and DOREEN WARRINER (1957) and only a brief summary will be given here. The Dujailah project is the largest and oldest settlement project in Iraq, having been started in 1946 as a model and experiment. The area allocated to smallholders in the settlement in April 1955 was said to be 180,000 donums[1]), i.e. 1800 families with holdings of 100 donums each.
A large part of the area allocated is not now under cultivation, mostly because of salt. The new irrigation network caused rapid salinization of the soil owing to the lack of drainage. At the end of 1953 the Chief Engineer Drainage reported on the worsening soil salinity conditions in the Dujailah Land Settlement Area. The need for field drainage was particularly stressed and I.D. 10,000[2]) asked for carrying out necessary drainage experiments.
The object of the experiments was defined broadly as the acquisition of more basic knowledge on the reclamation of saline soils in its relation to soil condition, drainage, and irrigation and cultivation practices.

— *The experimental farms*

In the winter of 1954–1955 the construction of the experimental plot was begun on a specially selected area near Shakha 8 of the Dujailah Settlement Project with very salty land which had already been out of production for several years. The soils of this area chiefly consisted of fairly good permeable clay loam and silt loam deposits (see chapter 2). A plan for a drainage and irrigation system was prepared in such a way as to afford a comparison between open and covered drains and between drains at different depths and with different spacings, the latter varying from 25 to 300 m. Provisions were made for measuring the discharge of the drains and the quantities of irrigation water to be applied. The area thus prepared covered 200 mesharas. The plan of the experimental farm is described in detail in annex 1, and may serve as an example of a pilot farm for the study of the reclamation of saline areas.
The experimental programme on this plot was begun early in 1956.

[1]) donum: local area unit, 2500 m^2.
[2]) I.D. = Iraq Dinar(s).

Most of the conclusions to be drawn from the Dujailah experiments are of a more general validity and may be applied to the reclamation of large areas of saline soils in Southern Iraq However, some of the experimental results and conclusions are only valid for the soil and hydrological conditions obtaining in the Dujailah area. In order to check our Dujailah findings it was felt necessary to have a number of small pilot areas in other locations with different soil and hydrological conditions. Additional experiments were therefore started in the Annanah and Twarij areas. On these areas a simplified plan and a limited experimental programme were carried out which was more governed by local needs.

The Annanah experiments were begun in 1957 on a plot situated near Annanah village on the western bank of the Hilla canal, facing the Babylon ruins. The main characteristics of the soil of the Annanah plot are: –

1. a heavily textured soil in the upper 1.5 m of the profile.
2. a shallow water table, less than 1 m below the surface.
3. a high salt and exchangeable sodium content in the upper 30 cm of the soil and a very sharp decrease below this layer.

The Annanah plot was chosen on a type of soil known as basin or irrigation depression soil. It has generally been assumed that it is not worthwhile to drain and reclaim these soils which should be consequently excluded from a reclamation project. This idea was based on three assumptions: –

1. The heavy texture of these soils together with their high salinity and exchangeable sodium would cause many difficulties during the process of reclamation.
2. After draining and reclamation the productivity of these soils would be low compared to the lighter textured and better soils.
3. The low level of these soils would have an unfavourable effect on the drainage cost of the project if they were included in the drainage project.

The object of the experimental programme was to test the first two assumptions. The experiments were laid out in a square area of six mesharas extending from the centre of the basin to the nearest irrigation ditch. The area was divided into 36 square basins of 400 m^2 each. A 150 m drain ditch was excavated to such a depth that the permeable layer below the heavily textured upper layer was reached underneath. Drainage water was pumped into the nearest main irrigation canal. Two sets of piezometers and several lines of underground water observation wells were installed.

A second small pilot area, near the Twairij pumping station and adjoining the main drain, was installed in the autumn of 1957. The soil of the Twairij plot is medium textured. The upper four metres of the profile is very stratified and consists of medium textured layers (from loamy sand to light clay). Below a depth of four metres the soil is a heavy clay.

The average salt content of the upper 30 cms of soil was 3,0 % on a very salty strip in the pilot area. On the remainder of the plot the topsoil had a salt content of somewhat less than 1 per cent. The first plan of the plot provided for an area of 12 mesharas to be extended later.
The object of the experiments was to check some results of the Dujailah experiments and to try out different reclamation treatments on this type of soil. As the first experiments were begun in the winter of 1957–1958 only a few results are available.

— *The experimental programme*

For the purpose of a systematic study of the problems involved in the reclamation of saline soils, the experimental programme was divided into three parts: -

1. a soil hydrology section, especially the desalinization of the soil profile in relation to irrigation applications, soil permeability, drain spacing and drain depth.
2. an agricultural section, comprising the crop response during and after the various stages of reclamation.
3. the study of the reclamation procedures to be recommended for the reclamation of certain areas.

The problems mentioned under 1 and 2 may be considered as independent groups which can be investigated separately, while the study of reclamation procedures mentioned under 3 should be considered as a combination of the results of the first two groups with a number of social, economic and other considerations. It will be clear that the latter goes beyond a purely agricultural investigation and will partly fall outside the scope of this work.
An important feature of this experimental programme is that the results also largely determine, or should determine, which standards are to be used in selecting salty land in which reclamation and future development is economically feasible. For instance, the question as to whether gypsum amendments are required for the reclamation of saline-alkali soils (chapter 4) will be an important factor in determining whether the reclamation will be economically sound. Other equally important factors in this respect are the amount of water required to desalinize the soil profile (chapter 3) and the crop response during and after leaching (chapter 5).
It is obviously a very time consuming task to find the final answers to all these vast and complicated problems. It should be remembered that even in the case of the reclamation of waste areas under humid climatic conditions, where a great deal of experience has already been gained, opinions and methods are still being developed. But on the other hand, since scarcely anything is known about the reclamation of saline soils under Iraqi conditions all information collected will be new and may help in formulating provisional concepts and criteria.

2. DATA ON THE SOILS AND SALTS OF THE DUJAILAH EXPERIMENTAL AREA

2.1. SOIL PROFILE

The soil profile of the experimental area in Dujailah consists of silty loam deposits underlain by an impermeable heavy clay at a depth of 4 m. For further details see annex 1. Table 2 shows the results of some mechanical analyses of this soil together with the moisture percentages of the saturated paste and the exchange capacities of the adsorption complex. Although some variation occurs and very sandy layers are sometimes found high up or low down in the profile, the mechanical composition in which the silt fraction predominates, is typical of irrigation deposits.

TABEL 2. Mechanical composition[1]) etc. of Dujailah soils

Depth cm	sand %	silt %	clay %	moisture % saturated paste	exchange capacity meq./100 g
0– 30	21	58	20	52	18
30– 60	13	65	22	55.5	17
60–100	12	68	20	51.5	18
100–150[2])	40	52	10	50	18
150–200	28	61	11	45.5	14

[1]) The values of the fractions are averages of about 10 mechanical analyses. The saturation percentages are averages of 50–100 moisture determinations for each horizon. The fraction limits are 2 and 50 micron.

[2]) The mechanical composition of the 100–150 cm layer is based on one analysis only. It may be concluded from the moisture percentage of the paste and the exchange capacity that the average clay content is somewhat erratic. A clay content of approx. 20% may be assumed.

2.2. PERMEABILITY AND WATER TABLE

Permeability tests were carried out in the saturated soil below the water table by means of HOOGHOUDT and ERNST's auger hole method (v. BEERS, 1958). The results are given in table 3.

TABLE 3. Permeability of Dujailah soil

depth cm from – to	number of observations	permeability (K) in cm per 24 hrs minimum	average	maximum
60 – 200	15	30	45	80
230 – 350	20	70	95	150

Between a depth of 60 cm and 200 cm the average permeability value of the soil is 45 cm per 24 hrs and between 230 and 350 cm, 95 cm per 24 hrs. In view of the similarity in texture the permeability of the soil below 3.50 m may also be assumed to be 95 cm per 24 hrs. Stated in simpler terms, the soil profile consists of 4.5 m of rather permeable material, with an average K value of from 70 to 80 cm per 24 hrs, underlain by an impervious layer.

Before irrigation of the experimental plots was started the depth of the water table varied from less than 1 m near the main feeder to more than 5 m in parts which have long been out of cultivation. After the first irrigation the water table rapidly rose to above the drainage level in the irrigated plots. The salt content of the ground water was as high as 3 % in some locations, but after irrigation was started it was considerably affected by leaching and seepage.

2.3. LIME AND GYPSUM CONTENTS

— *Lime*

All soils in Iraq contain large amounts of lime. Soil surveys in different parts of the country invariably show this characteristic. It is safe to conclude from our analysis and additional data (DELVER, 1960) that all soils in Iraq which are saline or in danger of becoming saline, are characterized by a lime content varying from 20 to 30 % (see table 4).

TABLE 4. Average lime content of different soils in Iraq

Dujailah			Annanah			Hilla		
depth cm	lime %	number of samples	depth cm	lime %	number of samples	depth cm	lime %	number of samples
0– 30	26	39	0– 20	23	20	0–30	22	45
30– 60	27	45	20– 60	23				
60–100	27	45	60–100	23				
100–150	26	44						
150–200	27	30						

This is an important feature, since lime may influence the building-up of a good soil structure and have a great effect on the behaviour of the structure during reclamation.

Analysis of many samples indicates that the lime in the irrigation deposits is proportionally distributed over the sand, silt and clay fractions (Mc. Donald, 1958). This probably indicates that lime particles are carried by the river water and deposited simultaneously with the soil particles.

— *Gypsum*

Gypsum is frequently found in the Iraqi soils. The gypsum content, as shown in table 5, varies in the unleached Dujailah soils from 0.26 to over 2 %. Most of the gypsum is located below a depth of 1 m in the profile. In the top 60 cm the gypsum content, although low, is still high enough to form a saturated solution if no other salts are present.
A saturated solution of pure gypsum contains 3.0 meq. of gypsum per 100 grams of water at 25° C. The solubility of gypsum increases considerably in the presence of other salts and more than 7 meq. gypsum per 100 grams can be dissolved in a 10 % NaCl solution.

Table 5. Gypsum content of Dujailah soil (percentage, based on dry weight)

depth cm	Plot XI and XII			Plot I (before leaching)			Plot I (after leaching)		
	meq/ 100 g	%	number of samples	meq/ 100 g	%	number of samples	meq/ 100 g	%	number of samples
0– 30	7	0,60	22	11	0.95	9	0	0	9
30– 60	5	0.43	22	3	0.26	15	0	0	9
60–100	6	0.52	22	19	1.64	15	12	1.03	7
100–150	19	1.64	22	29	2.50	15	19	1.64	7
150–200	19	1.64	22	12	1.03	15	8	0.69	7

Unlike lime, the gypsum, owing to its greater solubility, is considerably affected by leaching (table 5). After leaching with a depth of about 1.40 m of drainage water, there was a marked fall in the gypsum content in the whole sampled soil profile of Plot I. In the top 60 cm the gypsum content was reduced to 0. This means that as a supplier of Ca^{++} gypsum can only be an important factor at the beginning of the leaching and reclamation period (see also chapter 4).
Most saline soils in the lower Mesopotamian plain have a gypsum content of between 1 and 3 %, although in exceptional cases much higher contents of up to 6 %, have been recorded. It may be expected that these soils will contain little or no gypsum in the root zone once they have been reclaimed.
The gypsum is of secondary origin and was formed by precipitation through evaporation of the subsoil water. This also explains why the greatest accumulations in the profile occur above the capillary water zone.

2.4. THE SOLUBLE SALTS

Large amounts of soluble salts occur in the soils of the Lower Mesopotamian Plain, especially in the surface layers. Table 6 gives a typical example of the salt content of the soil under the conditions prevailing in the Dujailah area: –

TABLE 6. Salt content of the Dujailah soil

soil layer (cm)	0–30	30–60	60–100	100–150	150–200
EC_e[1]) (mmhos/cm)	65	36	35	34	35

[1]) electrical conductivity of a saturation extract (mmhos/cm).

Although there are a great number of components of water-soluble salts, in practice only the following ions are important for the analysis and classification of saline soils: anions: Cl^-, SO_4^{--}, CO_3^{--} and HCO_3^-, and cations: Na^+, Ca^{++} and Mg^{++}. Which ion will accumulate to a greater extent in given cases will entirely depend on such conditions as precipitation, natural leaching conditions, composition of salts in the irrigation water, etc. Figure 8 shows the composition of the salts of the soil in Dujailah.
The predominance of the sodium and chloride ions is immediately obvious; about 70 % of all cations consists of sodium and the same percentage of all anions is Cl^-. The rest of the cations is about equally divided between Ca^{++} and Mg^{++}, the rest of the anions almost solely consisting of SO_4^{--}. This distribution is uniform to a depth of 2 m, except for an increasing amount of SO_4^{--} at the expense of Cl^- in the upper 60 cm of soil. In fact, the Cl/SO_4 ratio decreases from more than 6 in the top 30 cm to about to 2 at 60 cm; from this depth onward the ratio remains constant.

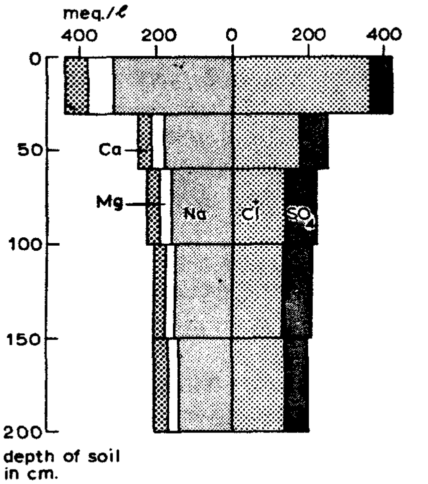


Fig. 8. Composition of salts in 1:1 extracts of the unleached soil of block I
Sampling date: 24-1-1956
The values presented are the averages of 12 samples for each layer

Fig. 9 shows the relationship between the Cl/SO_4 ratio and the salinity, expressed as meq.Cl per 100 grams of soil for a number of samples of a non-leached soil. Although there is a positive correlation, a considerable variation occurs. Figures 10 and 11 show the close relationship between Cl content and salinity of a great number of water samples and soil extracts, Fig. 12 the close correlation between sodium and total cations and Fig. 13 the relationship between the electrical conductivity and the total amounts of soluble salts.

To express the salinity of a soil extract or water sample (in a single value) a choice should be made from such analyses as the Cl content, the total soluble salts or the electrical conductivity, which are closely correlated.

For various reasons preference is given to the electrical conductivity of the saturated soil extract as an index of the salinity level of the soil with respect to its productivity. There are indications that the EC affords a better picture of salinity in relation to plant growth than, say, the total of soluble salts or the concentration of any specific ion.

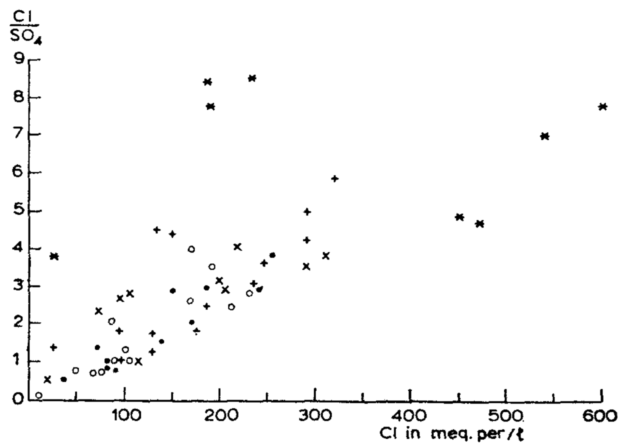


Fig. 9. Relation between the Cl/SO_4 ration in meq and soil salinity in 1:1 soil extracts of block I Sampling date 24-1-1956

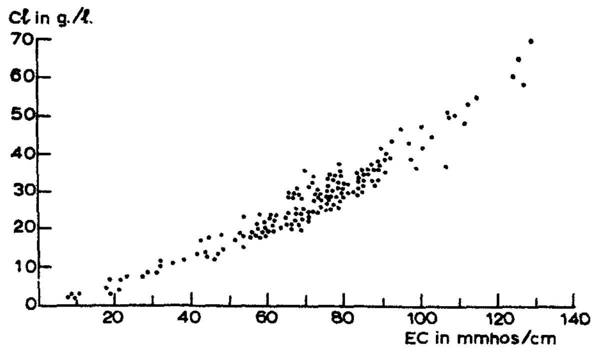


Fig. 10. Relation between Cl-content and electrical conductivity of water samples from wells and piezometers

Moreover the electrical conductivity can be determined by a very simple procedure and is easy to handle.
A conversion graph was made to relate the various salinity appraisals (annex III). This nomograph was partly constructed from data from the Salinity Handbook No. 60 and

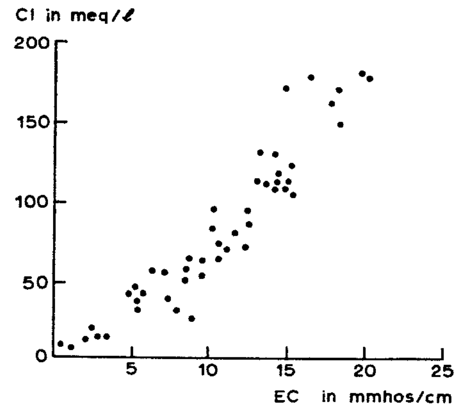


Fig. 11. Relation between Cl-content and electrical conductivity in 1:1 soil extracts
Samples taken before planting the wintercrop 1957–1958, in the upper 60 cm of soil in blocks I and III

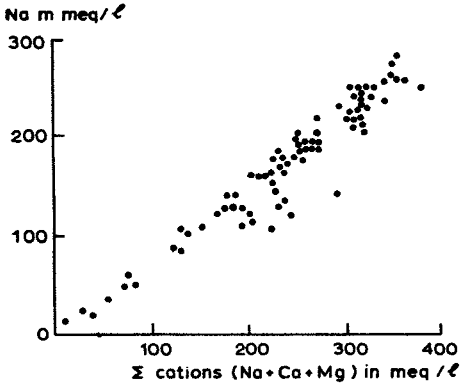


Fig. 12. Relation between Na and total cations in 1:1 soil extracts
Samples taken in 1956, before the leaching, in the upper 200 cm of soil in blocks VI and VIII

partly from the analytical results of Dujailah soils. By means of this nomograph the salinity of a given soil extract can be converted in the most convenient unit. Annex IV gives a nomograph for reducing electrical conductivity or resistance readings of solutions having temperatures of from 10° to 40° C to conductivity at 25° C.
With regard to the solution, the saturation extract is preferred as it represents the actual soil solution under varying conditions better than any other soil water extract based on a fixed-weight ratio. At the beginning of our experiments all EC measurements were therefore made in the extract of saturated pastes, later for practical reasons in 1:1

extracts, but then reduced to saturation extracts with the conversion factors of table 7 (see also Figs. 14 en 15).

Fig. 13. Relation between electrical conductivity and total soluble salts in 1:1 soil extracts

Samples taken in block I before planting the wintercrop 1956–1957

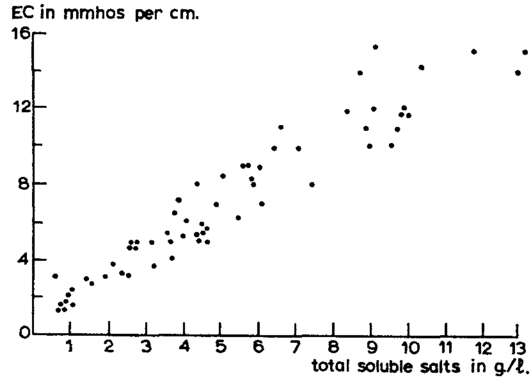


Fig. 14. Relation between the electrical conductivities of different extracts

Samples taken of the upper 30 cm of soil in block VIII before planting the wintercrop 1957–1958

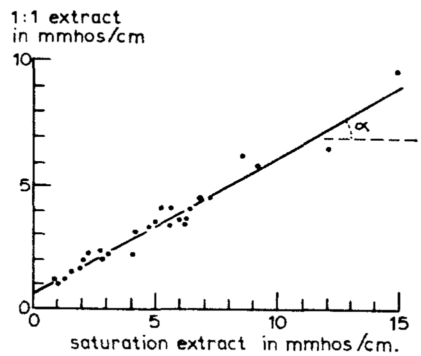


Fig. 15. Relation between the Cl-content of different extracts

Samples taken of the upper 30 cm of soil in block VIII before planting the wintercrop 1957–1958

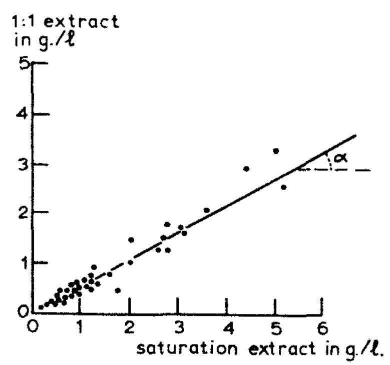


TABLE 7. Conversion factors f = $EC_e/EC_{1:1}$

depth of soil (cm)	gradient of Cl line (tg α)	average water percentage saturated paste	number of samples	conversion factor
0– 30	0.53	53	275	1.9
30– 60	0.55	55.5	140	1.8
60–100	0.52	51.5	100	1.95
100–150	0.50	50	90	2.0
150–200	0.45	45.5	75	2.2

2.5. 'LEACHING RATE' OF VARIOUS COMPONENTS OF SOLUBLE SALTS

During leaching the concentration of the different ions does not decrease proportionally. This may be concluded from the data in Fig. 16, which shows the distribution of the various ions after leaching of the same soil as in Fig. 8. There was a marked decrease in the Na percentage to a depth of 30 cm and in the percentage Cl to a depth of 100 cm. This means that the ion ratio changed during leaching. The Cl/SO_4, which was 6 at the surface before leaching, decreased to about 1; lower down in the profile there was also a marked decrease in this ratio to about 0.6. After a year of cultivation on this soil the Cl/SO_4 ratio was still below 1.0.
Table 8 shows the ions in their order of decreasing 'leaching rate'.

TABLE 8. Leaching rate of various ions. Percentage of original ion concentration remaining after leaching

depth cm	Cl^-	Na^+	Mg^{++}	Ca^{++}	SO_4^{--}
0–30	5.5	6.5	7.5	14	27
30–60	12.5	18	18	29	32

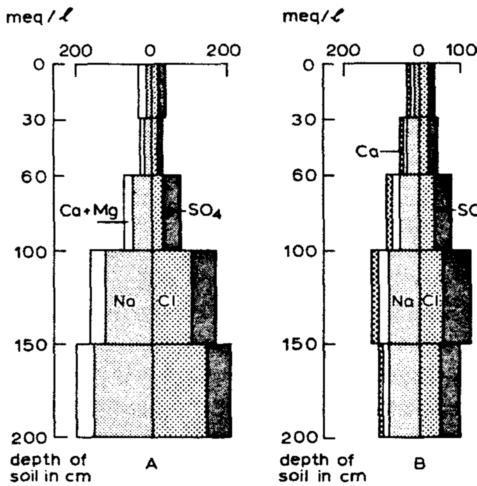
Some authors have observed the same phenomena and explained the differences in leaching by varying 'moving capacities' of the ions; depending on the effective size of the ions including the water films (JANITZKY, 1957). But leaching of salts is not merely a diffusion but mainly a replacement of the salty soil solution by leaching water moving downward, and one would expect the same leaching 'rate' for all the dissolved ions. Hence other factors are responsible for the differences shown in table 8. Adsorbed sodium will be replaced by calcium and come into solution. Calcium and sulphate ions will be continuously supplied by gypsum during leaching. It is only in the case of Cl^- that there is no interference of this kind. This explains why Cl^- is leached at the highest rate, or more exactly, why the decrease in Cl content is most pronounced.
During leaching the exchangeable sodium percentage in the top 30 cm of the soil profile decreased by 27 % (from 34 % to 7 %), corresponding to the release of approx. 5 meq. per 100 gram of dry soil. In the same period the gypsum content was reduced from 11 meq. per 100 gram of dry soil to zero. If the leaching percentages of Na^+, Ca^{++} and SO_4^{--}

are corrected by the amounts coming into solution during leaching, the corresponding figures of table 8 can be re-estimated at 5.5, 7.5 and 10 per cent.
Thus the influence of the decreasing ESP and gypsum content largely explains the measured difference in 'leaching rate' of the ions. A quantitative approach, however, is very difficult as the ions adsorbed on the complex or derived from the gypsum are gradually released during the leaching process.
The composition of the irrigation water will also affect the composition of the salts remaining in the soil after leaching.

Fig. 16. Composition of salts in 1:1 extracts of the leached soil of block I

A. Sampling date 20-6-1956. The values presented are averages of 50 samples for each layer

B. Sampling date 10-11-1957. The values presented are averages of 30 samples for each layer



The observation that with respect to the different ions leaching has the effect of a selective process, finally resulting in a composition of salts which differs from the original composition, will have important consequences. It explains, at least partly, the occurrence of different types of saline soils found in the Mesopotamian plain.
Such factors as climate, distance from water table, surface, relief and irrigation practices determine the rate of salt accumulation in the topsoil and partly the salinization type of the kind of salts that will accumulate (BURINGH, 1958). Although it is generally accepted that of these factors the distance from the water table and the total evaporation rate have the greatest influence, more attention should be given to the occurrence of occasional but repeated leachings by collected rainwater or irrigation water, as these determine the final composition of the salts in the surface soils, especially such as are intermittently cultivated.
Compared to soils exposed to alternate salt accumulation and leaching, those exposed to the salinization process only tend to accumulate more Cl^- and Na^+. The latter will have a higher percentage of Ca^{++} and SO_4^{--} and a lower percentage of exchangeable sodium.

3. LEACHING OF SALINE SOILS

3.1. THE LEACHING CURVE

In connection with the planning of the reclamation of saline areas it is of paramount importance to have a reliable estimate of the amount of leaching water required to reduce the soil salinity to a desired level. The empirical approach, despite its many limitations, seems to be by far the most suitable way of tackling this problem, as the more fundamental studies on salt and water movement (VAN DER MOLEN, 1956; GARDNER and BROOKS, 1957) have not yet produced any results of sufficient value for practical purposes. The principle of desalinization is very simple. The salts must be washed downwards, at least from the upper soil layers, by means of flooding and irrigation. The saline percolation water must be removed by means of a sub-surface drainage system under conditions of high water tables and insufficient natural discharge.

The data discussed here have been assembled from Block I and Block III of the Dujailah Farm (Annex I). Salinity data were obtained before, during and after leaching by means of frequent soil sampling. The EC figures of the saturation extracts of these samples are the averages of 10 to 20 soil samples, and in addition each soil sample up to 60 cm depth consists of 6 to 9 subsamples taken by pipe auger.

Leaching was carried out by flooding the bare soil or by over-irrigating the cropped soil with varying depths of water. The quantity of water discharged by the drainage system, as measured at the drain outlets, was taken as an index of the actual amount of leaching water. A correction was added for the direct flow of drainage water into the open collector drain. Since the area was underlain by an impermeable layer at a depth of about 4 m and boundary effects could be eliminated by a proper selection of the observation data, the resultant amounts of water represent fairly accurately the actual amounts of effective leaching water passing through the soil.

Figure 17 shows the decrease in the electrical conductivity of the saturated soil extract in relation to the amount of leaching water, over different soil depths. The decrease is represented by the fraction of the initial salt content remaining in the soil, viz. the ratio of the actual salt content (EC_e) to the initial salt content (EC_{eo}). The data from Blocks I and III are in close agreement to a depth of 1 m. At greater depths leaching is more rapid in Block III than in Block I. This difference can be explained by a difference in the flowline pattern in the two units, since owing to the greater depth and wider spacing of the drains in Block III the water movement in the upper soil layers is more vertical than the water flow in Block I.

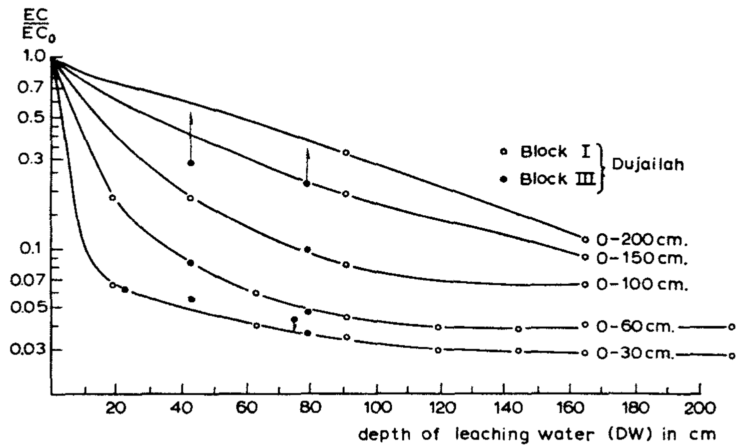


Fig. 17. Relation between soil salinity and total depth of leaching water

The data given in Figure 17 are shown in a different way in Fig. 18 (REEVE, 1957). The depth of leaching water on the abscissa is given per unit depth of soil.
The fraction of the initial salt remaining in the soil was corrected by subtracting a constant value EC_{ex}[1]) from both EC_e and EC_{eo}. This value EC_{ex} represents the equilibrium level of salinity in the soil to be obtained under the given conditions. Under our own experimental conditions EC_{ex} was found to be between 1.3 and 2.8 mmhos/cm, depending mainly on evaporation, drainage percentage of irrigation water and the salinity of the irrigation water. When the equilibrium value EC_{ex} is subtracted from the salinity values before and after leaching, the relationship as given in figure 18 becomes independent of the salinity of the irrigation water and the existing drainage conditions. The resultant curve is solely determined by the soil conditions.
Figure 18 shows two leaching curves in addition to the curve for the Dujailah soil. One is based on the results of a leaching experiment carried out near Annanah in Iraq (ANNANAH EXP., 1, 1958), the other is in accordance with a leaching study described by Reeve (REEVE et al., 1948). The Annanah and the Utah curves, however, are not as accurate as the Dujailah one, since estimates had to be made for the evaporation losses (which were not known in either case) in order to assess the actual nett amount of leaching

[1]) See also the theoretical approach in chapter 7.4.

water from the total irrigation duty. Since the salt content of the irrigation water used in Utah was higher than that of the irrigation water at Dujailah, the EC_{ex} was taken as 4. A comparison of the three curves shows that much more water is required to leach the Annanah soil than the Dujailah soil. The Utah soil occupies an intermediate position.

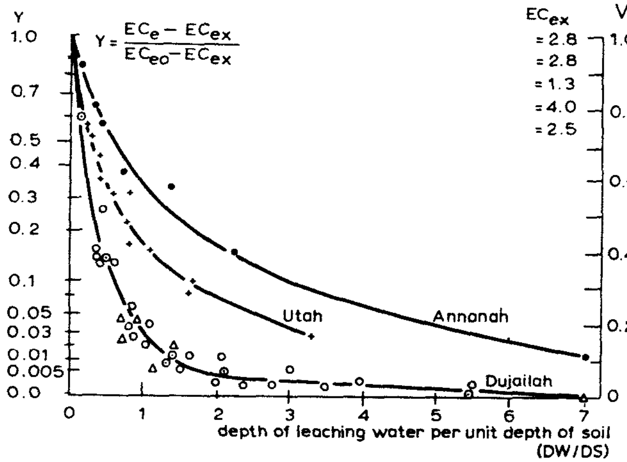


Fig. 18. Leaching curves

○ block I	Dujailah	$EC_{ex} = 2.8$
△ block III		
+ Utah, U.S.A. Reeve		$EC_{ex} = 4.0$
● Annanah		$EC_{ex} = 2.5$
⊙ Leaching infiltration test		$EC_{ex} = 1.3$

These different leaching efficiencies[1]) are related to the physical properties of the soil. The Dujailah soil mainly consists of loam and silty loam (DUJAILAH EXP., 1, 1954), the Annanah plot is situated on clay loam (ANNANAH EXP., 1, 1958) and silty clay soil, while the soil of the Utah experiment is described as a silty loam (U.S.D.A., 1954).
The distribution of the total pore space over pores of different diameter is probably of major importance to leaching efficiency. In a light textured soil the pores are usually more uniform in diameter than in a heavier soil in which large pores occur between the structural elements and fine pores in between. When a heavy soil is leached, the part of the water passing through the largest pores (cracks) has little leaching effect. For a proper understanding of the leaching curves a few observations are necessary: –

1. The EC_e values used for the construction of the curves in Fig. 18 are averages over a given depth of the soil profile. The salt distribution within this depth is not uniform as the salt content of the various layers of the soil profile differs considerably (DUJAILAH EXP., 6, 1959). A close analysis of the field data shows that although slightly

[1]) See also the theoretical approach in chapter 7.4.

different curves could very probably be constructed for the various soil depths these differences are of minor importance and can be neglected in practice.

2. The leaching of the various layers of the soil profile is not begun until the drains start discharging water. It is found that under field conditions a high subsoil water table is quickly built up by water flowing through cracks after irrigation has been started. The drains start discharging before the whole soil profile has been saturated, so that there is little leaching of the top layers of the soil profile during the period of a rising water table and before the drains discharge. For the quick leaching test no such conditions obtain, and a correction has to be introduced for water storage in the profile (see 3.2).
3. Owing to the fact that the leaching curve is an empirically determined relationship, its validity is confined to an initial salt content (EC_{eo}). within the same limits as given by the field data from which the curve is drawn. In the case of the Dujailah curve these limits are an electrical conductivity of the saturation extract of from 40 to 100, and for the Annanah curve an EC_{eo} of from 20 to 60.
4. The rate of leaching seems to have little or no bearing on the result. In Block I leaching was started by flooding and continued by means of normal irrigation; in block III the basins were cropped and irrigated in a normal way from the beginning. In both cases the leaching effect was only found to be related to the total amount of leaching water which actually drained through the soil.
Hence the method of leaching the soil, the amounts given and the frequency of watering are of little or no importance to the leaching effect when there is no resalinization between the flooding periods.
5. The leaching curve is practically independent of the type of soil-water extract used for calculating the electrical conductivity. Provided the proper equivalent value were chosen for EC_{ex}, the salinity could also be expressed as the percentage of salt in the dry soil.
6. The leaching curves relate to a vertical water movement and are therefore only applicable to a depth at which the water movement is vertical or practically vertical. Normally this condition is met when leaching the upper meter of soil in the case of wide drain spacings except, possibly, for a strip very close to the drain.

3.2. A SIMPLE FIELD TEST FOR DETERMINING THE LEACHING CURVE

In planning the reclamation of saline land, the leaching relationship as given in Fig. 18 will be a useful tool for deciding whether or not desalinization is possible and economically justified and which reclamation methods are most suitable, having regard to local soil and agricultural conditions. Since a leaching curve is only valid for the soil and salt conditions under which the relationship was established, it will usually be necessary to determine the leaching curves applicable to the specific conditions of each reclamation project. But it would not seem feasible to carry out time-consuming and expensive field experiments for this purpose.

An attempt was therefore made to discover whether the leaching curve could be based with sufficient accuracy on the results of a simple and rapid leaching test. The test was carried out with concentric cylinders having diameters of 50 and 70 cm, as used for infiltration rate measurements. The cylinders were pressed into the soil for about 5 cm and filled with water to a depth of 10 cm. The water level was kept constant throughout the period of the tests. The infiltration rate was measured for the inner cylinder. Soil samples in the inner cylinder were taken before the test was begun and after water had infiltrated to a depth of about 50 and 100 cm. At each location the test was carried out in quadruplicate. The duration of the test depends on the infiltration rate; in Iraq it was usually possible to complete it in two weeks.

In evaluating the test results, the depth of leaching water is found by subtracting from the total depth infiltrated the amount needed for moistening the soil (the latter was assumed to be the difference in moisture content of the soil samples before and after the test). The EC_{ex} is found as the EC_e of the upper 5 or 10 cm of the soil after leaching, which reaches a practically constant minimum value soon after leaching commences.

The results of the tests carried out in the Dujailah experimental area are shown in Fig. 18. Comparison with the data of the field leaching experiments in large basins shows that both results agree very well with the same salt-leaching relationship. The leaching curve can therefore be determined sufficiently accurate by means of simple leaching-infiltration tests as described above.

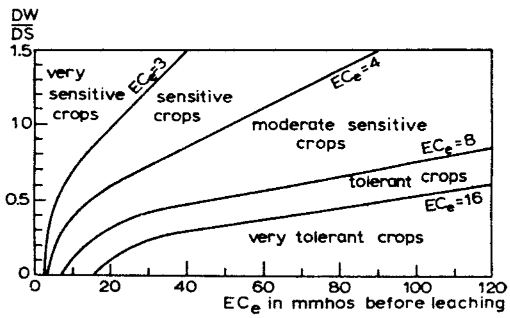
3.3. USE OF THE LEACHING CURVE

Leaching can be carried out in various ways, the main difference depending on whether the leaching water is applied to bare soil or in combination with a selected follow-up of crops adapted to the changing salinity status of the soil. Legume crops deserve special attention in this connection since when the harmful salts are leached valuable plant nutrients (mainly the readily soluble nitrogen and potassium components) are washed down at the same time (DUJAILAH EXP., 5, 1958; DRAINAGE AND LAND RECLAMATION, 1958). Which leaching method is to be preferred in a specific case will depend on numerous factors, e.g. the need of a crop return during the reclamation period, the availability of irrigation water, the effect of leaching on soil fertility, the possibilities of applying fertilizers and the technical skill of the farmers. In short, the selection of the proper leaching method is not merely a chemico-physical soil problem, since economic and social aspects are also closely bound up with the reclamation of an area. If for various reasons a specific reclamation procedure seems advisable, the leaching curve will enable its various steps to be planned more accurately and show the consequences with respect to the water requirements and the time needed to complete the reclamation. This will be illustrated by an example.

Let us assume that the average EC_e of the Dujailah soil is 50 for the upper 30 cm and 40 for the upper 60 cm. The plan is to flood the soil until the EC_e, of the upper 30 cm has

fallen to 10, and to follow this up with one or more years of legumes until the EC_e at 0–60 cm is below 4. After this the soil can be considered as having been reclaimed.
The leaching rate during flooding is 2 cm per day. The depth of leaching (drainage) water for each year of legumes is 25 cm. The EC_{ex} is 2.8. Evaporation from the flooded soil is 2 cm/day; moistening the soil profile to field capacity requires 15 cm of water.
According to Fig. 18 the amount of leaching water needed to reduce the EC_e 0–30 cm from 50 to 10 is about 14 cm: $(EC_e - EC_{ex}) / (EC_{eo} - EC_{ex}) = 15\,\%$, so that DW/DS = 0.47 and DW = 14 cm. Thus flooding will take 7 days. The total water-use, including evaporation and moistening of the soil profile, will be 43 cm. The total depth of leaching water after one year of legumes will be 39 cm and after two years 64 cm. The corresponding EC_e values for the upper 60 cm of the soil are 5.8 and 3.9. Thus 7 days of flooding and 2 years of legumes (e.g. biennal sweet clover) will be required to reclaim this Dujailah soil.

Fig. 19. Leaching graph for Dujailah soils



If the same assumptions are accepted for the Annanah soils, except $EC_e = 2.5$, a similar calculation shows that the leaching water required to lower the EC_e 0–30 cm from 50 to 10 will be 68 cm, so that 34 days of flooding will be required and a total of 150 cm of irrigation water.
The EC 0–60 cm after one year of legumes will be 21, after two years 16, after three years 12, and after four years 9. Thus the Annanah soil will need 34 days of flooding with a total watering of 150 cm to start the first (salt-tolerant) crop. After four years of legumes the average EC_e of the upper 60 cm of the soil will still be 9.
It should not be concluded from the examples given that the reclamation of the Annanah soil would not be justified. It was found that for other reasons (mainly fertility) the Annanah soil offers many advantages over the Dujailah soil.
To facilitate the calculations, Fig. 19 was constructed on the basis of the leaching curve for the Dujailah soil. In this graph the depth of leaching (drainage) water is shown as a function of the salinity before leaching and of three different levels after leaching.

3.4. LEACHING AND SALT REMOVAL BY DRAINS

When a saline soil is being leached there are two important phenomena of the salt movement to be considered. In the first place, the salts in the upper layers of the soil are washed downward, a fact which directly determines the improvement of the soil for agricultural use. Secondly, the water table will rise and thus cause a discharge of saline sub-soil water via the drains. The amounts of salt thus transported out of the area governs the salt balance of the area as a whole. It was found that most of the salt in the top 30 cm of the soil was removed by means of 20 cm of leaching water. After 165 cm of leaching water had passed through, the drain was still discharging highly saline water. This means that after the upper layers of the soil have been completely desalinized, desalinization of the whole soil profile will continue for a very long period. Thus even after the soil has been reclaimed for agricultural purposes, the drains will continue to discharge salty groundwater, a factor that should not be overlooked if the drain discharge is to be disposed of in rivers, lakes or depressions. With an average drain discharge of 300 mm per year and a drain spacing of 200 m, the drainage water will remain saline for probably 50–100 years, depending on the flow pattern of the soil-water movement and the soil characteristics.

3.5. THE SALT BALANCE IN A LEACHED SOIL

Distinction is generally drawn between the leaching of excess salts which have accumulated in a soil, and the subsequent drainage of a certain amount of the added irrigation water in order to maintain the low salinity level obtained.
The draining and leaching of soils for agricultural purposes would be useless if it were impossible to prevent resalinization of a soil once reclaimed. The success of a drainage project depends on the possibility of keeping soil salinity at a sufficiently low level to ensure satisfactory agricultural production.
The level at which salinity should actually be maintained provides a basis for the calculation of the minimum drain discharges required and the estimation of the agricultural yields to be expected. For these reasons it is a major factor in determining the drainage requirements.
In view of the importance of the problems involved, experiments were started with the object of studying the salinity of the topsoil of leached basins in relation to drainage conditions. Since these experiments are mainly based on equilibrium conditions between irrigation and drainage quantities and the soil salinity and could not be started until the excess salts had been removed from the soil, only a few data are available. They are, however, sufficient to enable certain conclusions to be drawn.

There is no constant soil salinity value during the cropping periods. With each irrigation the salt is pushed downward, but during the intervals between irrigation it rises again owing to surface evaporation. In addition to these minor fluctuations there is an increase in salt content during the fallow periods between two cropping seasons. In order to eliminate these accumulated salts the general local practice is to apply fairly large amounts of water during soil preparation and soon after sowing. This salt movement is illustrated by the data in Fig. 20.

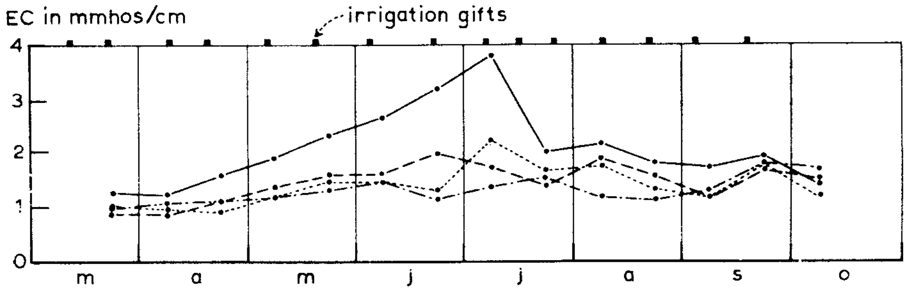


Fig. 20. Average soil salinity (1:1 extract) of block I, basin 5B, 1958
—— 0–15 cm soil layer
------ 15–30 cm soil layer
– – – 30–45 cm soil layer
-.-.-.- 45–60 cm soil layer

These data were assembled by samplings every three days in basin I–5b. Each sample consisted of 10 sub-samples taken at fixed and labelled locations. Basin I–5b was fully reclaimed, a total of nearly 2 m of water having passed through the soil. The sampling results, shown as the averages of 15-day periods, relate to the salt balance of a completely reclaimed and intensively drained and cropped soil.

The salinity in the top 15 cm is always greater than lower down in the profile where it is fairly uniform to a depth of at least 60 cm. Salinity in most of the root zone only fluctuates slightly, viz. between $EC_{1:1} = 1.2$ ($EC_e = 1.8$) in winter and $EC_{1:1} = 1.6$ ($EC_e = 3$) in summer.

At the surface the salt content rises to an EC_e of more than 6 during the fallow period; this high salt content is rapidly reduced by the first waterings of the summer crop. During the fallow period a small amount of salt is introduced from deeper layers below 60 cm depth. The higher equilibrium in the salt content during the summer irrigation period is due to a lower drainage percentage of the irrigation water.

The salt movement during a summer fallow is of particular interest. Fig. 21 shows the data relating to a partly reclaimed basin, VI–10b, with a cropping pattern of barley, summer fallow and wheat. The basin is situated near a drain in a block drained with a spacing of 100 m. The sampling was done in the same way as in basin I–5b.

After the last irrigation of the winter crop in May we may distinguish:
- the period until the end of May, during which the salt content of all layers drops, due to the irrigation.
- the period from the end of May until the beginning of July, during which all layers sampled show an increase of salt, due to capillary upward movement of salty groundwater.
- the period from the beginning of July until the end of the fallow, during which the average salinity in the upper 60 cm of soil remains constant. The salt content in the top 30 cm still increases at the expense of the salinity in the 30–60 cm layer.

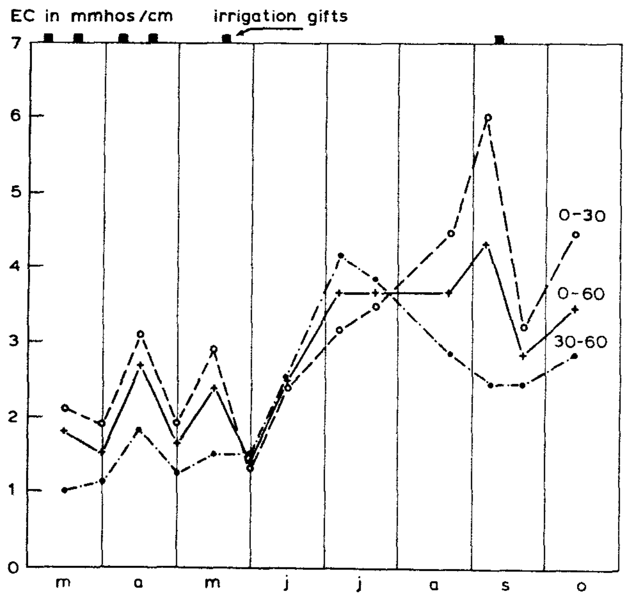


Fig. 21. Average soil salinity (1:1 extract) of block VI, basin 10B, 1958
o - - - o 0–30 cm soil layer
•-.-.-.-• 30–60 cm soil layer
+——+ 0–60 cm soil layer

During the fallow the water table dropped from 0.85 to 1.75 m below surface.
It follows from these observations that whilst the upward moisture transport from below 60 cm depth soon drops to a negligible level, the moisture transport within the upper layers may still continue.

The rapid increase in salinity of the top soil after leaching, caused by the first irrigation after summer, should also be noted. Although this irrigation resulted in considerable leaching, the September weather, which is still hot and has a high evaporating power, promotes a marked upward salt movement in the wet soil profile.
The upward salt movement during the summer fallow is an important factor for determining the drainage criteria, especially when there is partial summer fallow (see chapter 8).

3.6. DRAIN DISCHARGE AND LEACHING PERCENTAGE

With a given drainage system, as for instance in the experimental plots, the minimum salinity depends on the amounts of irrigation water applied and the amount of water discharged by the drain. Table 9 shows the measured average drain discharges for the leaching and various cropping periods.

TABLE 9. Drain discharges during various periods

Location	leaching		1956 summer crop		1956/57 winter crop		1957 summer crop	
	mm/day	dr/irr[1])	mm/day	dr/irr	mm/day	dr/irr	mm/day	dr/irr
Block I[2])	12	53 %	2.2	26 %	1.4	54 %	1.5	12 %
Block VIII[2])			2.0	14 %[3])	0.9	36 %	0.9	13 %

[1]) Fraction of the irrigation water drained.
[2]) Block I is drained with tiles with a spacing of 25 m and a depth of 1.20 m and block VIII by ditches with a spacing of 150 m and a depth of 2.00 m (Annex I).
[3]) This data relates to a rice crop.

As a result of numerous auger-hole tests the permeability of this particular soil is well-known and averages 0.8 m per day (see chapter 2). For a steady discharge of 1 mm/day the drain spacing required would be 130 m with drains of 2 m depth and a water table at 1 m depth midway between the drains; this gives a very good agreement with the conditions obtained in Block VIII.
There appears to be little difference in discharge between summer and winter cropping periods. Local irrigation practices maintain an approximately constant average subsoil-water level throughout the cultivation periods, resulting in the same head and same discharge during summer and winter irrigation. As the irrigation supplies differ considerably, the drainage expressed as a percentage of irrigation quantities is also found to differ substantially.
The high daily drainage figures for the 1956 summer season were caused by poor growth due to late sowing in Block I and the rice crop in Block VIII.

At a rough estimate the leaching percentage is three to four times as high in winter as in summer. This is caused by: –
1. equal drain discharges during both seasons together with much higher summer irrigation requirements as compared to winter cropping
2. the effect of rainfall on drain discharge during winter.

As the fraction of the irrigation water drained determines the salinity of the soil, this means that the soil solution is less saline in winter than in summer, which agrees with the field observations. Consequently, if a constant salinity level in the soil is aimed at when there is intensive cropping during both winter and summer, a higher discharge is required during summer. In our own experiments, for instance, the same leaching

percentage during summer and winter cultivation would mean for Block I that a discharge of only about 0.4 mm/day would be needed during winter cropping, compared with a discharge of 1.5 mm/day during summer (DRAINAGE AND LAND RECLAMATION 1958).
Under certain assumptions the leaching percentage is related to the salt content of the irrigation water and the equilibrium salt content of the soil moisture as follows (U.S.D.A., 1954): -

$$LR = 100 \cdot \frac{D_{dw}}{D_{iw}} = 100 \cdot \frac{EC_{iw}}{EC_{dw}}, \text{ in which}$$

LR = leaching percentage
D_{dw} = depth of drainage water
D_{iw} = depth of irrigation water
EC_{dw} = electrical conductivity of drainage water = electrical conductivity of soil moisture
EC_{iw} = electrical conductivity of irrigation water

Assuming there to be no salt precipitation in the profile and no removal of salt from the harvested crop, the salt balance will be independent of the depth of the root zone. If the average conductivity of the irrigation water in Dujailah is taken as $EC = 0.6$, the equation becomes $LR = 0.6/EC_{dw}$. With the use of this equation it is possible to calculate the leaching percentage required to maintain the conductivity of the soil moisture at a given level.
However, the measurable EC of the drainage water and the saturation extract are comparable but not identical. The moisture content of the saturated soil in situ is about 30 %, as is known from numerous moisture analysis of soil profiles after irrigation and infiltration tests. The moisture content of the saturated paste is also known and is about 50 %. This gives an EC_{dw}/EC_e ratio of 5/3. The equation then becomes: $LR = 0.36/EC_e$.
Table 10 shows both the observed and the calculated leaching percentages for a number of cases. The observed leaching percentages are average values over the irrigation periods.

TABLE 10. Leaching percentages and salinity

block	seasons	observed soil salinity EC_e	leaching percentage	
			calculated	observed
VIII	'56/57	2	18	36
I	'56/57	2	18	54
I	'57	4	9	12
I	'57/58	2	18	32
I	'58	3	12	24

There is no direct agreement between the observed and calculated leaching percentages; the observed leaching percentages both for winter and summer irrigation periods are much higher than the calculated percentages. Not all irrigation water appears to be effective in leaching and establishing the salt balance in the soil. This rather important aspect will be discussed in more detail in chapter 7.

Anticipating this more qualitative treatment, it may be noted here that for normal field crops a leaching requirement of some 20 % will result in a soil EC_e of 3, which may be considered sufficient for the normal growth of most field crops. When more sensitive or more valuable crops are grown a leaching requirement of about 35 %, resulting in a soil EC_e of 2, may be considered suitable.

4. ALKALINITY ASPECTS OF LEACHING OF SALT AFFECTED SOILS

4.1. INTRODUCTION

It is well-known that a soil containing a high percentage of sodium on the exchange complex becomes deflocculated and is characterized by an unstable soil structure, low permeability and low air content. The soil surface may turn dark owing to dispersed organic matter and under dry conditions forms hard prismatic units with smooth rounded surfaces. Clay particles may be washed down into the profile, causing an incipient clay pan. Soils in this condition are called alkaline. They are extremely difficult to handle as they are plastic and sticky when wet, and hard and compact when dry.

The alkali soils are well described by KELLEY (1951) and occur over considerable areas in the western United States, India, Pakistan, Egypt, Russia, Hungary, etc. In particular, since artificial irrigation was introduced large areas of formerly productive soil have become unproductive as a result of alkalinity.

If a soil high in exchangeable sodium is also saline, the soil particles remain flocculated owing to the ionic concentration of the surrounding soil solution, and no such features as described above will develop so long as the ionic concentration of the soil solution remains sufficiently high. But if the salts are leached in such a saline-alkali soil and the saline soil solution is replaced by a non-saline solution, conditions may be created for the development of an alkali soil with all its characteristics and low agricultural value.

There is a considerable amount of confusion regarding the terminology of the soils described here. The terms alkali, black alkali and solonetz are not well-defined and often used in slightly differing senses.

Most authors have recently abandoned the terms black alkali for dark soils with a high exchangeable sodium percentage and white alkali for a saline soil which is not necessary alkaline. The term solonetz usually indicates the typical morphological status of an alkali soil.

In the following discussions use will be made of the terminology proposed by the U.S. Salinity Laboratory (U.S.D.A. 1954): –

- *Non-saline non-alkali soils.* Electrical conductivity of the saturation extract (EC_e) less than 4 mmhos/cm at 25° C and less than 15 % of sodium adsorbed.
- *Saline soils.* EC_e more than 4 mmhos/cm, the exchangeable sodium on the adsorption complex (E.S.P.) less than 15 %.
- *Alkali soils.* EC less than 4 mmhos/cm, E.S.P. more than 15.
  The pH of the saturated paste is usually more than 8.5.
- *Saline-alkali soils.* EC_e more than 4 mmhos/cm, E.S.P. more than 15.
  The pH is less than 8.5.

The limit of 15 % exchangeable sodium is based on research in the United States. This limit depends on many different local conditions and should not be taken as a rigid general rule. VAN DER MOLEN (1958) for instance, reports that in Holland deflocculation may occur with much lower percentages.

4.2. THE SALINE-ALKALI SOILS OF IRAQ

Salinity surveys have been carried out in different project areas in Iraq. They revealed that the soils of the Plain of the Tigris and Euphrates rivers South of Baghdad are highly saline. Nearly 2 million mesharas (500,000 ha), or more than 60 % of the important areas of Dujailah, Nahrwan and Gharraf Extension, have an electrical conductivity of the surface soil higher than 16 mmhos/cm (chapter 1.3). These soils are unsuitable for growing even very tolerant crops.
With very few exceptions these highly saline soils are alkaline. Although the pH of the soil paste seldom exceeds 8.5, exchangeable sodium percentages of over 50 are quite common. The average exchangeable sodium percentage for all saline soils is estimated to be somewhere between 20 and 25. Some soil survey reports mention the occurrence of non-saline alkali soils (BURINGH, 1960) which they classify with such terms as alkali flats, alkali basin soils, etc. But these observations and classifications are mainly based on the morphological characteristics of the soil profile and not on the results of chemical analyses. In our experience there are very few non-saline alkali soils. Nearly 100 samples were taken at different depths in 25 soil profiles and pits in the Nahrwan area, but none was found to be non-saline alkali; of more than 150 samples of 12 selected topsoils and approximately 50 profiles sampled in the Adhaim area, only 2 topsoils could be classified as non-saline alkali, and no non-saline alkali soil could be found in 50 profiles sampled in the Ishaqi area (BINNIE, DEACON and GOURLY, vol. II, 1956). Of the many hundreds of samples taken in the Dujailah Experimental Farm none could be termed non-saline alkali (DUJAILAH EXP. 4, 1957; 6, 1959).
Since the great majority of the saline soils in Iraq had to be classified as saline-alkali soils it was essential to know how they would behave during reclamation. In particular

it was necessary to know whether these soils would develop into a non-saline alkali soil as a result of leaching, with all the repercussions on structure, permeability, etc.

4.3. PRELIMINARY INVESTIGATIONS

From the moment the first analytical results of investigations of the exchangeable sodium percentages were reported and the high level of the E.S.P. values became known, many soil and drainage experts were seriously concerned. Consequently many reports and memoranda gave a warning to the effect that if these soils were not leached with the utmost care, using gypsum or other suitable amendments, reclamation would fail (BINNIE, DEACON and GOURLEY, 1956).

On the other hand, a number of observations made it seem quite likely that the situation was not as serious as had been predicted and that these soils could probably be leached without encountering any great difficulties in the development of alkali soils. The most important considerations in this respect are as follows: –

1. As already mentioned, of the numerous soil samples analysed hardly any exhibit the true alkali characteristics, i.e. a low salt content together with a high exchangeable sodium value, although analyses of both slightly and highly saline soils were represented. This is a remarkable fact since leaching although without drainage, is regularly practised by the local farmers in order to reduce the salt content of the surface soil before planting. During the fallow period the salt content of the surface soil may reach high values through capillary rise from a shallow saline water table, this being fed in turn by seepage from irrigated neighbouring plots. Salinity values of the surface soil higher than $EC_e = 30$ mmhos/cm may be reached in this way during fallow periods of regularly irrigated soils. Before sowing this high salinity value is reduced by one or two generous waterings. If there was a serious danger of true alkali soils developing the regular leaching by farmers would result in many such soils.
2. All soils of the Lower Mesopotamian Plain contain abundant calcium. Gypsum is present in most subsoils and partly in the surface soils, although in a low concentration (chapter 2.3.). In the extremely saline areas calcium chloride is often present in considerable quantities. Most of the calcium however, is in the form of carbonates. From 20 to 30 % of the soil usually consists of lime (DUJAILAH EXP. 6, 1959). Although owing to its low solubility calcium carbonate is of little use as a source of Ca ions in the exchange process, it still has some value (VAN DER MOLEN, 1958), especially where it is fine-grained. The calcium carbonate in the alluvial soils of Southern Iraq, partly occurs in particles of 2 microns and less in clayey soils.
3. The irrigation water has favourable characteristics. Table 11 shows the composition of the Tigris river water at Baghdad over 1949. As shown by the data in the table, the irrigation (leaching) water may be a valuable source of Ca ions in the leaching process. Moreover the (Ca + Mg)/Na ratio of the water is very favourable, as shown by the low sodium adsorption ratio (U.S.D.A., 1954).

TABLE 11. Composition of Tigris water sampled at Baghdad 1949

	Minimum (May–June)	Maximum (Dec.–Jan.)	Year average
Salt p.p.m.	180	370	250
Ca meq/l	2.0	3.2	2.5
Mg meq/l	0.7	2.1	1.4
Na meq/l	0.2	1.4	0.9
S.A.R.[1])	0.2	1.0	0.6

[1]) Sodium Adsorption Ratio: $Na/\sqrt{\frac{(Ca + Mg)}{2}}$ (concentrations in meq/l.).

Since during leaching the saline soil solution is replaced by leaching water having a high (Ca + Mg)/Na ratio, a sodium soil is rather unlikely to develop. For instance according to the U.S. salinity laboratory a soil in equilibrium with a soil solution having a sodium adsorption ratio of 1 is expected to have an exchangeable sodium percentage of approximately only 1 (U.S.D.A., 1954).

Russian literature also describes the reclamation of solonetz soils of the zone of brown and chestnut-coloured soils by irrigation with good quality water. According to ANTIPOV-KARATAEV (1956) the exchangeable sodium could be decreased in the presence of calcium carbonate without any gypsum application.

All the above arguments point to the conclusion that the reclamation of the saline-alkali soils of Iraq probably involves no alkali problem at all. This conclusion was supported by the results of some preliminary leaching experiments undertaken in 1955 (DUJAILAH EXP. 2, 1955). These showed that together with the decrease of salt content the average E.S.P. of the 0–30 cm and 30–60 cm soil layers fell from 36 to 9 and from 36 to 21, in a 21-day leaching period.

Even after these experimental results had been reported not everybody was convinced. In 1956 a consulting firm (BIRNIE, DEACON and GOURLY, 1956) still recommended the use of gypsum at the rate of 1.7 tons per acre for each milli-equivalent of Na per 100 grams of soil in which the E.S.P. was to be reduced.

4.4. INFILTRATION RATE AND EXCHANGEABLE SODIUM

Combined infiltration-leaching tests were made in order to study the effect of leaching on the stability of the soil structure, this being evaluated by changes in the infiltration rate. Field experiments were undertaken in order to study the change in exchangeable sodium and salt content resulting from different leaching practices.

Table 12 shows the result of a number of infiltration rate tests of Dujailah soils and of two Abu-Ghraib soils (A–1 and A–2). All soils were saline-alkaline, with an exchangeable sodium percentage between 30 and 40.

The infiltration rate tests were performed over periods ranging from less than a week to over seven weeks. They were carried out with two concentrical cylinders having diameters of 50 cm and 70 cm. The cylinders were carefully pressed down into the soil for about 5 cm. A constant water head of about 10 cm was maintained in both cylinders. The rate at which water soaks into the soil through the inner cylinder was measured and termed the infiltration rate.

TABLE 12. Average infiltration rate in cm/day for each 50 cm infiltrated

water depth infiltrated	Test number									
cm	VI–5	A–1	VI–B	VI–10	A–2	VI–9	VI–7	III–3b	II–3	III–6B
0– 50	1.5	2.1	9	10		8	18	15	38	38
50–100	–	3.0	8.5	5	–	7	21	17	34	35
100–150	–	–	4	6	–	7	15	–	31	39
150–200	–	–	2.5	6.5	–	15	8	–	27	41
200–250	–	–	–	9	–	–	5	–	31	41
>250	–	–	–	7	–	–	6	–	38	46
Total hours	744	932	786	1225	145	576	762	126	670	239
Total cm infiltration	45	95	176	337	41	201	296	82	882	396
Avge infiltr. cm/day	1.5	2.5	5	6.5	7	8.5	9.5	16	32	40

The exchangeable sodium percentage after the tests and the soil texture are shown in table 13. There are marked divergencies between the average infiltration rates of the various tests. No correlation was found between infiltration rate and texture nor could the infiltration rate be correlated to the exchangeable sodium figures. The depth of the subsoil water table possibly has some effect on the intake rate. The exchangeable sodium decreases during the tests and seems to reach the minimum at 0.4 meq per 100 gram soil or an exchangeable sodium percentage of from 2 to 4.

In most cases the infiltration rate remained practically constant throughout the observation period. In some cases a decrease was observed, but this was not very serious and was probably due to a rising subsoil water table during the observation period rather than to a structural deterioration. The results of these tests provide clear evidence that infiltration with large amounts of water, which can be considered as fast leaching, did not cause a serious deterioration of the soil structure nor a decrease in soil permeability. Nor was any deterioration of the soil structure observed in field leaching trials. These were performed on highly saline-alkali soils (Dujailah) both by leaching a bare soil without a crop stand and by over-irrigating a crop.

TABLE 13. Soil analyses, 0–5 cm samples taken after infiltration leaching tests

Test number	VI–5	A–1	VI–8	VI–10	A–2	VI–9	VI–7	III–3B	II–3	III–6B
Clay %	17	51	30	–	48	44	28	38	25	34
Clay + silt %	77	94	87	–	95	87	83	90	85	83
Exch. Na %	4	2	4	–	2	5	7.5	4	3	2.5
Exch. Na meq/100 g	0.4	0.4	0.7	–	0.4	0.9	1.0	0.8	0.4	0.4

In one of the trials gypsum was applied at the rate of 1500 kg/meshara and sulphur at the rate of 300 kg/meshara. During a complete irrigation period the surface soil of the treated basins was observed and compared with the untreated basins. There was no visible difference in soil structure or intake rate, nor any other kind of difference, as a result of the amendments.

These observations agree with the results of the investigations in the Gharraf Extension Project (T.A.M.S., 1957). The soils contained no gypsum and the effect of leaching the alkali from the soil without chemical amendments was considered questionable. Here a leaching test was performed on two plots, the first one untreated, the second having a quantity of gypsum mixed into the surface soil prior to leaching. The results of this test also showed that no gypsum is needed for the reclamation of these soils.

Heavily saline alkali basin soils with a poor structure have been reclaimed in Annanah. There too was no marked structural deterioration during leaching. Leaching was more difficult, however, and owing to their heavy texture, these soils will always have to be handled with care (ANNANAH EXP. 1, 1958, HULSBOS and BOUMANS, 1960).

4.5. EXCHANGEABLE SODIUM BEHAVIOUR IN THE LEACHING OF FIELD PLOTS

Soil samples were taken at different intervals during field leaching experiments and analysed for salt content and exchangeable sodium. The results of these analyses are summarized in table 14. Up to 60 cm depth the figures given are the averages of at least 20 samples each consisting of 9 subsamples; the deep samples are averages of 6 to 18 samples taken at different locations (DUJAILAH EXP. 6, 1959).

TABLE 14. Decrease of exchangeable sodium and salt during leaching

Depth soil layer, cm	0–30		30–60		60–100		100–150	
	EC_e	ESP	EC_e	ESP	EC_e	ESP	EC_e	ESP
Before leaching	106	34	37	38	34	44	36	44
After 12 days leaching; 15 cm drainage[1])	6.5	15	13.5	33	–	–	–	–
After 42 days leaching; 52 cm drainage	3.0	8	2.6	23	–	–	–	–
After 69 days leaching and 84 days cropping	2.6	7	2.2	21	7.5	38	24	43
After 69 days leaching and 93 days cropping	3.8	5.5	2.0	20	–	–	–	–
After 69 days leaching and 3 cropping seasons	3.6	4.2	3.9	10	8.1	19	16	21

[1]) 15 cm drainage indicates that during the period specified a water depth of 15 cm was discharged by the field drains.

The data clearly show that during leaching the E.S.P. decreases simultaneously with the salt content, though at a lesser rate. There was a considerable fall in the E.S.P. at all points where samples were taken. These data agree with the results of the infiltration-leaching tests discussed above and also indicate that it will be difficult to decrease the E.S.P. to below a value of 4.

The gypsum content of the soil is greatly effected by leaching. This is clearly demonstrated by the data in table 15.

TABLE 15. Average gypsum content of Dujailah soils

Depth cm	Plot XI and XII			Plot I (before leaching)			Plot I (after leaching)		
	meq/ 100 g	%	number of samples	meq/ 100 g	%	number of samples	meq/ 100 g	%	number of samples
0– 30	7	0.60	22	11	0.95	9	0	0	9
30– 60	5	0.43	22	3	0.26	15	0	0	9
60–100	6	0.52	22	19	1.64	15	12	1.03	7
100–150	19	1.64	22	29	2.50	15	19	1.64	7
150–200	19	1.64	22	12	1.03	15	8	0.69	7

After leaching with a depth of 140 cm there was a considerable drop in the gypsum content of the entire profile sampled. In the top 60 cm of the soil the gypsum content was even reduced to 0. This means that since gypsum is washed down very rapidly, it is only during the early stages of the leaching process that it can play an important role as a source of Ca ions in replacing sodium at the exchange complex. The relatively low gypsum content of the soils cannot be the cause of the substantial and permanent decrease in exchangeable sodium when leaching is continuous.

The decrease in exchangeable sodium during leaching may be explained as follows. The saline soil solution is gradually replaced by irrigation water and the effect is similar to that of diluting the soil solution with irrigation water. Table 16 shows how the E.S.P. of a soil decreases when the soil solution is diluted. The E.S.P. values were calculated according to the empirical S.A.R.-E.S.P. relationship, as given by the U.S. Salinity Laboratory (U.S.D.A., 1954).

Since salts may go into solution and interactions between exchangeable and soluble

TABLE 16. Decrease of exchangeable sodium when soil solution is diluted with irrigation water according to table 11

	EC mmhos/cm	Na meq/l	Ca + Mg meq/l	SAR	ESP
Soil extract before leaching	110	600	250	53	43
Diluting 2 ×	60	300	127	38	34
,, 4 ×	31	151	66	26	27
,, 10 ×	15	61	29	16	18
,, 20 ×	8	31	17	11	13

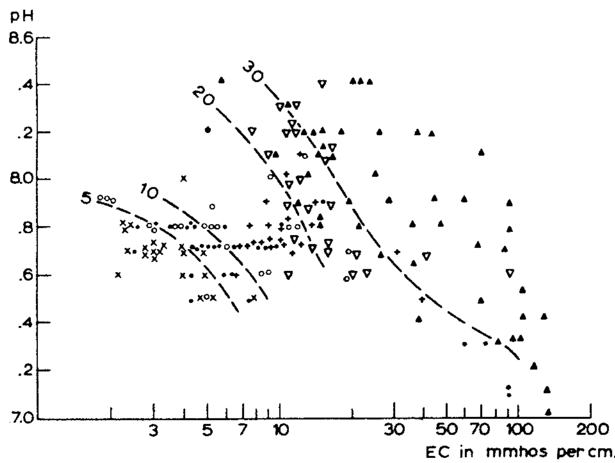
cations will alter the ionic concentrations of the soil solution, the actual leaching process is more complex than assumed here. Moreover, the equilibrium conditions are not usually complied with during a rapid leaching process. But the general trend, shown in table 16, viz. that diluting a soil solution will result in a decrease in E.S.P., will be the same for actual leaching.

4.6. RELATIONSHIP BETWEEN EXCHANGEABLE SODIUM, PH AND SALINITY

As already mentioned, many soil scientists have tried to discover adsorption equations for expressing the relationship between soluble and exchangeable cations. Various results are obtained with the different equations, especially when mono- and bivalent ions are present. Some success has been obtained in the U.S.A. by a semi-empirical approach (U.S.D.A., 1954).

Fig. 22. Relationship between soil salinity (1:1 extract), pH and exchangeable sodium

× ESP: 0– 5
● ESP: 5–10
○ ESP: 10–15
+ ESP: 15–20
▽ ESP: 20–30
▼ ESP: > 30



In the case of the Dujailah soils there is still an insufficient amount of accurate analytical data to enable such a relationship to be established. Instead, a correlation was sought between exchangeable sodium, pH and salinity. Such a correlation presumably exists, since both the E.S.P. and the salinity decreased during leaching. We were encouraged by the fact that a correlation between pH, salinity and alkalisation had already been established for different soils in North Africa and France (PASCAUD et MINART, 1958).
The relationship between pH, E.S.P. and EC is plotted in Fig. 22. Lines of equal alkalinity could be drawn through the observation points. Figure 22 shows the analytical results of all samplings of the experimental fields from the start of the experiments in the spring of 1956 to the end of 1957. The pH is measured in the paste and the conductivity in the saturated extract. Analysis of the graph shows it to be based on two tendencies. The first

is the known fact that the pH decreases with an increasing salt content, all other factors being excluded. This is caused by an increasing replacement of adsorbed H-ions by cations of the saline soil solution.
The second and most interesting tendency is the increase in exchangeable sodium with increasing salinity and a constant pH (Fig. 23), which is in agreement with the results discussed above. It follows from these two tendencies that when all other factors remain constant, an increase in exchangeable sodium will result in an increase in pH. This is also known and is explained by hydrolysis which leads to the formation of sodium hydroxide.

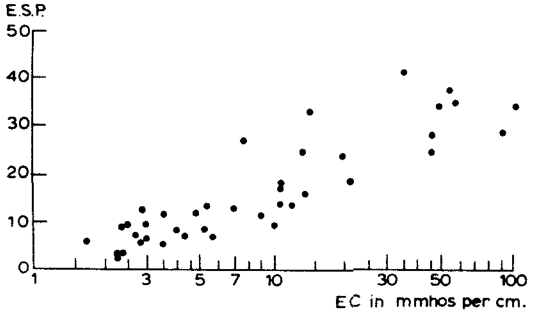


Fig. 23. Relationship between soil salinity (1:1 extract) and exchangeable sodium at a constant pH = 7.8

Hence this correlation study confirms the results of the leaching tests, which showed a simultaneous decrease in E.S.P. and salinity.
A practical application of the data in Fig. 22 is that the alkalinity level can be predicted on the basis of two very simple measurements, viz. the pH and the EC. Since graphs for different soils and soils of a different salinity type are found to be similar, Fig. 22 may be considered valid for all saline soils in Iraq.
According to PASCAUD and MINART no such relationship could be found for sandy and organic soils.

5. CROP YIELDS AND ROTATIONS DURING RECLAMATION

5.1. INTRODUCTION

The first aim of the reclamation experiments was to obtain information on desalinization of the soil profile in relation to irrigation, soil permeability, drain spacing and drain depth. But the ultimate objective of studies on drainage requirements and reclamation methods is the examination of their effect on the agricultural productivity of the soil. This means that the response of crop yields to drainage and desalinization has to be studied in addition to soil hydrology aspects.

An investigation was made of the influence of various drainage and reclamation treatments on the productivity level of the soils and the yields of some locally grown crops and varieties. Only one trial with a newly introduced crop (potatoes) was carried out. Factors that might disturb the soil-salinity – yield relationships were eliminated as far as possible. The basins were levelled before sowing and ploughed with the local plough. The seeds were broadcast at equal sowing rates for the various basins. Irrigating, harvesting and threshing followed local farming practices.
Different dressings were applied of such nitrogenous and phosphatic fertilizers as sulphate of ammonia (21 % pure N) and triple superphosphate (42 % P_2O_5). In a few plots the effect of potassium, gypsum and sulphur dressings was studied. No reliable influence of potassium fertilizers on the crop yield was observed and gypsum and sulphur were not found to exert any noticeable effect on the productivity of the soil (DUJAILAH EXP., 4, 1957). Consequently these trials are not discussed.

Before dealing with the results of the experiments we should mention the difficulty in finding a representative value of soil salinity in relation to crop growth and yield. The soil was sampled by pipe auger or, when the soils were too hard, by a normal type of clay auger in such a way as to obtain a representative average for a basin or sub-basin at the time of sampling.

The 0–30 cm and 30–60 cm horizons were separately sampled. The soil was sampled before, during and after leaching and after harvesting a crop. As was pointed out in chapter 3, irrigation during the cropping season will cause a decrease in salinity depending on initial salinity and rate of percolation to the subsoil. Where the initial salinity is high there is a greater decrease in soil salinity during the growing season, so that neither the EC_e before nor the EC_e after cropping will represent the true soil salinity value under growing conditions. Comparing the yields with the salinity before sowing would give the impression that the crop is more tolerant to salt than if the yields were compared with the soil salinity taken after the harvest.
The soil salinity-yield relationship is further complicated by the fact that the salt tolerance of a crop will not be constant during the different stages of the growing period, and also because plant growth is only influenced by the salts occurring within the depth of the root zone, the latter being variable. Moreover since the salts in most saline soils are not evenly distributed over the soil profile, the assessment of the salt tolerance will also be influenced by the depths of the soil profile sampled.
For practical reasons the soil salinity of the 0–30 and 30–60 cm horizons before sowing, or at an early stage of the growing period, is the best criterion for assessing the salt tolerance of a crop. The relationship thus found enables us to predict whether a given soil will be suitable for growing a certain crop and what the probable decrease in yield will be.

5.2. EFFECT OF SALINITY AND FERTILIZER ON YIELDS

a. Barley

In the winter of 1956/57 a total of 13.5 mesharas of barley was grown on different plots at Dujailah. The yields of some basins previously under sorghum were extremely low and not comparable with the other yields. Consequently these are omitted from the calculation of the averages. As Table 17 shows, the yields of barley differed widely according to the salinity level of the soil and the amount of fertilizer applied.

TABLE 17. Barley yields in kg/meshara. Dujailah, 1956/57

EC_e[1])	no N		6 kg N/mesh		12 kg N/mesh		24 kg N/mesh	
	no P	P[2])	no P	P	no P	P	no P	P
2	230	185	–	–	400	330	–	660
2– 4	185	175	–	–	375	320	540	535
4– 8	225	220	340	305	325	435	430	435
8–16	125	200	430	305	460	420	425	425
0–16	191	195	–	–	367	376	–	514

[1]) EC_e of the soil horizon 0–60 cm before sowing.
[2]) 10 kg P_2O_5 per meshara.

Where the EC_e exceeded 8, a maximum yield of 125 kg/meshara was obtained on unfertilized plots. There was a maximum yield of 660 kg/meshara in one of the well-drained, well-leached basins in which the EC_e had fallen to below 2 which had received both nitrate and phosphatic fertilizer.

The effect of nitrogen application is very obvious; the average yield increased from 191 for the untreated basins to 376 and 514 kg/meshara with dressings of 12 and 24 kg nitrogen per meshara respectively. The use of nitrogenous fertilizers seems justified even on the more saline soils. On the other hand, phosphate seems to have little or no effect.

The effect of salt, and hence of drainage and leaching, is clearly demonstrated in the yields of basins, which were given 24 kg of nitrogen per meshara, since this dressing renders insignificant the effect of the original nitrate content of the soil. With the salinity increasing from an EC_e of less than 2 to one of more than 8 the yields fell from 660 to 425 kg/meshara. Even the latter is to be considered a good yield under Dujailah conditions, the average farm yield being less than 300 kg/meshara. During the next winter season (1957/58) a considerably higher yield was obtained in block VIII with the Tribute variety. The average yield increased from 514 kg to 620 kg per meshara with a maximum of 857 kg/meshara.

One meshara barley (Tribute) on partly reclaimed soil in the Annanah area in the winter of 1957/58 (ANNANAH EXP. 1, 1958) confirmed the results of the Dujailah plot. The average yield was 185, 486 and 520 kg per meshara, using 0, 7,5 kg and 15 kg N/mesh respectively (DRAINAGE AND LAND RECLAMATION, 1958).

At Annanah the effect of drainage on the barley yield was studied in the winter of 1956/57. Outside the experimental area, close to the main irrigation canal, a barley crop was sown by the local farmer on land influenced by the drain. Yields were recorded of sampling areas of 50 m^2 each at various distances from the drain. The subsoil water level was recorded in observation wells during February, March and April. The effect of the groundwater depth is clearly shown in table 18.

TABLE 18. Barley yields in relation to water table, Annanah 1956/57

average depth of water table in cm below surface	barley yield in kg/mesh
50	162
65	238
100	388
110	325
148	437
156	714

Actually the variation in yield is not related to the groundwater depth but to the subsoil drainage (and consequently the leaching) which decreases with increasing distance to the drain as is reflected in the groundwater depths.

At Twairij about 6 mesharas were sown with barley after the plot had been provided with drains and certain parts leached with 30, 50 or 80 cm of irrigation water. The yields obtained are summarized in table 19.

TABLE 19. Barley (Tribute variety yields in kg/mesh, Twairij 1957/58

	average	maximum
no fertilizers	560	988
5 kg N/mesh	680	997
10 kg N/mesh	670	1155
20 kg N/mesh	800	1295

During the first year of cultivation high yields of barley were obtained at Twairij even without the use of fertilizers. A comparison of these results with those obtained at Dujailah reveals some striking differences. At Dujailah only low yields could be obtained from the leached soils without the addition of fertilizers, whereas at Twairij much better yields were obtained under the same conditions. It would seem that the natural forces building up soil fertility are much more active in Twairij than in Dujailah, the Annanah plot occupying a middle position in this respect.
The quality of the irrigation water could have some bearing on this problem. Analysis of irrigation water of the main ditch at Twairij (Euphrates water) shows figures of 5 to 10 ppm of nitrate, compared to zero or traces in Dujailah (Tigris) irrigation water. This may partly explain the results obtained, but further research is required.

b. Wheat

So far there is less data available on wheat, which is a less salt tolerant crop and usually only sown on the better soils.
At Dujailah all wheat was grown on basins which had been heavily leached and where the EC_e values of the upper 30 cm of the soil were already less than 4 before sowing. A yield of over 400 kg/meshara was obtained on these plots with nitrogen dressings of 12 or 24 kg/mesh (table 20). This seemed fairly promising as at present wheat-growing is almost an impossibility in the Dujailah area.

TABLE 20. Wheat yields in kg/mesh, Dujailah 1956/57

EC_e[1])	No N		12 kg N/mesh		24 kg N/mesh	
	No P	P[2])	No P	P	No P	P
2	–	130	–	417	375	–
2–4	–	160	370	359	–	425
4–8	90	–	335	367	–	–

[1]) EC_e of 0–60 cm horizon before sowing.
[2]) 10 kg P_2O_5 per meshara.

The year after (1957/58) a better yielding variety, Ajeebah, was sown, resulting in much higher yields, as is shown in table 21. The salinity was low, viz. less than $EC_e = 4$ in all basins. The average yield was 680 kg/mesh. (the maximum being 750 kg/mesh), which may be considered very satisfactory.

TABLE 21. Average wheat yields (Ajeebah variety), Dujailah 1957/58, block I

	No fertilizer	10 kg N/mesh	20 kg N/mesh	20 kg N + 8 kg P_2O_5/mesh
yield in kg/mesh	200	350	440	680

A gradual, though slow build-up of soil fertility has been observed as the yield in the non-fertilized basins is also increasing. Moreover it has been noticed that phosphate has a very marked effect in the basins which received heavy nitrogen dressings for 2 years.
On the Annanah plot one meshara was planted with wheat on a partly reclaimed soil in 1957/58.
The yields (table 22) are higher than at Dujailah. The average yield of the unfertilized basins is particularly remarkable. The maximum yield obtained was 800 kg/mesh with the use of 20 kg N/mesh.

TABLE 22. Average wheat yields in kg/meshara (Ajeebah variety), Annanah 1957/1958

	No fertilizer	5 kg N/mesh	10 kg N/mesh	20 kg N/mesh
yield in kg/mesh	420	440	500	535

At Twairij 6 mesharas were planted with wheat in the winter of 1957/1958. The yields are shown in table 23. High yields of both wheat and barley can be obtained on these soils without the use of fertilizer.

TABLE 23. Wheat yields in kg/meshara (Ajeebah variety). Twairij 1957/1958

	No fertilizer	5 kg N/mesh	10 kg N/mesh	20 kg N/mesh
avge yield kg/mesh	465	532	574	682
max. yield kg/mesh	610	700	810	890

c. Fodders

Alfalfa and sweet clover were mostly grown on the more saline soils which were more or less unleached. This was done to test alfalfa and sweet clover as pioneer crops to be grown on the saline soils immediately after installation of the field drains. In this way an attempt could be made at gradually reclaiming the soil during crop growth and without heavy initial leaching. Table 24 shows some yields of alfalfa and sweet clover in relation to the soil salinity and nitrogen dressings.

TABLE 24. Yield of green material in kg/mesh, Dujailah, 1956/57

EC_e 0–60 cm	alfalfa		sweet clover	
	no nitrogen	8.5–20 kg nitrogen per meshara	no nitrogen	7–25 kg nitrogen per meshara
<8	1220	2600	3450	4885
8–16	865	2520	1790	2225
16–30	–	–	1260	1470
>30	460	560	1150	1300

With a high soil salinity the growth was poor as was shown by the yields. The maximum yields on the less saline soils were somewhat higher but still low owing to a low soil bacterial activity during earlier growing stages. This view is confirmed by the relatively great response to nitrogenous fertilizer.

The yields of both crops improved a great deal during the year of growth. The yield of the first three cuts of alfalfa in the second year exceeded the total yield of the first year, and at least six more cuts were expected in the second year.

The fodder crops show a distinct correlation between soil salinity and yield. Under all conditions sweet clover gave a far more satisfactory yield than alfalfa. Our results indicate that sweet clover may be a very valuable crop during the initial reclamation period.

Some Dujailah plots were sown with berseem with very little success. The yields were below those of alfalfa on the less saline soils. On soils with higher salinities (EC_e >8) the yield was practically nil, indicating a low tolerance of this crop to salt.

d. Other summer crops

In the summer of 1957 two mesharas of the Annanah plot were put under rice. The results are summarized in table 25.

TABLE 25. Rice yields in kg/mesh, Annanah 1957

	Average	Maximum
no fertilizer	750	950
7.5 kg N/mesh	850	1000
15 kg N/mesh	890	957

Very good yields were obtained from the first crop even without the use of fertilizer. The average EC_e of the surface soil was about 10 before planting and fell to 3 after the harvest. It would seem that rice is a good reclamation crop on these soils.

One meshara at Annanah was also planted with sesame in the summer of 1957. The yields obtained, including those from the basins which received no fertilizers, were well above the average for the area.

e. Potatoes

A potato-growing trial (Bintje variety), showed the low salt tolerance of this crop. Below $EC_e = 4$ a reasonable yield was obtained (table 26). With only a slight increase in soil salinity there was a considerable drop in the yield.

TABLE 26. Yields of potatoes in kg/mesh, Dujailah 1956/1957

EC_e 0–60 cm	6 kg N/mesh	15 kg N/mesh	45 kg N/mesh
2–4	1365	–	–
4–8	–	332	285

5.3. EFFECT OF SOIL NITRATE CONTENT ON YIELDS

A barley crop was sown in 1955 on about 20 mesharas. The results of the yields and the soil analysis are summarized in table 27. The EC_e and the nitrate figures are averages of two soil samplings, one taken before sowing and the other during growth. No fertilizers were applied to these basins.

TABLE 27. Barley yield in relation to nitrate and salt. Dujailah 1955/1956

EC_e 0–30 cm	Barley yield kg/mesh		Average NO_3, ppm	number of plots
	average	maximum		
2– 4	246	392	16	4
4– 8	344	445	33	4
8–16	334	732	50	9
16–30	259	307	54	4

The following deductions may be made from the table: –

a) The highest average yield was obtained with salinity level between EC_e 4 and 16; below and above this range the yield decreased.
b) The unexpected decrease in yield with low salinities goes with a lower soil nitrate content.

The normal tendency of yields to increase with decreasing soil salinity appears to be complicated by a simultaneous decrease in soil nitrate content, which has a reverse effect on yield. No simple relationship can be found between soil salinity and yield without taking into account the nitrate level of the soil. An attempt was therefore made to separate the two influences on yield.
In Fig. 24 the yield is plotted against the soil nitrate content of basins which had EC_e values of from 8 to 12. A rectilinear response of the yield to the nitrate level of the soil is shown.

If the effect of nitrate on yield is assumed to be independent of the effect of salt on yield, the influence of nitrate can be eliminated by reducing the yields obtained to a constant nitrate level of say 50 ppm. If the yield data thus corrected are plotted against the corresponding EC_e values, the dependence of yield on salinity becomes clear, as shown in Fig. 25.

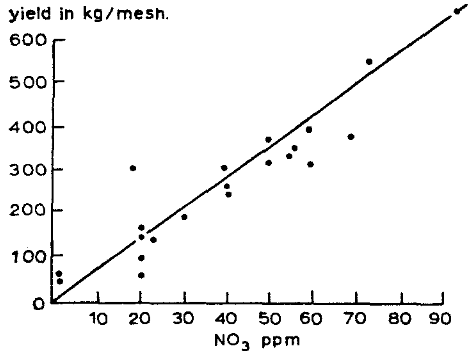


Fig. 24. Relation between the yield of barley and the nitrate content of the upper 30 cm of soil
$EC_e = 12$ mmhos/cm

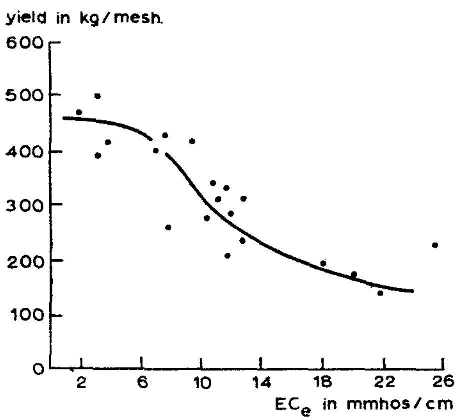


Fig. 25. Relation between the yield of barley and salinity of the upper 30 cm of soil
NO_3 content: 50 p.p.m.

As shown in Fig. 26, a number of curves can now be drawn for different nitrate levels. The two figures show that the yields definitely fall at EC_e values of over 8–12 and that quite good yields of barley can be obtained on saline soils if the nitrate level of the soil is high. This agrees with the data of table 17.

As Fig. 27 shows, there is a general positive correlation between the EC_e and nitrate value of the soil in situ, so that it is not surprising that the highest yields are obtained on soils of moderate salinity. Under these conditions the nitrate soil salinity ratio seems to reach the optimum for barley growth.

Points A, B and C in Fig. 26 represent the average nitrate contents of Fig. 27 for the corresponding EC_e values. While the soil salinity is reduced as a result of leaching, the line A-B-C demonstrates the decrease in yield during leaching under field conditions.
It is not claimed that Fig. 26 represents the absolute yield values, even for Dujailah

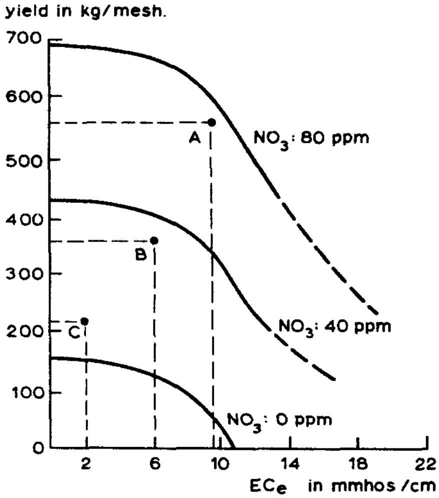


Fig. 26. Relation between the yield of barley and salinity of the upper 30 cm of soil at various nitrate levels

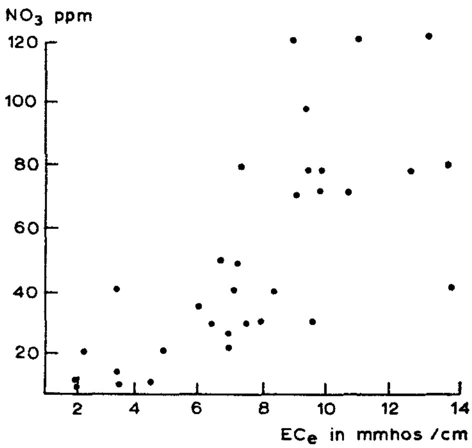


Fig. 27. Relation between EC_e and nitrate content of the upper 30 cm of soil

conditions, but is probably not far off these values, basing them on the yields obtained by the local farmers.
The above analysis proves that of the many factors influencing yield soil salinity is the most important, followed by the nitrogen level of the soil. As the latter will be raised by

nitrogenous fertilizer dressings, the marked response of the yields to such dressings, as demonstrated above, can be readily understood.

It follows from these experiments that if the soils have been leached to a certain salinity level (approximately $EC_e = 8$) more benefit may be expected from fertilizer application than from further leaching. This was found to be true of all winter crops tested and even of legumes. However, the increase in yield resulting from nitrogenous fertilizer will differ according to the salt tolerance of the crop. This means that in order to obtain optimum results leaching of saline soils should be accompanied by an improvement in other growing conditions, in particular the application of plant nutrients.

5.4. USE OF CROP ROTATIONS IN THE RECLAMATION

It has often been thought that once the drainage system has been established it would only take a few weeks for the soil to be reclaimed from salt by leaching through flooding. The matter proved to be much more complicated as in many cases no higher yields resulted from leaching. It was found that it took much longer to build up a reasonable level of soil fertility than to leach the salts.

The most obvious way of eliminating the salts is to preleach the soil until the salt content is sufficiently low over a certain depth of the profile and then to start cropping. Our results show that the best nett profit can probably be obtained from the land by following this method, provided ample amounts of fertilizer are given to the crop and the land is intensively cropped.

But this procedure cannot be recommended for large-scale application in Iraq. The present extensive fallow farming system cannot be changed overnight into intensive farming and there would be technical and economical difficulties in the way of supplying farmers with sufficient water and fertilizer. Moreover the considerable increase in yield over a fairly short period would create a labour shortage and marketing difficulties. Hence the object of the experiments was to find a reclamation procedure in which the heavy initial leaching was avoided and leaching carried out gradually by normal irrigation or over-irrigating the land which is kept under a certain crop rotation. This type of leaching is a slow process, the production capacity of the land is improved accordingly, and the farmers are given time to adapt themselves to changing conditions and gradually intensify their farming systems.

Under these circumstances long-term crop rotations, with or without moderate flooding before cropping, and including legumes in order to maintain soil fertility, seem more suitable for reclamation. For the Dujailah experiments a cropping pattern has been introduced which is based on the following three principles: –

1. Approximately 25 cm of the soil profile is leached every cropping season, either in winter or summer, with normal local irrigation practices on a drained soil. This was concluded from the experimental results available so far as being a more or less

uniform standard for all drain spacings and various crops (with the exception of rice). Accordingly a crop like sweet clover, which grows from November to August, is counted as 2 seasons or 50 cm leaching, and crops like alfalfa or grasses as 25 cm leached soil for every winter or summer season they are in cultivation.

2. If the salts in the soil are leached to a depth of 125–150 cm the reclamation is considered as being complete. This means that according to the leaching graphs (Fig. 19, Chapter 3), for a soil with an initial salt content of approximately $EC_e = 60$ mmhos/cm a leaching depth of approximately 1.50 is required to arrive at an EC_e of less than 4 mmhos for this layer.
3. The crop sequence proposed is such that the salt-resistant crops grown in the first stage are gradually replaced by less resistant crops as the salinity conditions of the soil improve.

   The simplest reclamation rotation basis on these principles is given as I–0, table 28 (DUJAILAH EXP. 5, 1958). It is an extensive rotation chiefly consisting of barley and wheat crops and resembles the kind of rotation at present practised on the better soils of Iraq.

   All other rotations are derived from this one by substituting a number of crops, starting with initial leaching with an equivalent water depth or with legumes.

TABLE 28. Crop rotation during reclamation

	1st year		2nd year		3rd year		4th year	
	winter	summer	winter	summer	winter	summer	winter	summer
I: NO INITIAL LEACHING								
I–0: no legumes	Ba	fa	Ba	fa	Wh	fa	Wh	Gg
I–1: 1 year legumes	Scl	Scl	Ba	fa	Wh	fa	Wh	Gg
I–2: 2 years legumes	Scl or Alf		Scl or Alf		Wh	Gg		
I–3: 3 years legumes	Alf		Alf		Alf			
II: 25 CM INITIAL LEACHING								
II–0: no legumes	Ba	fa	Wh	fa	Wh	Gg		
II–1: 1 year legumes	Scl	Scl	Wh	Gg				
II–2: 2 years legumes	Scl or Alf		Scl or Alf					
III: 50 CM INITIAL LEACHING								
III–0: no legumes	Wh	fa	Wh	Gg				
III–1: 1 year legumes	Scl	Scl	Wh	Gg				
III–2: 2 years legumes	Scl or Alf		Scl or Alf					
IV: 100 CM INITIAL LEACHING								
IV–0: no legumes	Wh	Gg						
IV–1: 1 year legumes	Scl	Scl						

Ba = barley Wh = wheat Scl = sweet clover fa = fallow Gg = green gram Alf = alfalfa

Initial leaching mainly serves to shorten the reclamation period and can also be applied to very saline lands on which a crop grown without initial leaching would probably not give any return. Legumes serve to maintain or augment the chemical fertility level and ameliorate the physical status of the soil.
From this lay-out the best reclamation procedure should be arrived at by selecting the combination of initial leaching, legumes and length of crop rotation which will give the highest yields and best financial return under the given circumstances. The utility of the reclamation rotations can be gauged from the salinity and fertility characteristics of soil samples and the crop yields. The combination of factors in the crop rotation that give the best result from the point of view of reclamation will be compared as far as possible for plots with different drain spacing and depth. By the summer of 1959, when our observations ended, there was still not enough experimental data to enable us to draw definite conclusions on the best rotations for Dujailah soils. According to the scheme discussed here, these results will be made available in a few years' time.
For the sake of completeness the rotation planned for intensive cropping after reclamation is presented in table 29.

TABLE 29. Proposed crop rotation after reclamation

1st year		2nd year		3rd year		4th year	
winter	summer	winter	summer	winter	summer	winter	summer
wheat or barley	fallow	berseem or sweetclover or broadbeans	lubia sesame greengram	fallow	cotton or peanuts	barley or wheat	fallow

In our opinion this rotation is a good approximation of the one which can be practiced on reclaimed soil by the settlers. It is a 4-year rotation with 25 % winter fallow and 50 % summer fallow, one winter crop in three and alternate summer crops being legumes. The rotation includes small grains, fodders and cash crops. The rotation proposed here is not, however, claimed to be the only one possible. More experimental work is required and the results of this may lead to even better alternatives.

6. CONSUMPTIVE USE

6.1. INTRODUCTION

During the cultivation period following leaching the quantities of irrigation water and the amounts discharged by the drains were measured in connection with the experimental work. This data was mainly assembled in order to study the salt movement in the soil; it can, however, also be evaluated to provide information on the consumptive use by crops.

Very little information is available on the consumptive use under Iraqi conditions, so that the water requirements of new irrigation schemes have hitherto been assessed by indirect methods in which the consumptive use was calculated from meteorological data, using the Blaney-Criddle or Penman method. These methods have yielded very satisfactory results in the U.S.A. and Europe, but it is still doubtful whether they give good results under the extreme and different climatic conditions of Iraq. In this chapter the field consumptive use data actually measured will be discussed and compared with the results obtained with the Blaney-Criddle and Penman methods.

The terms consumptive use (C.U.) and evapotranspiration (ET) as used in this section are equivalents and include both the transpiration of the crop and the evaporation of the cropped soil.

6.2. EXPERIMENTAL CONSUMPTIVE USE

— *Field data*

The data was assembled from the Dujailah experimental farm from a plot with covered drains 1.2 metres deep and with a 25-metre spacing. To eliminate disturbing influences at the boundaries only the data of a 25 × 150 metre drainage unit in the centre of the plot was evaluated (see Fig. 28).

The plot was leached during the spring of 1956 and from then on continuously under summer or winter crops. Except for the first crop following leaching, all crops were given fertilizer. Nitrogen was applied to the whole unit at the rate of 10 kg N per meshara per season, and half the unit was also given triple phosphate at the rate of 8 kg P_2O_5 per meshara per season. The C.U. was calculated from the following water balance equation: –

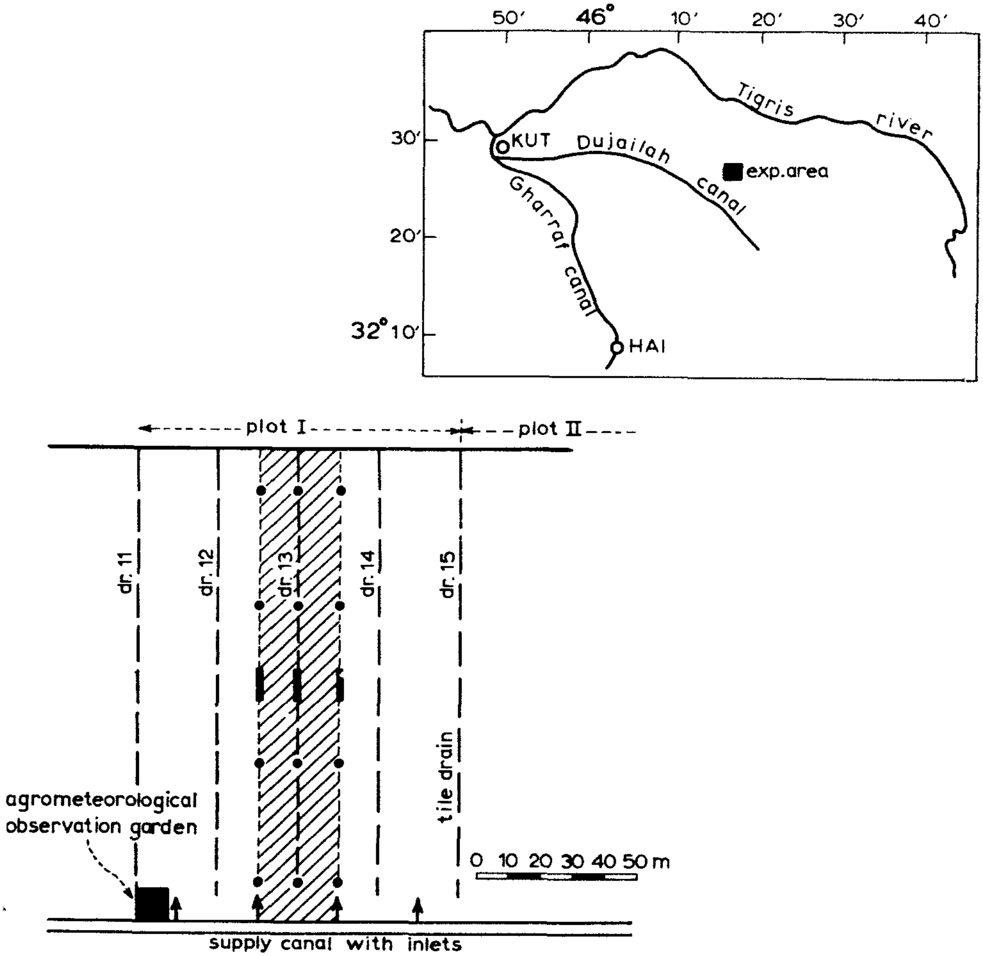


Fig. 28. Location and layout of experimental area

▒ drainage unit for which water balance data are given

● observation wells

— piezometer sets; 6 wells at 0.5, 1.0, 1.5, 2.0, 3.5 and 5 m depth

$$ET = I + N + G - P + \Delta M = I + N - D + \Delta M \tag{1}$$

ET = evapotranspiration or consumptive use (mm)
I = total amount of irrigation water applied (mm)
N = effective rainfall = precipitation minus surface runoff (mm)
G = moisture supply from below (mm)
P = downward percolation (mm)
ΔM = decrease in water stored in the soil profile (mm)
D = P - G = quantity of water draining from the subsoil (mm)

Subsoil water supply by seepage from the main canal could be ignored since these amounts were found to be negligible. Hence the quantity of water draining from the soil (D) can be assumed to be equal to the actual discharge of the field drain. Irrigation quantities, drain discharges and precipitation amounts are measured as described in Annex I. The growing season was subdivided into short periods for each of which the water balance was established. Each period includes one irrigation, the corresponding discharge period ending on the last day on which the drain discharge was recorded. As a result the moisture conditions in the profile will be approximately the same at the beginning and end of each period, the effect of ΔM being eliminated. Hence the water balance per period becomes: -

$$ET = I + N - D \tag{2}$$

The water balance data per period is given in table 30 (see page 72).

— *Accuracy*

The precipitation errors will be relatively slight, so that the ET error will mainly depend on the degree of accuracy with which I and D are known.

Thus: -

$$\Delta ET = \Delta I - \Delta D \tag{3}$$

$$(\delta ET)^2 = (\delta I)^2 + (\delta D)^2 \tag{4}$$

or: -

$$\left(\frac{\delta ET}{ET}\right)^2 = \left(\frac{I}{ET}\right)^2 \cdot \left(\frac{\delta I}{I}\right)^2 + \left(\frac{D}{ET}\right)^2 \cdot \left(\frac{\delta D}{D}\right)^2 \tag{5}$$

ΔET, ΔI, ΔD: the ET, I, D errors
δET, δI, δD: the mean error of ET, I, D
$\frac{\delta ET}{ET}$, $\frac{\delta I}{I}$, $\frac{\delta D}{D}$: the relative mean error of ET, I, D

TABLE 30. Water balance data and consumptive use, Dujailah, 9-12-1956 to 23-5-1958

period from	to inclusive	I mm	N mm	D mm	C.U. mm	C.U. mm/day	mean error[1]) C.U. %
9–12	29–12	60	16	49	27	1.3	21
30–12	25–1	56	11	35	32	1.2	14
26–1	23–2	58	12	29	51	1.8	9
24–2	10–3	0	49	21	28	1.9	8
11–3	24–3	54	6	22	38	2.7	9
25–3	9–4	48	47	39	56	3.5	8
10–4	14–6	324	66	95	295	–	6
15–6	25–6	87	–	20	67	6.1	7
26–6	2–7	85	–	18	67	9.6	7
3–7	9–7	56	–	7	49	7.0	6
10–7	19–7	130	–	8	122	12.2	5
20–7	29–7	132	–	7	125	12.5	5
30–7	7–8	109	–	6	103	11.4	5
8–8	13–8	104	–	4	100	16.6	5
14–8	22–8	100	–	5	95	10.6	5
23–8	2–9	101	–	4	97	8.8	5
3–9	11–9	110	–	14	96	10.7	6
12–9	24–9	137	–	22	115	8.9	6
25–9	31–12	80	134	58	156	–	5
1–1	10–1	58	6	35	29	2.6	16
11–1	25–1	59	17	48	28	1.9	20
26–1	6–2	74	14	60	28	2.3	26
7–2	17–2	89	–	55	34	3.1	21
18–2	28–2	67	–	38	29	2.6	18
1–3	15–3	89	1	28	62	4.1	9
16–3	12–4	150	–	54	96	3.4	10
13–4	21–4	71	–	16	55	6.1	7
22–4	25–5	111	–	28	83	–	8

[1]) The percentage mean error refers to the total C.U. per period. The error in the daily C.U. will also be influenced by the accuracy of the length of the period in days and therefore be greater.

I = irrigation N = precipitation D = drainage C.U. = consumptive use

Equation (5) shows the relationship between the relative mean errors of ET, I and D. These errors of I and D were estimated at 5 and 10 % respectively. The calculated percentage mean ET errors are given in table 30.

Table 30 shows that during the summer season, with high ET values and low drainage quantities, the ET values are fairly accurate, viz. there is a 5–10 % margin of error.

The ET-values for the winter cropping season are much less reliable, with mean errors of from 10 to 20 %.

— *Field results*

The irrigation, drainage and consumptive use data per calculation period is given in table 30. This data summarized per cropping season is given in table 31.

TABLE 31. Principal irrigation, drainage and consumptive use data per crop

	Barley 1956/1957	Green Gram 1957	Wheat 1957/1958
date of sowing	*1–12*	*1–6*	*28–11*
date of first irrigation	*1–12*	*1–6*	*23–12*
water table before 1st irrigation in m[1])	11.10	11.16	11.14
1st watering in mm	147	190	80
date of last watering	*28–3*	*19–9*	*17–4*
date of harvest	*15–5*	*29–9*	*12–5*
water table at harvest in m[1])	11.18	11.25	11.13
growing period, days	166	121	166
total number of waterings	6	14	10
total irrigated (I) in mm	433	1475	737
average depth per watering in mm	72	105	74
total rainfall (N) in mm	200	–	126
total supplied (I + N) in mm	633	1475	863
total drained (D) in mm	236	180	378
total consumptive use (C.U) in mm	397	1295	485
average consumptive use in mm/day	2.4	10.7	2.9
drainage percentage of irrigation	55	12	66

[1]) water table referred to mean sea level.

The average water depth per irrigation was 73 mm for both winter-crop seasons. The total depth of irrigation was 433 mm over 1956–1957 and 757 mm over the following season. This difference is mainly due to the fact that during the second winter the soil was deliberately irrigated more heavily in order to reduce the salt content of the soil.

For the green gram summer crop the average amount of water supplied per irrigation was 105 mm. Such heavy waterings are contrary to Iraq farming practice, but had to be given owing to difficulties in the regular water supply. It was found, however, that waterings of over 100 mm at relatively long intervals did not cause any excessive losses or harm to the plant development. The total irrigation for the second summer crop was nearly 1500 mm.

The consumptive use for barley during the winter 1956–1957 was about 400 mm and around 500 mm for wheat grown the following winter. In both cases the growing period was 166 days. The difference between the two winter seasons is unrelated to the type of crop, but, as will be discussed below, it is related to climatic conditions during the two years. The precipitation still appears to be an important factor for winter growth.

During the first winter the precipitation contributed as much as 50 % to the total C.U. Owing to the rainfall, the crop could be sown without irrigation during the second season and received its first watering after about a month.
Assuming the average C.U. for winter crops to be 450 mm and the average precipitation 150 mm the average irrigation required, allowing for a 20 % subsoil run-off, would be 375 mm.
The C.U. for the green gram summer crops was 1300 mm over a growing period of four months.

Allowing for 20 % drainage, the irrigation required would be in the order of 1600 mm per summer crop, or more than four times the average water depth required for winter cultivation. The monthly water requirements in summer are even more than five times the winter requirements. This means that less than 20 % of the area under a winter crop can be planted with a summer crop with constant canal supply over both seasons. Even if all leaching required is carried out during the winter season the area under a summer crop should not exceed 25 % of the area under a winter crop.
It may thus be concluded that with an irrigation scheme designed to irrigate 80 % of the gross area in winter, only 20 % of this area can be irrigated during the summer. If more than 20 % summer crops are required, it should be accepted that the summer water requirement is the governing factor in the canal design.

6.3. CONSUMPTIVE USE ACCORDING TO THE BLANEY-CRIDDLE, PENMAN AND PAN-EVAPORATION METHODS

There is a wide choice of formulas for computing the C.U. from meteorological data. For the present study the Blaney-Criddle, Penman and pan-evaporation methods were selected. The first is in general use in Iraq because only temperature records are needed, the second has a very sound physical foundation and is therefore considered to have more uniform validity for a wide range of climates, the third is a direct empirical method which has advantages if it appears to be reliable.

— *The Blaney-Criddle method*

The consumptive use formula of BLANEY-CRIDDLE (1950), reduced to millimetre units, is written as follows: -

$$U = K_b f \qquad (6)$$

$$f = \frac{25.4tp}{n} \qquad (7)$$

U = average consumptive use in mm/day
K_b = empirical Blaney-Criddle coefficient which may vary according to crop, season and area

f = consumptive use factor
t = mean monthly temperature in ° Fahrenheit
p = monthly daytime hours as a fraction of the annual total
n = number of days per month

The coefficient K_b for arid climates is given as between 0.65 and 0.85 (BLANEY and CRIDDLE, 1950); here 0.75 is used.

— *The Penman method*

The consumptive use according to PENMAN (1948) is given by

$$ET = K_p E_o \tag{8}$$

K_p = empirical coefficient
E_o = the evaporation of a free water surface, to be calculated with the PENMAN-formula as a function of temperature, humidity, wind speed and hours of actual sunshine in relation to day-length.

The empirical coefficient K_p depends on the development of the crop and differs slightly according to the season. The values given by PENMAN (1955) for England are 0.6 and 0.8 for winter and summer growth respectively in case of a short grass cover with an optimal water supply. The same values are used in our calculations.

— *The pan-evaporation method*

It was established as an empirical relationship (KOHLER et al., 1955) that the evaporation of a free water surface is approximately 0.7 times the evaporation measured in an evaporation pan according to the specifications of the U.S. Weather Bureau and known as the class 'A' pan. Since according to PENMAN the consumptive use is also direct proportional to the evaporation of a free water surface, we may write

$$C.U. = K_e E_e \tag{9}$$

E_e = pan-evaporation, U.S. Weather Bureau Class 'A' pan
K_e = empirical coefficient

For our calculations of K_e we used the empirical coefficients of Penman multiplied by 0.7, giving 0.42 for winter crops and 0.56 for summer crops.

— *Results*

The various calculated consumptive use values, as well as the consumptive use, actually measured, are given in table 32 and Fig. 29. The same table also shows the values for f (Blaney-Criddle), E_o (Penman) and E_e (pan-evaporation).

TABLE 32. Measured and calculated C.U. and related values in mm per day

year	month	exp. C.U.	Blaney-Criddle f	Blaney-Criddle C.U.	Penman E_o	Penman C.U.	pan evaporation E_e	pan evaporation C.U.	crop	notes
1956	12	1.2	3.0	2.2	1.4	0.8	–	–	Barley	[1])
1957	1	1.3	2.9	2.2	1.6	1.0	–	–	sown 1–12	
	2	1.8	3.5	2.6	3.2	1.9	2.6	1.1	harv. 15–5	
	3	2.5	4.4	3.3	4.1	2.5	3.5	1.5		
	4	3.6	5.2	3.9	4.9	2.9	7.6	3.2		[2])
	6	7.1	7.4	5.6	10.8	8.6	22	12	Green gram	[3])
	7	11.0	7.6	5.7	11.7	9.4	23	13	sown 1–6	
	8	11.4	7.2	5.4	9.8	7.8	22	12	harv. 29–9	[6])
	9	9.6	7.3	5.5	8.9	7.1	18	10		[4])
1958	1	2.3	3.1	2.3	1.8	1.1	2.3	1.0	Wheat	
	2	2.7	3.5	2.6	3.5	2.1	3.8	1.6	sown 28–11	
	3	4.0	4.6	3.5	5.4	3.2	7.7	3.2	harv. 12–5	
	4	4.5	5.8	4.4	7.0	4.2	13	5.5		[5])

NOTES:
[1]) Exp. C.U. from 9–12 to 31–12.
[2]) Exp. C.U. from 1–4 to 9–4.
[3]) Exp. C.U. from 15–6 to 31–6.
[4]) Exp. C.U. from 1–9 to 24–9.
[5]) Exp. C.U. from 1–4 to 21–4.
[6]) The green gram is still green when harvested.

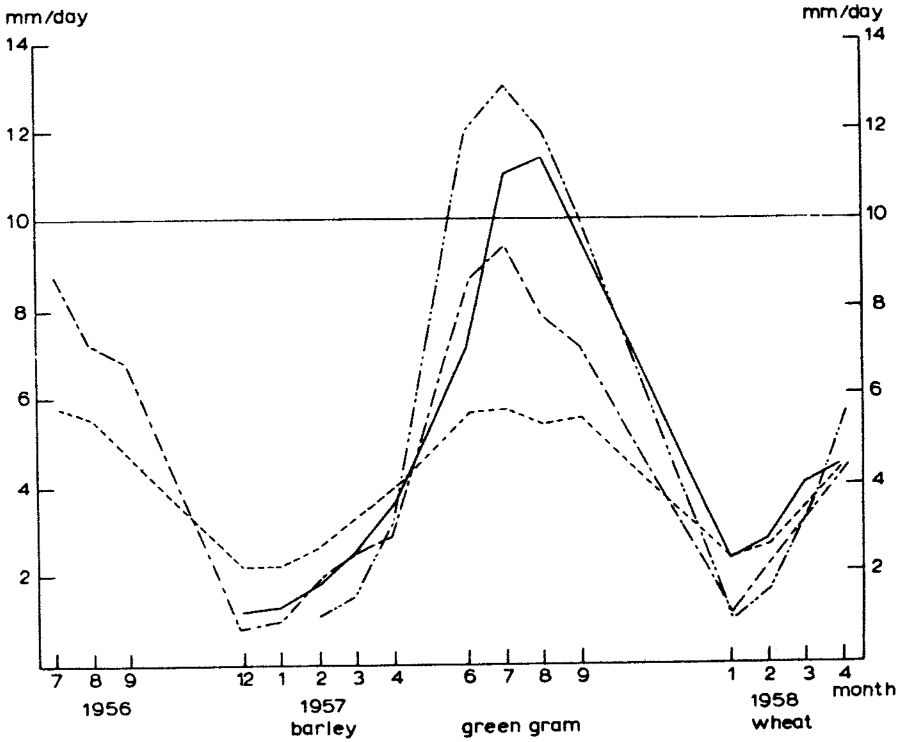


Fig. 29. Consumptive use Dujailah experiments, 1956–1958

—— field experiments
------ Blaney-Criddle, K_b = 0.75
-.-.-. Penman, K_p-winter = 0.6
K_p-summer = 0.8
-..-..- pan evaporation, K_e-winter = 0.42
K_e-summer = 0.56

6.4. DISCUSSION

— *General*

The C.U. actually measured varies from ca 1 to 2 mm/day in December and January to over 11 mm in July and August. The maximum recorded was 100 mm over a 6-day period (table 30), i.e. 16.6 mm/day. Both the maximum and average July and August values are extremely high compared to data given in the literature for other countries. These unusually high results are supported by the pan-evaporation records which show an average of nearly 30 mm/day over July 1957. Considering also the extreme climate of Iraq, with an average temperature of over 35°C during July and August, a humidity below 20 % and a wind speed of over 4 m/sec. they do not seem unlikely.
The Blaney-Criddle formula with a crop coefficient of 0.75 gives far too low values for the C.U. of the summer crop. This is very important in connection with the assessment of water requirements of irrigation schemes by the Blaney-Criddle method. During the winter period the Blaney-Criddle values agree very well with the experimental data, although they are slightly on the high side. The Penman results show a somewhat better agreement with the experimental data than the Blaney-Criddle values, although they are still on the low side and particularly low in summer.
The deviations between the experimental and calculated values may be partly explained by the fact that the experimental conditions do not always entirely coincide with the conditions required for applying the calculation methods. But there is no question that the Blaney-Criddle and Penman methods, if applied with the empirical coefficients specified in the literature, give too low values for summer consumptive use. If the coefficients are adjusted to the conditions of Iraq better results are obtained as will be discussed below.

— *Experimental and Penman values*

To facilitate the discussions, the experimental C.U./E_0 ratio for the various monthly periods has been calculated and is presented in table 33.

TABLE 33. Empirical K_p coefficients according to C.U. (experimental) = K_pE_0

	Green gram				Barley (1956–1957) followed by wheat (1957–1958)				
	June	July	Aug.	Sept.	Dec.	Jan.	Febr.	March	April
1956–1957	–	–	–	–	0.9	0.8	0.6	0.6	0.7
1957–1958	0.7	0.9	1.2	1.1	–	1.3	0.8	0.7	0.6

For winter crops the coefficients for both barley and wheat are 0.6 and 0.7 during the last two months of the growing season. These coefficients seem quite reasonable; for England PENMAN (1955) gives 0.6 for winter and 0.8 for summer growth. The data are not entirely comparable as the Penman results refer to a short grass covered soil with an optimum water supply. For the first and second month of the winter growing season the coefficients are noticeably higher than during the other months. This is different from what would normally have been expected, as during the first months after sowing the soil is only partly covered and there will only be slight transpiration by the plants.

This disagreement may possibly be due to a systematic error in the irrigation or drainage quantities. During the first months of the winter cropping season systematic errors in the irrigation and drainage quantities have a substantial effect on the percentage accuracy of the C.U. (see table 30). During the remaining months of the winter season and in summer, errors in the drainage quantities, which are most likely to occur, have scarcely any effect on the percentage accuracy of the C.U.

Another possible explanation may be found in the heat energy stored in the soil, these not being allowed for in the Penman formula. There are great annual variations in soil temperature in Iraq; at a depth of 50 cm an annual temperature amplitude of 20° C was recorded at the Dujailah station. There is intense heating of the soil during the non-irrigated period between the summer and winter crops and the soil temperature will fall rapidly as soon as the winter irrigation season begins. The heat energy which then becomes available will contribute to the evaporation of the soil and crop.

The Dujailah records are unsuitable for working out this aspect quantitatively, but even a rough calculation shows that a decrease of 10 degrees centigrade per month, averaged over 50 cm of the soil profile would be sufficient to account for the disagreement between the experimental and the calculated results for the first two months of the winter crop.

The coefficients for the summer season are 0.7 for the first month and 0.9 to 1.2 for the remaining months. These values are far above those obtained for the winter crops and those given by PENMAN for England.

The high coefficients for Iraqi summer conditions seem reasonable since:

1. the summer drainage discharge has very little effect on the C.U. and a considerable systematic error in the irrigation quantities, which is not very likely, may reduce the summer consumptive use, but will reduce the winter C.U. values even more. As a result the summer coefficients would more closely approximate those given in the literature, but on the other hand the winter coefficients would be unfavourable compared to other countries.
2. MAKKING (1951) reports that the crop length has a great effect on evapotranspiration. It was only in the case of very short grass that he found empirical coefficients of less than 1.
3. Where the cropped area is small and surrounded by non-irrigated land, the actual evapotranspiration may exceed the potential evaporation (E_0), because conditions for evaporation and transpiration are much more favourable along the boundary of the cropped area than inside it. This influence is known as the desert effect.

The experimental results were obtained from an area of 100 × 150 m surrounded by

land not cultivated in summer. But the actual conditions under which summer crops are grown in Iraq are not so very different as only a small part of the total area is cultivated with summer crops, usually in small plots.
Summarizing it may be concluded that the Penman method can be used for estimating the consumptive use in Iraq provided the following values are used for the K_p coefficient. For winter 0.6 to 0.7, with possibly a higher value for the first month; for summer 1.0 to 1.2, which may be reduced to approximately 0.7 for the first month.

— *Experimental and Blaney-Criddle values*

The empirical K_b coefficients, obtained by dividing the experimental C.U. by the C.U. factor according to Blaney and Criddle, are summarized in table 34. The general trend of the results is the same as that found with the Penman method.
The K_b coefficients for the second winter crop are between 0.7 and 0.9. These values seem reasonable compared to the values published by Blaney and Criddle (1950). These authors give values of from 0.65 to 0.85 for arid climates and different crops. The coefficients for the 1956–1957 winter crop are lower than those for the 1957–1958 winter crop, and the value for the first month of the growing season is lower than for the other months.

Table 34. Empirical 'K_b' coefficients according to C.U. (experimental) = $K_b f$

	Green gram				Barley (1956–1957) followed by wheat (1957–1958)				
	June	July	August	Sept.	Dec.	Jan.	Febr.	March	April
1956–1957	–	–	–	–	0.4	0.5	0.5	0.6	0.7
1957–1958	1.0	1.4	1.6	1.3	–	0.7	0.8	0.9	0.8

The summer K_b value is 1.0 during the first month and 1.3 to 1.6 for the remaining months. These values are about twice those found for the U.S. and used in Iraq. This difference might be partly explained by the desert effect and by the extreme climate of Iraq. Most of the work on the Blaney-Criddle coefficients was carried out at Davis, California. The nearest station from which meteorological data were available (Climate and Man, 1941) is Sacramento, about 35 km away.
Table 35 (see next page) gives a comparison between Hai and Sacramento with respect to temperature and precipitation; no information was available on humidity and wind speed at Sacramento.

— *Experimental and pan-evaporation values*

The coefficients by which pan evaporation has to be multiplied to obtain the experimental C.U. are summarized in table 36 (turn page).

TABLE 35. Climatic data for Hai (Iraq) and Sacramento (U.S.A.)

		Hai (12 years)	Sacramento (40 years)
Temperature (centigrades)	avge. January	10.6	13.1
	avge. July	35.7	28.8
	max. observed	50.0	45.5
	min. observed	-6.7	-8.3
rainfall average (mm)	year total	132	404
	June-August	0	4
	May–October	6	48

TABLE 36. Empirical K_e coefficients, according to C.U. (experimental) = K_eE_e

	Green gram				Barley (1956–1957) followed by wheat (1957–1958)				
	June	July	Aug.	Sept.	Dec.	Jan.	Febr.	March	April
1956–1957	–	–	–	–	–	–	0.7	0.7	0.5
1957–1958	0.3	0.5	0.5	0.5	–	1.0	0.7	0.5	0.4

The table shows that K_e decreases during the winter growing season. A similar effect was observed in the empirical coefficients for the Penman method, table 33, and was discussed there.

Except for the first month, the coefficients for the summer of 1957 are fairly constant, varying between 0.4 and 0.5.

Table 36 also shows that there is no great difference between the average winter and summer coefficients and that the winter values slightly exceed the summer ones, even when the high January value is omitted. This differs from what was found with the Penman and Blaney-Criddle methods in which the summer coefficients were 1.5 to 2 times the winter ones. The fact that the consumptive use/pan evaporation ratio is fairly constant throughout the year would appear to be further evidence of the reliability of the measurements and the experimental C.U. values.

The data available so far shows that the pan evaporation might be a useful tool for estimating the C.U. provided the proper coefficients are available. The resultant C.U. values would not appear to be less accurate than those obtained with other methods.

— *Comparison of Penman, Blaney-Criddle and pan-evaporation results*

In addition to the question as to which empirical coefficients to employ in the Penman, Blaney-Criddle and pan-evaporation method in order to assess the C.U. in Iraq, it is of interest to compare the methods among themselves, disregarding the empirical aspect.

Fig. 30 shows the mutual correlations between E_o (Penman), f (Blaney-Criddle) and E_e (pan-evaporation). The pan evaporation correlates fairly well with E_o and f, but the

regression line for E_0 practically passes through the origin, which is not the case with f. This explains why the Blaney-Criddle method gives higher values in the lower ranges compared to the Penman or pan-evaporation values.
The correlation between f and E_0 is surprisingly good. The empirical relationship is shown by $E_0 = 1.9\,f - 4.0$.

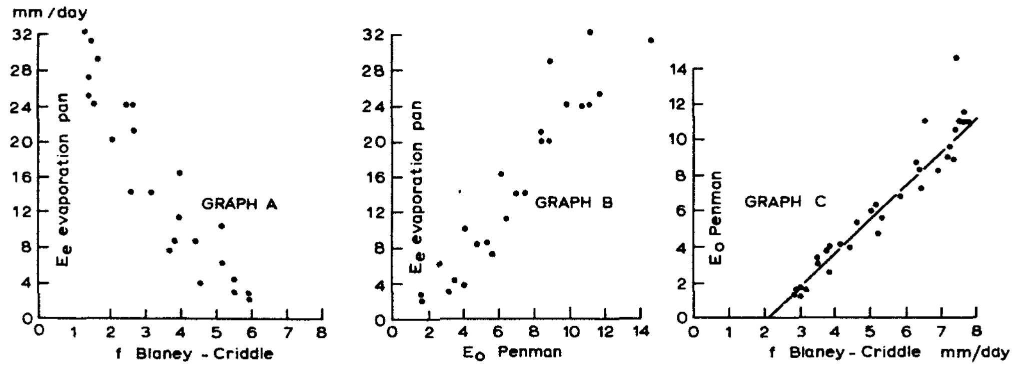


Fig. 30. Correlation between pan evaporation, potential evaporation according to Penman and consumptive use factor according to Blaney-Criddle
Observations are monthly averages in mm/day
Graphs A and B: period from 1-4-1956 to 31-5-1958
Graph C : period from 1-1-1956 to 31-8-1958

Apparently the climatic factors affecting evaporation and transpiration are closely interrelated in Iraq. Hence for Iraqi conditions practically the same results will be obtained with the Penman and the Blaney-Criddle formulas provided the proper empirical coefficients are used for each method and the different seasons. In general, therefore, the Blaney-Criddle method is to be preferred on account of its simplicity.

6.5. CONCLUSIONS

Field measurements of the consumptive use were compared with evaporation pan records and the consumptive use according to Blaney-Criddle and Penman.
The agreement between field data and Blaney-Criddle or Penman values was found to be reasonable for the winter season. During the summer the actual consumptive use was much higher than the calculated values when use was made of the empirical coefficient proposed by the authors, viz. 0.7 to 0.8 in the Blaney-Criddle and 0.8 in the Penman formula. The disagreement between values actually measured and those calculated may be explained by the so-called 'desert effect' and by the extreme summer climate of Iraq. Consequently the summer water requirements of irrigation schemes in Iraq may be greatly underestimated insofar as they are based on the Blaney-Criddle method.

But if modified empirical coefficients adapted to Iraqi conditions are used in the Penman and Blaney-Criddle calculation as well as in the evaporation pan method they could be very useful for estimating the consumptive use for both the summer and winter season. Mutual comparison of the three methods showed that their results were all equally reliable. For this reason the Blaney-Criddle method is to be preferred as being the most simple one.

The field experiments only covered one summer and two winter seasons, but so long as no better information is available the following coefficients are advised for use in the Blaney-Criddle formula: -

— winter crops	first month	0.5
	second month	0.7
	remaining period	0.8
— summer crops	first month	1.0
	second and last month	1.3
	period between	1.5

7. SOME PRINCIPLES GOVERNING THE DRAINAGE AND IRRIGATION OF SALINE SOILS

7.1. INTRODUCTION

The reclamation of saline land and the control of soil salinity require adequate subsoil drainage; moreover the irrigation requirements for saline soils differ from those applied to soils in which there are no salinity problems. But it is still necessary to specify what these specific irrigation requirements are under saline conditions and what is meant by adequate subsoil drainage. Certain aspects of these problems have already been mentioned in the previous sections. In the present section an attempt is made to give a general systematic treatment of these problems in their various aspects. Hence certain aspects already discussed may reappear here, although in a different context.

The required supply of irrigation water to the field will consist of an amount equal to the consumptive use plus an excess for leaching, The total amount of water thus obtained represents the field irrigation requirement, to which should be added waste and conveyance losses in order to obtain the irrigation requirement from a given canal take-off. The present discussion will, however, be confined to the field irrigation requirement.

The drainage requirement should be specified in order to decide whether any natural drainage present is sufficient and, if not, to what extent an artificial drainage system is required. The drainage requirements should be specified in such a way as to enable the system to be properly designed with respect to the depth, spacing and drain discharge capacity.

The function of a drainage canal is to evacuate water from the soil and to transport it to an outlet. Sometimes a distinction is made between the main drains, which are mainly for transporting water, and minor field drains mainly used for controlling the depth of the water table; in principle, however, each drain serves both purposes. The problem of water transport via canals, although an important aspect of the design, has no direct bearing on soil salinity. Our discussions will therefore be confined to the minor or field drains and only with respect to their function of controlling the water table and evacuating water from the soil.

The drainage of the soils of humid climates has been intensively studied (LUTHIN, 1957; VISSER, 1954). In humid areas drainage is needed to remove excess rainfall and to keep the ground water at a sufficiently deep level so as to provide the moisture conditions in the soil required for crop growth and farming operations. Consequently the drainage requirements are expressed in terms of the quantity of excess rain to be removed by the drainage system in a given period and of the ground water depth which should not be exceeded during the discharge periods. The required rate of drainage and the ground water depth depend on the rainfall characteristics, the soil and the type of crop.

Whereas in humid regions it is excess rainfall that causes the drainage need, in arid countries it is the lack of rainfall. Both problems are, however, fundamentally the same as regards the movement of water through the soil.

It is therefore logical to express the requirements of saline areas in a similar way as for humid areas, viz. as the quantity of leaching water to be discharged in a given period and the ground water depth (probably with a tolerated variation) which should not be exceeded in the interim. The quantity to be drained should be such as to keep the salt level of the soil sufficiently low. The required ground water depth is related to the air-moisture conditions required in the soil for plant growth and farming operations, and also to the risk of salinization by upward capillary movement of moisture.

As early as 1947 the drainage requirements for saline lands were defined in the above manner by the Drainage Manual Committee for the Imperial Valley and afterwards by the U.S. Salinity Laboratory (U.S.D.A., 1954). These principles have not yet been generally accepted. Several authors, for instance THORNE and PETERSON (1954) and BURINGH (1960) mainly specify the ground water depth which should be maintained but pay little or no attention to the quantity of water to be drained. Moreover the ground water depth specified varies from 4 to 5 ft (MAGISTAD and CHRISTIANSEN, 1944) to 10 ft or more (BURINGH, 1960). Apparently the ground water depth is given such importance in view of the risk of salinization by upward capillary movement of saline ground water, especially during periods when there is no irrigation. As to the quantity to be drained the authors probably assume the normal percolation losses to be sufficient for leaching.

The risk of salinization by upward capillary movement is usually exaggerated as it is often overlooked that the salinity of the ground water will decrease once the drainage system has been installed and leaching is begun. It should also be noted that except in areas which receive a subsoil water supply from canals or neighbouring areas the degree of salinization caused by capillary movement is only slightly related to the depth of the water table.

In many cases the normal percolation losses may be sufficient to ensure leaching but such an assumption should be checked; it is usually incorrect when the irrigation water is very salty. Moreover the quantity to be drained has to be specified in any case in order to calculate the drain-spacing required.
It will be clear that drainage is not a problem of static ground water but of movement of water through the soil. Ground water depth and discharge of the system are necessarily related and should not be regarded as separate and independent factors. The quantity of water to be drained depends on the salt balance in the soil. If insufficient water passes through the soil, salinity can never be effectively controlled by merely lowering the water table. For instance, owing to natural drainage certain irrigated regions in the Diyalah area in Iraq have a water table of 2 m or more from the surface. But these regions are saline up to now (McDONALD and partners, 1958) owing to the insufficient irrigation for leaching.

7.2. DRAINAGE FORMULAE

The function of the drainage formula is to describe the movement of ground water in a drained soil and to state quantitatively the relationship between the conditions governing this movement, viz.: –

- permeability of the soil profile; the hydraulic conductivity of the various soil layers together with their thickness and position.
- the rate of flow or discharge of the system.
- the hydraulic gradient causing the flow, viz. the difference between the water level in the soil and in the drain in relation to the drain spacing.

When the system consists of a regular pattern of parallel drains the hydraulic gradient is usually expressed in terms of drain distance and the available hydraulic head half-way between the drains, the latter being the difference between the water levels in the drain and the soil.
No general mathematical solution is known of the drainage flow, taking into account all possible aspects. The problem is so complex that simplifications had to be made. This means, however, that different drainage formulas have been developed, depending on the number and kind of simplifications, each formula being most suited for the actual field conditions which most closely approximate the conditions assumed for deriving the formula. A few drainage formulas will be briefly discussed.

— *Steady flow formulae*

These formulae are based on the assumption that the drain discharge and the depth of the water table remain constant and do not vary with time. One of the most suitable solutions for this case is given by HOOGHOUDT (LUTHIN, 1957). His equation takes into account the horizontal and radial water movement in the soil as well as the occurrence of an impervious stratum in the subsoil. ERNST made an empirical study of the drainage flow with the relaxation method. The results of his work were summarized by BOUMANS in a nomograph which is appended below (annex VI). Subsequently ERNST developed another useful method (1954) which makes it possible to take into account a stratification of layers with different permeability in the subsoil. For a brief description of this method reference is made to annex V.

A supplement to the Hooghoudt method, specially adapted to the specific conditions occurring in certain areas in Iraq, was developed by LINDENBERGH (annex VII). The formula has the advantage that problems related to the irregular stratification of the soil profile can be eliminated by the assumption of anisotropic permeability conditions. The method also shows the relatively great importance of the permeability of the soil in the neighbourhood of the drains and hence of a proper location of the drainage canals.

— *Non-steady flow formulae*

As already mentioned, the steady flow formulae assume a constant water table and a constant discharge of the drains. It will be clear that these assumptions do not agree with the actual situation because in an irrigated soil the water table and the drain discharge fluctuate according to the intermittent supply of irrigation water.

Non-steady drainage formulae which take into account the variation of water table and discharge with time are given by DUMM (1954) and KRAIJENHOFF VAN DE LEUR (1958). The latter allows for a constant vertical percolation of water from the surface into the saturated zone and is therefore most suitable for the drainage of saline soils. DUMM and KRAIJENHOFF assume the ground water flow to be horizontal, a simplification which had to be made to compensate for the mathematical complications of non-stationary flow.

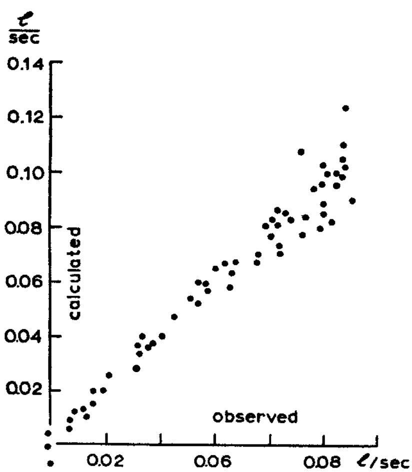


Fig. 31. Drain discharge observed and calculated with Annex VI for various plots (Dujailah)

The disadvantage of non-steady flow formulae is that they are complicated and difficult to handle. In most cases, however, the non-stationary drainage problem can be estimated sufficiently accurately by means of steady flow formulae if average values are used for the hydraulic head and the discharge. In this respect it should be noted that the reliability of drainage calculations is less affected by refinements of the calculation technique than by unavoidable variations and inaccuracies in the determination of such soil characteristics as the position of various soil strata and their hydraulic conductivity in a horizontal and vertical direction.

The justification of the use of steady flow formulae under non-stationary conditions is demonstrated in Fig. 31. This graph shows that assuming steady flow the calculated drain discharge agrees closely with the field discharges actually observed under non-stationary conditions. The plots concerned were irrigated at intervals of from 5 days to two weeks and both the water table and the drain discharges fluctuated accordingly.

7.3. THE WATER AND SALT BALANCE OF THE SOIL

In order to keep the salt content in the root zone at a certain level the amounts of salt added to the root zone during a given period of time should be evacuated by water percolating to the subsoil.

Salt is added to the root zone by irrigation water and ground water or soil moisture moving upward from deeper layers. Ignoring the salt supplied by rainfall, the salt balance for a certain depth of soil and over a certain period of time is in equilibrium provided: –

$$I \,.\, C_i + G \,.\, C_g = P \,.\, C_p \qquad (1)$$

I : irrigation supply (in mm water depth)
C_i : salt concentration of irrigation water [1])
G : moisture supply from below to the soil layer in question (in mm/water depth)
C_g : salt concentration of the water supply G [1])
P : percolation water draining from the soil layer in question (in mm/water depth)
C_p : salt concentration of percolation water P [1])

The equilibrium in salt balance of the soil will be first reached in the surface layers but will gradually extend downward and finally be established throughout the soil profile. Thus the salt concentration C_g of the water supply from below may be taken as being equal to the salt concentration of the percolation water, or: –

$$C_g = C_p \qquad (2)$$

If the period over which the salt balance is considered is such that the differences in moisture stored in the soil can be ignored, the moisture balance for the soil layer in question is: –

[1]) C_i, C_g and C_p as weight of salt per volume, or as EC (the electrical conductivity of a solution is fairly directly proportional to the salt concentration).

$$I + N + G = ET + P \tag{3}$$

N : effective rainfall (rain minus surface runoff) in mm
ET : evapotranspiration in mm

Substituting (2) and (3) in (1) we obtain: –

$$P - G = \frac{C_i}{C_p - C_i} (ET - N) \tag{4}$$

If there is a difference ΔM in the moisture stored in the soil between the beginning and end of the period in question, formula (4) becomes

$$P - G = \frac{C_i}{C_p - C_i} (ET - N + \Delta M) \tag{4a}$$

The quantity $P - G$, being the resultant of the downward flow P and the upward flow G, represents the depth of water to be evacuated from the subsoil (see fig. 32).

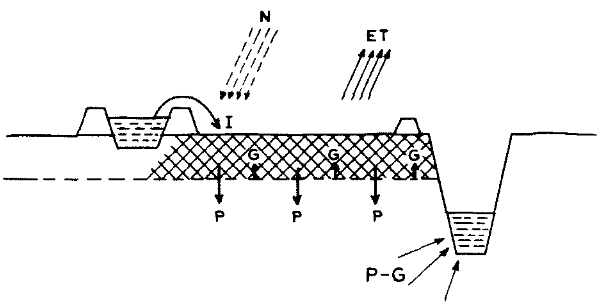


Fig. 32. Sketch of the water balance-factors (form. 4)

The salt concentration of the soil solution percolating from the soil layer in question (C_p) will be less than or equal to the concentration of the soil moisture in that layer (C_{sm}), or: –

$$C_p = f \cdot C_{sm} \tag{5}$$

in which f is a coefficient equal to or less than unity, and termed 'leaching efficiency'.
C_{sm} relates to periods of downward water movement, viz. to a moisture content of the soil between field capacity and saturation and probably close to the former.
Soil salinity is usually expressed as the electrical conductivity or salt concentration of diluted soil solution, e.g. the saturation extract, the 1 : 1 and other soil-water ratios.
Assuming the moisture content to be at field capacity during periods of downward water movement, equation (5) may be written: –

$$C_p = f \cdot \frac{M_{ex}}{M_{fc}} \cdot C_{ex} \tag{5a}$$

M_{ex} : moisture content in the soil-water mixture from which the extract is to be obtained (dry weight basis)
C_{ex} : salt concentration of the extract sub M_{ex}
M_{fc} : moisture content at field capacity (dry weight basis)

In the case of medium-textured non-organic soils the saturation percentage is approximately twice the field capacity, in which case (5a) may be simplified to

$$C_p \approx 2f \,.\, C_{es} \tag{5b}$$

C_{es}: soil salinity, expressed as the salt concentration or the electrical conductivity of the saturation extract

Substitution of equation (5a) in (4) gives: –

$$P - G = \frac{M_{fc} \,.\, C_i}{f \,.\, M_{ex} \,.\, C_{ex} - M_{fc} \,.\, C_i} (ET - N) \tag{6}$$

If the amount of irrigation water actually used is given, P – G may be expressed by combining (3) and (6) as: –

$$P - G = \frac{M_{fc} \,.\, C_i}{f \,.\, M_{ex} \,.\, C_{ex}} I \tag{7}$$

In the case of medium-textured non-organic soils (6) and (7) may be approximated by

$$P - G \approx \frac{C^i}{2f \,.\, C_{es} - C_i} (ET - N) \tag{6a}$$

$$P - G \approx \frac{C_i}{2f \,.\, C_{es}} I \tag{7a}$$

P, I, ET, N and G should relate to the same period and, of course, be expressed in the same units. The same is true of M_{ex} and M_{fc} and of C_i and C_{ex} or C_{es}.

If for C_{ex} or C_{es} the permissible salt level of the soil is substituted, P – G is the depth of water to be evacuated from the subsoil in order to prevent C_{ex} or C_{es} to be exceeded. P – G, then, represents the amount of water required for leaching, or the leaching requirement.
The following example will illustrate the foregoing.

Assuming that

ET	=	220 mm/month
N	=	20 mm/month
f	=	0.55
M_{fc}	=	30 (percentage on dry weight basis)
M_{ex}	=	50 (percentage on dry weight basis)
C_i	=	1 mmhos/cm
C_{ex}	=	4 mmhos/cm

the leaching requirement (P – G) for maintaining the average soil salinity at 4 mmhos/cm is – according to formula (6) – 75 mm/month.

7.4. LEACHING EFFICIENCY

A leaching efficiency coefficient – f – was introduced in the salt balance; it denotes the ratio between the salt concentration of the water draining from a soil layer and the salt concentration of the soil solution in that layer.
For the Dujailah soil f was determined experimentally and found to be 0.6 (Fig. 33).

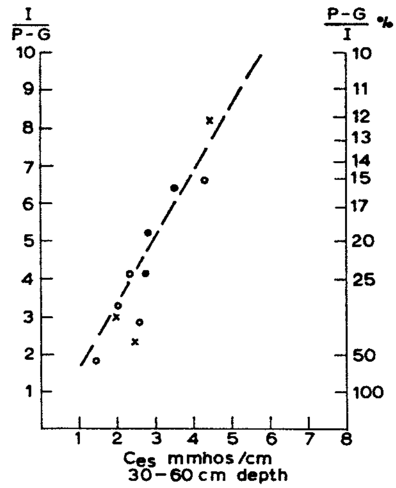


Fig. 33. Equilibrium soil salinity C_{es} in relation to irrigation (I) and leaching (P-G)
The line is drawn for:
M_{ex} = 0.56
M_{fc} = 0.28
C_i = 0.7 mmhos/cm
f = 0.6
● 3-days samplings, averaged per spot
○ 3-days samplings, averaged per basin
× samplings averaged per basin and per season

In Fig. 33 the EC_e (electrical conductivity of the saturation extract) of the soil layer 30–60 cm is plotted against the ratio I/P – G. The figure shows that the empirical observations coincide fairly well with the curve calculated according to equation (7) with an efficiency coefficient of 0.6.
The observations are from a plot which was initially leached to a depth of 1.5 m and afterwards cultivated during three summer and winter seasons, during which the soil salinity was observed.
The I/P – G and EC_e values relate to periods covering one or more irrigations, or a complete cropping season.
The EC_e was determined as the average from samplings every three days and relates to single sampling spots or averages of the whole irrigation basin.

It is not surprising that the leaching coefficient is found to be less than 1. Water is mainly transported in a soil through the larger pores, cracks, root holes, etc. The salts in these pores will be leached relatively rapidly with the result that afterwards a part of the leaching water will pass to the subsoil without being very effective in leaching the salts from the finer non-capillary pores. This effect will be more pronounced in the more heavily textured soils with a macrostructure than in the light-textured soils with a more

single grainlike structure. The leaching of a heavy soil can therefore be regarded as a combination of two processes, viz. the replacement of the salty soil solution in the non-capillary pores by moving leaching water, and the movement of salts from the capillary pores to the non-capillary pores by diffusion and capillary movement.
Alternate drying and wetting of the soil may be favourable in the latter case, but is unfavourable insofar as it leads to the formation of wide cracks.
In general more non-capillary pores, including cracks and root holes, occur in the surface layers of the soil than in the deeper horizons. The leaching efficiency will therefore be relatively low near the surface, augment with increasing depth, and approach the value 1 for soil layers below the permanent water table.
The relation between soil depth and leaching efficiency means that the coefficient to be used depends on the depth of the root zone, which differs for different crops but also varies during the development of the crop. This agrees with the well-known fact that more leaching is needed in the initial period than in a later stage of the development of the crop.
The leaching efficiency should be related to the shape of the leaching curves in Fig. 18 (chapter 3). The leaching process of a salty soil may be written as the following differential equation: –

$$T \, . \, M \, . \, dC_{sm} = dI \, . \, C_i - dP \, . \, C_p \qquad (8)$$

T : depth of soil layer
M : soil moisture content (volume basis)
C_{sm} : salt concentration of soil moisture
I : quantity irrigated ($= P + ET$)
ET : evapotranspiration
C_i : salt concentration of irrigation water
P : quantity percolated
C_p : salt concentration of percolation water

Substituting $C_p = f \, . \, C_{sm}$ according to equation 5, and assuming the quantity percolating to be proportional to the quantity irrigated,

$$P = \frac{I}{r} \text{ and } dI = r \, . \, dP$$

then
integration of (8) with boundary conditions $P = 0$, $C_{sm} = C_{smo}$, gives: –

$$\frac{P}{T} = \frac{M}{f} \ln \frac{C_{smo} - \frac{rC_i}{f}}{C_{sm} - \frac{rC_i}{f}} \qquad (9)$$

ln = natural logarithm

in which: $$r = \frac{I}{P} = 1 + \frac{ET}{P}$$

It should be realised that the actual physical and chemical processes occurring in the soil during leaching are much more complex than would appear from equations (8) and (9).

It is found, however, that the leaching formula (9) agrees fairly well with the empirical leaching curves discussed in chapter 3 (Fig. 18), and may therefore be of practical use for describing the leaching process.

A comparison of equation (9) with the curves in Fig. 18 shows that the leaching efficiency, f, is related to the shape of the curve as well as EC_{ex}. The leaching curve therefore provides a means of calculating the value of f. The following is found for the curves of Fig. 18: –

	Dujailah	Utah	Annanah
soil texture	loam – silty loam	silty loam	silty clay
$\frac{M}{f}$ from data Fig. 18	0.7	1.4	2.8
M estimated from texture	0.4	0.45	0.5
f calculated	0.6	0.3–0.4	0.2
$EC_{ex} = \frac{rC_i}{f}$ from Fig. 18	1.3	4.0	2.5
rC_i estimated	0.7 –0.8	–	1.0–2.0
f calculated	0.55–0.6	–	–

In the case of the Dujailah soil the f values agree reasonably well with the value derived earlier from observations of the equilibrium situation. In the case of the Utah and Annanah soils, the low efficiencies found may not be very reliable.

The leaching coefficient does not appear in other leaching equations (U.S.D.A. 1954). The introduction of this aspect is believed to increase the practical use of the salt balance calculations.

7.5. REQUIRED IRRIGATION AND DRAINAGE QUANTITIES

The irrigation quantity required is defined as the water supply needed over a given period to make up for evapotranspiration and to allow for sufficient leaching in order to control the salinity in the root zone at a desired level. This quantity is found from (3) and (6) as being: –

$$Ir = (ET - N)\left\{1 + \frac{M_{fc} \cdot C_i}{f \cdot M_{ex} \cdot C_{ex} - M_{fc} \cdot C_i}\right\}$$

In the case of medium-textured non organic soils according to (6a)

$$I \approx (ET - N)\left\{1 + \frac{C_i}{2f \cdot C_{es} - C_i}\right\} \qquad (10a)$$

The drainage quantity required is defined as the quantity of water to be discharged by the drainage system during a given period in order to control the salinity in the root zone at the desired level. This quantity – Dr – consists of the leaching requirement, P – G, but should also take into account natural drainage – Dn – and or subsoil water supply to the area from outside – S –.
When the amount of irrigation is given, Dr may be found from (7)

$$Dr = \frac{1}{f} \cdot \frac{M_{fc}}{M_{ex}} \cdot \frac{C_i}{C_{ex}} \cdot I + S - Dn \qquad (11)$$

When the evaporation and rainfall are known, Dr becomes, according to (6)

$$Dr = \frac{M_{fc} \cdot C_i}{f \cdot M_{ex} \cdot C_{ex} - M_{fc} \cdot C_i}\{ET - N\} + S - Dn \qquad (12)$$

In the case of medium-textured non-organic soils according to (7a) and (6a): –

$$Dr \approx \frac{1}{2f} \cdot \frac{C_i}{C_{es}} \cdot I + S - Dn \qquad (11a)$$

$$Dr \approx \frac{C_i}{2f \cdot C_{es} - C_i}(ET - N) + S - Dn \qquad (12a)$$

The notation used in the above formulae may be summarized as follows: –

Ir	: quantity to be irrigated	mm water depth over the period in question
Dr	: quantity to be drained	
ET	: evapotranspiration	
N	: rainfall	
S	: subsoil water supply from outside	
Dn	: natural subsoil drainage	
M_{fc}	: field capacity	dry weight basis
M_{ex}	: moisture content of extraction mixture referring to C_{ex}	

C_i	: salinity of irrigation water	electrical conductivity or concentration of salt solution
C_{ex}	: permissible salinity of root zone	
C_{es}	: permissible salinity of saturation extract in root zone	
f	: leaching efficiency	between 0 and 1

7.6. DRAINAGE FOR SALINITY CONTROL AND RECLAMATION

Amelioration of saline land consists of the reclamation period during which the excess salts are leached from the profile and the subsequent period during which resalinization has to be prevented. The leaching problems of the initial period were discussed in chapter 3. The present chapter deals with the leaching and drainage problems of the second period, viz. after the soil has been reclaimed and also, of course, when the soil has not yet been affected by salt.

It is important to examine whether a drainage system adapted to the permanent needs of the second period also meets the more temporary drainage requirements of the initial reclamation period.

It will be clear that owing to the nature of the leaching process it should always be possible to undertake the initial leaching of the soil with the drainage facilities based on the subsequent permanent needs of the reclaimed soils. It may be possible, however, that as a result reclamation proceeds too slowly and will therefore be unacceptable in general or under certain conditions.

A calculation of the length of the reclamation period to be expected from certain given drainage facilities by means of the leaching curves discussed in chapter 3 will give some idea whether such conditions are likely to occur. Let us take a soil, similar to the Annanah soil, having an initial EC_e of 80 in the upper 60 cm of the profile. The quantity to be drained in order to keep the equilibrium salt level at 6 mmhos is calculated to be 60 mm per month.

When the initial leaching is carried out at the rate of 60 mm/month, according to Fig. 18 it would roughly take 4 years of leaching to reduce the salt content from EC_e 80 to 6, which does not seem very promising. The problem should, however, be approached in a different way.

As long as the soil is too saline for any cultivation a subsoil water table at or very near to the surface will do no harm. Since the drainage is designed to keep the ground water at e.g. 1 m below the surface, the same system will permit a leaching rate much above the leaching requirement when the subsoil water table is allowed to rise to the surface. In the example given, the rate would be roughly doubled and come to about 120 mm/month if the drains are about 2 m deep.

Further, before the salinity has reached the equilibrium level of $EC_e = 6$ mmhos/cm cultivation with salt-tolerant crops is possible and can even be begun when the EC_e in the soil has dropped to 16. During the cropping periods the reclamation will be based on a leaching of 60 mm/month as the water table must now be kept at 1 m below the surface. As the salinity of the soil decreases the tolerant crops can gradually be replaced by less tolerant crops until the reclamation may be considered complete. If leaching is carried out in this way the reclamation period will only be unproductive during the initial stage when the soil is too salty to bear any crop, but acquires a certain gradually improving agricultural value as soon as the first crop is grown. When introduced in the example these aspects give the following results: –

	EC_e	months	mm leaching
initial leaching without crop	80 to 16	11	1330
continued leaching, salt-tolerant crops	16 ,, 8	16	970
completion of leaching, medium-tolerant crops	8 ,, 6	10	600
total reclamation	80 ,, 6	37	2900

The unproductive leaching period has now been reduced to 11 months. Salt-tolerant crops can be grown during the next 16 months and less tolerant crops during the last 10 months. After these 37 months the soil may be considered as reclaimed and ready for cropping by any suitable rotation system.

In the example given the unproductive leaching period is still long, owing to the very unfavourable leaching characteristics of the Annanah type of soil. In the case of most soils leaching will be a much more rapid process and an analysis of the length of the required reclamation period will usually lead to the conclusion that there is no need to supply extra drainage facilities for reclamation in order to supplement to those permanently required for the control of soil salinity.

Moreover, any additional drainage requires a capital investment which is rather unattractive as it has to be written off over a very limited number of months. In certain cases a good temporary solution may be to construct very shallow and cheap ditches to facilitate the reclamation; these can be filled in afterwards. But there is no general answer to the question as to whether it would be justified to provide additional drainage for the relatively short reclamation period only. The answer depends on the policy adopted in the planning of a given scheme in relation to the reclamation method and the anticipated periods of the various stages of the reclamation and includes economic, technical as well as social aspects. In each specific case the decision has to be made by weighing up all the pros and cons.

7.7. IRRIGATION EFFICIENCY AND DRAINAGE

If the irrigation water contains no salt, neither leaching nor drainage is needed provided the amounts of irrigation water consumed by the crop are exactly equal to those supplied. Under practical conditions, however, the irrigation always exceeds the minimum requirement owing to such factors as the uneven distribution and infiltration of water on the land. According to general experience, some 20 to 40 % of the water supplied to the field is usually lost, resulting in an irrigation efficiency which is normally in the order of from 60 to 80 %, the actual variance being even higher. The efficiency depends on the irrigation method, farming skill, land slope and soil conditions.

The unavoidable irrigation subsoil losses will cause a rise in the water table and eventually lead to waterlogging if no drainage is provided. Thus even if salt-free irrigation water were used a certain drainage would be required to prevent waterlogging caused by percolation losses.

But irrigation water always contains a certain amount of salt, which means that leaching is needed to control the salt content of the soil. However in order to calculate the irrigation and drainage quantities required it is not necessary to take into account such leaching in excess of the subsoil percolation losses. The subsoil losses contribute to the leaching and can usually be regarded as being completely effective in this respect. The difficulty that the leaching will not be uniform because the percolation losses are unevenly distributed over the field can be substantially overcome by employing an irrigation technique which is so adjusted that the differences in leaching on the field are offset over a number of years by shifts in the irrigation units and changes in the irrigation methods.

If the leaching required for salinity control proves to be less than the normal percolation losses it is not the leaching but the anticipated percolation losses that will determine the intensity of the drainage system required. Consequently the quantity to be drained from an irrigated soil has a certain minimum value which depends on many factors, e.g. soil, slope, irrigation method and farming skill, but will probably usually be in the order of 20 % of the irrigation supply.

For the same reason, the quantity of water to be supplied in excess of the consumptive use in order to arrive at the irrigation requirement has a certain minimum, depending on the percolation losses. Usually, however, the consumptive use values applied and the assumptions of anticipated cropping intensity allow for a certain amount of percolation losses.

8. SOME APPLICATIONS AND CALCULATIONS

8.1. INTRODUCTION

In this chapter an attempt is made to arrive at a systematic method of calculating the drainage and irrigation needs of salt-affected soils.
It is realized that many local conditions and practical, technical or economic considerations have a great effect on the final solution. It is therefore expressly stated that the calculation techniques should never be used as purely routine methods; one should always adopt a critical attitude and be aware of the extent to which the assumptions made correspond with local conditions and experiences. It should also be noted that the accuracy of the calculated results depends on the reliability of the assumptions made and the accuracy with which the soil constants are determined. The assumptions often depend on uncontrollable factors, and the accuracy with which soil constants can be determined for a given area is limited by erratic changes in the natural soil profile. Consequently the results of the calculations should always be considered as an approximate value.
Only a very small number of actual situations will be discussed, each requiring a different approach to the calculation technique. Many other factors may occur, e.g. the rotation system, natural drainage and seepage conditions, varying salt content of irrigation water, limited supply of irrigation water and stratification of soil profile. It is believed, however, that with the use of the bases given and on the analogy of the examples it is possible to obtain a reasonable solution in each case.

8.2. DRAINING PERMANENTLY CROPPED SOILS

– *Irrigation and drainage quantities*

The irrigation and drainage requirements may be calculated by means of the formulas given in paragraph 7.5. For Dujailah conditions with a saturation percentage of twice the field capacity and f = 0.6, C_i = 0.6 mmhos/cm, the equations (10a) and (12a) may be simplified to: -

$$Ir = ET - N + \frac{ET - N}{2C_{es} - 1} \qquad (13)$$

$$Dr = \frac{ET - N}{2C_{es} - 1} + S - Dn \qquad (14)$$

The evapotranspiration and rainfall differ during the year, so that the Ir- and Dr-values will also vary for the various months of the year. This is shown in table 37, calculated with equations (13) and (14), assuming S and Dn to be zero.

TABLE 37. Quantities required for irrigation and drainage, Dujailah

month	(ET - N) mm	Ir in mm		Dr in mm	
		C_{es} = 2	C_{es} = 4	C_{es} = 2	C_{es} = 4
1	44	59	50	15	6
2	53	71	61	18	8
3	99	132	113	33	14
4	127	169	145	42	18
5	165	220	189	55	24
6	210	280	240	70	30
7	340	453	389	113	49
8	350	467	400	117	50
9	290	387	331	97	41
10	220	293	251	73	31
11	134	179	153	45	19
12	43	57	49	14	6
Year	2075	2767	2371	692	296
average	173	231	198	58	25

This example shows a variation in the quantity of drainage required during the various months of the year, depending on the equilibrium salt level selected, of from 15 to 117 mm per month for C_{es} = 2 and from 6 to 50 mm per month for C_{es} = 4.

These varying requirements create a problem in the planning of the drainage scheme. If planned according to the maximum summer needs, the system will have an overcapacity during the winter period and will become expensive. If planned according to the minimum winter needs, the permissible salt content will be exceeded during the summer.

Provided a constant value is used for the monthly drainage, the anticipated fluctuation in soil salinity during the average year may be found by making a numerical analysis by trial and error of the salt regime in the soil according to equation 8. The total quantity of salt B_x in a depth of soil T at the end of month x is found to be the quantity B_{x-1}

at the end of the previous month plus the amount added by irrigation $I \cdot C_i$ and minus the amount $(P - G) \cdot f \cdot C_{sm}$ discharged during the period.

$$B_x = B_{x-1} + I \cdot C_i - (P - G) \cdot f \cdot C_{sm} \quad (15)$$

in which C_{sm} may be approximated by

$$C_{sm} = \frac{B_x}{T \cdot M_{fc}} \quad (16)$$

$P - G$: leaching
f : leaching efficiency
C_{sm} : salt concentration of soil moisture at field capacity
T : soil depth
M_{fc} : moisture content of the soil at field capacity (volume basis)

The calculation may be started at an estimated salinity level for any month, and should be continued over a number of successive years until the results remain constant. As an example table 38 shows the final results of such a trial and error analysis, using the following data: –

$P - G$ = 60 mm per month
T = 600 mm (soil layer 0–60 cm)
M_{fc} = 40 % (volume basis)
C_i = 0.6 mmhos/cm
f = 0.6

TABLE 38. Analysis of the yearly variation in soil salinity with constant drainage

month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
irr. mm	*104*	*113*	*159*	*187*	*225*	*270*	*400*	*410*	*350*	*279*	*194*	*103*
(P – G) mm	60	60	60	60	60	60	60	60	60	60	60	60
$I \cdot C_i$ (mmhos x mm)	62	68	95	112	135	162	240	246	210	168	116	62
$(P - G) \cdot f \cdot C_{sm}$ (mmhos x mm)	144	132	122	118	117	118	126	144	159	168	168	159
B_x (mmhos x mm)	877	813	786	780	798	841	955	1057	1108	1108	1056	959
C_{sm}	3.7	3.4	3.3	3.2	3.3	3.5	4.0	4.4	4.6	4.6	4.4	4.0
C_{es}	1.8	1.7	1.6	1.6	1.6	1.8	2.0	2.2	2.3	2.3	2.2	2.0

— *Ground water depth and drain depth*

Under humid conditions the average minimum ground-water depth is usually within the range of from 50 to 150 cm, depending on crop and soil. As already discussed, for irrigated soils ground-water depths of 150 cm and over are often mentioned in the literature. These depths are thought necessary for preventing salinization by the upward

capillary movement of ground water. It has been explained, however, that the ground-water depth has no direct relation to the salt balance of the soil. The minimum depth is therefore primarily determined by the amounts required for the aeration and root development of the crop and may be expected to be in the same range as the depths specified for humid conditions.
On the other hand, the ground-water depth may influence evapotranspiration of the soil and thus indirectly the leaching required and the quantity to be drained. Under the permanent cropping conditions as are assumed in this section this aspect would not appear to be of very great importance.
Not much direct experimental information is available on the minimum ground water depth required in irrigated areas. Some field data from the Dujailah experiments are summarized in table 39 which shows the total average ground-water depth, the average minimum depth recorded after each irrigation, and the average maximum depth before each irrigation for the different cultivation periods. All crops were doing well and the water table did not seem to have any effect on growth or yield. It would seem, therefore, that average depths of 60 to 100 cm and minimum depths as shallow as 25 cm have no harmful effect.

TABLE 39. Ground-water depth in cm below surface (Dujailah Experiment)

year and crop	1956 – green gram				1958 – barley			
month	June	July	Aug.	Sept.	Jan.	Febr.	March	April
gen. average	65	82	82	100	70	80	100	103
average minimum	25	45	60	72	40	55	75	85
average maximum	70	105	102	118	100	110	105	120

The depth of the drains should be greater than the minimum ground-water depth so as to provide the necessary hydraulic head for ground-water movement to the drains. With deeper drains, however, the drains may be more widely spaced than with shallow drains. The relation between drain depth, groundwater depth and drain spacing is expressed in the drainage formula. A comparison of the costs of a number of alternatives with different drainage depths and corresponding spacings will be useful for deciding the depth to be taken in a specific case. If a slow permeable soil is underlain by a good permeable layer it will generally be advantageous to excavate the drains as far as the better permeable subsoil.
The drainage depth is also limited by the depths of the collector and main drains, which are themselves related to the general layout of the drainage scheme as determined by the topography and method of evacuating drainage water from the area.

— *Field drainage system*

The method of calculating the required field-drainage system will be illustrated by the examples I (table 40) and II.

TABLE 40. Calculation scheme example I

A. *Basic data*													
1. month	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	year
2. land use						irrigated fodder							
3. ET–N (mm/month)	130	30	–10	–20	10	70	90	120	140	170	200	150	1080
4. average groundwater depth (cm)						$\leqslant$ 80							$\leqslant$ 80
5. EC irrigation water (mmhos/cm)						1.5							1.5
6. average permiss. soil salinity (C_{es} in mmhos/cm)						4							4
7. Leaching efficiency						0.5							0.5
B. *Irrigation and drainage quantities*[1]													
8. Ir. (mm/month)	184	84	44	34	64	124	144	174	194	224	254	204	1728
9. Dr. (mm/month)	54	54	54	54	54	54	54	54	54	54	54	54	648
C. *Monthly variation soil salinity*[2]													
10. I. C_i (mm.mmhos)[3]	276	126	66	51	96	186	216	261	291	336	381	306	
11. (P–G) f C_{sm} (mm.mmhos)[3]	252	250	238	214	199	188	186	191	196	209	223	246	
12. B_x (mm.mmhos)[3]	2220	2096	1924	1761	1658	1656	1686	1756	1851	1978	2136	2196	
13. EC soil moist. at field cap. (mmhos/cm)	9.3	8.8	8.0	7.4	6.9	6.9	7.0	7.4	7.7	8.2	8.9	9.2	
14. EC_e (mmhos/cm)	4.6	4.4	4.0	3.7	3.5	3.4	3.5	3.7	3.9	4.1	4.4	4.6	4.0
D. *Calculation drain spacing (tile drains)*													
15. Dr (m/day)						1.8×10^{-3}							
16. Hydr. Cond. (K, in m/day)						1							
17. Depth imperv. floor (m)						3							
18. Drain depth (m)		1.1			1.4			1.7			2.0		
19. Hydraulic head $\bar{m}$ (m)		0.3			0.6			0.9			1.2		
20. Depth d from drain level to imp. floor (m)		1.9			1.6			1.3			1.0		
21. K/Dr		550			550			550			550		
22. d/$\bar{m}$		6.3			2.7			1.4			0.83		
23. L/$\bar{m}$		152			107			87			74		
24. spacing L (m)		46			64			78			89		

1) Equations 10^a and 12^a.
2) The root zone is 600 mm in thickness and field capacity is assumed to be 40 % (based on volume).
3) Equations 15 and 16.

Example I

This example relates to a soil which is permanently under crop and irrigation. Neither the natural drainage nor a natural supply of subsoil water are of importance. The soil profile consists of a silt loam cover 3 m thick underlain by an impervious layer of clay. The calculations are summarized in table 40.

Part A gives the basic data. The ET – N values do not refer to Iraq conditions. The water table is allowed to fluctuate around an average depth of 80 cm.

Part B gives in the year column the quantities of drainage and irrigation required. The most economic drainage system is obtained when the total drainage quantity is regularly distributed over the year. The corresponding monthly irrigation requirements are also given.

Part C shows the method of calculating the seasonal variation of the soil salinity from the initially selected annual average. If the maximum salt concentration during the year thus calculated cannot be tolerated, a lower permissible annual average salinity level should be taken.

Part D shows the method of calculating the drain spacing required. In the example it is assumed that the fields are drained by tiles.
The calculation is made with the use of the nomograph in annex VI.
The drain spacing is calculated for four alternative drain depths.

Example II

This example relates to a soil profile consisting of a slowly permeable top layer of 1.75 m depth (K = 0.2 m/day) overlying a rapidly permeable subsoil of 1.25 m depth (K = 10 m/day). At a depth of 3 m there is an impervious layer. Drainage is by means of ditches, with a bottom width of 0.5 m and side slopes 1 : 1. The water depth in the ditches is 0.25 m. A ground-water depth of 0.6 m from the surface is tolerated and the required drainage rate is 1.8 mm/day.
The example serves to demonstrate the favourable effect on the required drain spacing when the drains cut into the good permeable subsoil. The drain spacing is therefore calculated for both shallow and deep drains. The calculations according to annex VI are summarized in table 41 (see next page).

8.3. Draining seasonally cropped soils with fallow

— *General remarks*

The problem of draining land which is only irrigated at one season of the year (winter) is a very common one in Iraq. Owing to the discontinuity of the irrigation the ground water and salt movement in the soil are also discontinuous and exhibit a seasonal fluctuation.

TABLE 41. Calculation drain spacing. Example II (according to annex V)

	shallow drains	deep drains
depth of drain bottom (m)	1.25	2.0
water level of drain below surf. (m)	1.00	1.75
m (m)	0.4	1.15
Dr (m/day)	1.8×10^{-3}	1.8×10^{-3}
U (m)	1.2	1.2
d (m)	0.75	1.25
K_2 (m/day)	10	10
D_2 (m)	1.25	1.25
K_1 (m/day)	0.2	0.2
D_1 (m)	0.95	0.58
m_v (m)	8.5×10^{-3}	5.2×10^{-3}
m_h/L^2 (m^{-1})	1.8×10^{-5}	1.8×10^{-5}
m_r/L	2.6×10^{-3}	5.8×10^{-4}
L(m)	98	240

At the end of the summer fallow period the profile has dried out and the ground water is deep, the depth depending on the type of soil and any natural drainage or seepage. Owing to the capillary upward movement of moisture in the fallow season most of the salts will be concentrated near the surface. The first irrigation during the cropping period moistens the soil to field capacity, after which the salts are leached from the surface layers downward. A great deal of water from the first irrigations will pass to the subsoil through cracks without being very effective in leaching. The downward percolation of water will cause the water table to rise and the drains will begin to flow as soon as the ground water rises above drain level. The ground water continues to rise, causing increasing drain discharge until the rate of drainage is equal to the rate of downward percolation. In a very short irrigation season this equilibrium may not be reached and the drain discharge may continue to lay behind the percolation rate.
After the last irrigation the downward percolation of leaching water will soon come to an end, but the drainage of ground water will continue as long as the subsoil water table is above the drain level. The water table will drop accordingly, gradually slowing down as the discharge decreases. At the same time the soil profile will begin to dry up under the influence of surface evaporation. Soil moisture will move upwards under the influence of capillary forces, causing a further accumulation of salt at or near the surface.

— *Irrigation and drainage quantities*

The irrigation and drainage quantities for the conditions described in this paragraph can also be calculated by means of the equations in par. 7.5 provided they are applied over a full cultivation cycle including the non-irrigation season. Hence one should know

both the consumptive use of the crop and the evaporation of soil moisture during the fallow season. This ET-fallow depends on the moisture content of the soil at the end of the cultivation period, the evaporating power as determined by the climate, the soil properties affecting the capillary transport of moisture, the length of the fallow period and the weed growth. The best way of calculating a value for the ET-fallow is by taking moisture samples at the beginning and end of the fallow period. Ignoring subsoil supply from outside and drainage of ground water during the fallow, the ET-fallow is found to be the difference of the total moisture in the profile before and after the fallow period. As will be discussed later, subsoil water supply and, to some extent, the ground water depth may affect evaporation during the fallow period.
The calculation of the annual irrigation and drainage quantities for soils with winter cultivation and summer fallow is illustrated by example III.

EXAMPLE III

Cropping season: November 1 to May 1.
(ET – N) of the cropping season: 425 mm, assuming the actual evapotranspiration over November during the initial development of the crop to be 50 % of the potential evapotranspiration. Difference in moisture storage in the profile during the fallow period: 200 mm.
The following cases will be considered:

A No subsoil seepage supply or drainage in the fallow season (S = 0, Dn = 0). ET-fallow = 200 mm.
Total ET – N during cropping and fallow period = 625 mm.

B. A subsoil seepage supply S = 200 mm per year, of which 50 mm evaporates during the fallow period.
No natural drainage ($D_n = 0$).
ET-fallow = 250 mm.
ET – N total = 675 mm.

C. No subsoil seepage supply (S = 0).
Natural drainage Dr = 100 mm per year. 25 mm of which during the fallow period.
ET-fallow = 175 mm.
ET – N total = 600 mm.

Using the simplified equations 13 and 14 for Dujailah conditions, the values given in tabel 42 were calculated for the annual irrigation and drainage quantities required.

TABLE 42. Example III. Annual irrigation and drainage requirements

Case	A		B		C	
equilibrium salinity level C_{ex}	2	4	2	4	2	4
irrigation mm/year	833	714	900	711	800	686
drainage mm/year	208	89	425	296	100	0

The example demonstrates that the irrigation, and particularly the drainage needs, are influenced by the hydrological conditions in the area. The drainage layout and the cost of the whole irrigation scheme will be greatly affected if one has to allow for a certain amount of natural drainage or an underground supply of salt water.
The annual irrigation requirement refers to the cultivation season only, whereas the subsoil runoff may continue throughout the fallow period. The equilibrium salinity level used in the calculation should be considered as the annual average. The actual soil salinity will fluctuate according to the season and may be calculated in the same way as explained before. The maximum salt accumulation will be near the surface at the end of the fallow season, so that most of leaching should be carried out with the first irrigations in order to reduce the salinity to a suitable level; moderate leaching will be subsequently needed to maintain this level.

— *Ground-water depth and drain depth*

The ground-water depth should obviously be such that plant development is not restricted by lack of oxygen in the root zone. Moreover both the ground-water depth and the drain depth may affect evaporation during the fallow period, and hence the irrigation and drainage requirements. When there is no underground water supply, or when it can be ignored, the moisture content of a given soil towards the end of the fallow period will reach a more or less constant value independently of the initial moisture in the soil, since during a fallow period of sufficient length the soil profile will dry out to the point at which the upward movement of moisture becomes negligible. This phenomenon was observed in various Iraq soils. Consequently the ET-fallow is influenced by the initial amount of moisture in the soil and this in turn is related to the ground-water depth. This is illustrated by the data given in table 43.
The table shows that the depth of the water table at the end of the irrigation season influenced evaporation during the subsequent fallow period. But this influence is not considerable and should not be exaggerated. On heavier soils in particular it will be of minor importance as the moisture content at field capacity differs little from saturation.
Actually the problem is more complex. Groundwater may also be discharged by the drains after the last irrigation, the effect being that the influence of the ground-water depth decreases even more.
If there is an underground supply the depth of the water table is of more importance for the fallow evapotranspiration.
This supply or seepage should be added to the drainage requirement but may have an additional influence on the required runoff when it leads to increased evaporation during the fallow period. Without any drainage the total seepage supply may be evaporated. When there are drainage facilities part of the seepage will be intercepted by the drains and the rest will be evaporated. The ratio between the two parts depends on the depth at which ground water can be maintained during the fallow period.

TABLE 43. Effect of ground-water depth on soil moisture distribution, Dujailah

time	immediately after last irrigation		immediately after last irrigation		end fallow	
ground-water depth	60 cm		150 cm		200 cm	
depth of soil layer cm	moisture		moisture		moisture	
	vol. %	mm	vol. %	mm	vol. %	mm
0– 10	40	40	40	40	3	3
10– 30	40	80	40	80	13	26
30– 60	40	120	40	120	17	51
60–100	47	188	40	160	24	96
100–150	47	235	40	200	31	155
150–200	47	235	47	235	40	200
0–200		898		835		531
evapotranspiration		367		304		
ET-crop (till harvest)		90		90		
ET-fallow		277		214		

If the ground water is kept sufficiently deep the upward capillary movement becomes very slow and ground water evaporation may be ignored. The depth required depends on the soil characteristics, especially with regard to capillarity and stratification, and is also influenced by weed vegetation. Reliable data on this depth are scarce; as a general guide we may take it to be in the order of 1.2 m for the light and heavily textured soils and in the order of 1.5 to 1.8 for the medium-textured soils.

EXAMPLE IV

Example IV in table 44 illustrates the effect of the ground-water depth on irrigation and drainage quantities when the ground water is fed from an outside source.

TABLE 44. Example IV. Irrigation and runoff requirements in relation to seepage and ground-water depth (calculated with equations 13 and 14)

Case	seepage mm/day	average ground-water depth in fallow (cm)	Ir mm/season	Dr mm/year
I	0	–	600	75
II	1	50	806	466
III	1	100	703	453
IV	1	150	600	440

Case I no seepage
Case II all seepage evaporates during the fallow period
Case III half the seepage evaporates during the fallow period
Case IV no seepage water evaporates during the fallow period
Cropping season: 185 days, fallow period: 180 days, (ET – N)-cropping season 425 mm.
Difference in moisture content of the soil before and after fallow: 100 mm.
Equilibrium soil salinity (EC_e): 4 mmhos/cm.

It can be seen that under seepage conditions it is important to maintain a deep water table in order to economize on irrigation water. The effect of the waterdepth on the drainage required seems slight, but is rather important if we consider the monthly requirements as will be discussed later.

So far we have assumed the seepage supply to be continuous. This condition may be met in certain regions (valleys), but will not be very common.
Seepage of varying magnitude, depending on the season and ground-water depth, is however, a condition found to some extent in most irrigated areas. This seepage may originate from higher elevated soils, hills and mountains, canals and neighbouring irrigated land.
In this connection reference may also be made to cultivation by the open fallow system, in which the land is only cultivated during alternate winters. Thus half the land is cultivated each winter, the other half lying fallow. On the cultivated land the ground water is raised by irrigation, resulting in a subsoil water movement from the cultivated to the non-cultivated soils and an increase in evaporation and salt accumulation near the surface on the fallow land.
This and all other systems in which there is any kind of seepage may be dealt with according to the principles outlined above.
Summarizing, it may be stated that drainage and irrigation quantities should be calculated for a full cultivation cycle, viz. one year for a soil cropped each winter and remaining fallow in summer, and two years, for example, in the open fallow system.
The evapotranspiration during a cycle should include the evaporation during the fallow. The effect of seepage on this evaporation should not be overlooked.
The minimum permissible ground-water depth is related to the aeration needs of the plant roots, but it is also important for reducing the evaporation in the non-cultivated season, especially when seepage occurs during this season, either as a result of artesian pressure, canal seepage or the irrigation of neighbouring plots.

— *Field drainage system*

Since water table and discharge vary according to the season the drainage of a soil which is intermittently cropped is fundamentally a problem of nonsteady ground water movement. However, as shown below, these problems may be calculated with sufficient accuracy with the steady flow formulae.
The examples V, VI and VII demonstrate the calculation technique and show how this fairly complex problem may be dealt with systematically.

EXAMPLE V (TABLE 45)

This example deals with a soil situated, for example, in an extensive plain. The topo-

TABLE 45. Calculation scheme example V

Period	1	2	3	4	5	year
A. *Basic data*						
1. date	1/11 – 1/12	1/12 – 15/4	15/4 – 1/5	1/5 – ?	? – 1/11	1/11 – 1/11
2. days	30	135	15	x	180–x	360
3. land use	fieldcrop			grazing		
4. irr. use	irrigated		non irrigated			
5. gr. waterdepth (cm)	180	≥ 80	≥ 80		180	180
6. ET–N (mm)	59	302	64	130		555
7. var. moist. stor. (mm)	+240	0	–240			0
B. *Irrigation and drainage quantities*						
8. Ir[1] (mm)	740		0			740
9. Dr[1] (mm)	185–46 = 139		46		0	185
C. *Spacing (draindepth = 1.8 m, K = 1 m/day, impervious floor at 4 m)*						
10. $\bar{m}$ (m)	2/3 × 1	1	1/3 × 1		0	
11. $\bar{\bar{m}}$ (m)	0.94		0.33		0	
12. Dr (m/day)	0.84×10^{-3}		$\frac{46.10^{-3}}{15+x} = 0.31.10^{-3}$ ↑		0	
13. K/Dr	1185		3250 ↑			
14. d/$\bar{\bar{m}}$	2.34		6.6 ↑			
15. L/$\bar{\bar{m}}$	153		432 ↑			
16. L (m)	**144** →		→ 144			
17. days (2)	30	135	15	134	46	
D. *Supplementary drainage calculations*						
18. $\bar{m}$ (10)	0.67	1				
19. L/$\bar{m}$	215	144				
20. d/$\bar{m}$	3.3	2.2				
21. K/Dr	1700	1100				
22. Dr (mm/day)	0.59	0.91				
23. Dr (mm)	18	123	46		0	
24. Dr corrected (mm)	17	122	46		0	185
E. *Irrigation quantities: moisture balance*						
25. ET–N (6)	59	302	64	130		555
26. Dr (24)	17	122	46		0	185
27. Var. moist. storage (7)	+240	0	–240			0
28. Ir (mm)	316	424	0			740

[1]) C_{es} = 2.

graphic conditions are such that neither an underground supply of salt water nor natural drainage may be expected.
The method of dealing with this problem is summarized in the calculation scheme of table 45.
The table is divided into columns which split the year up into a number of periods of importance to the salt and/or water balance of the soil.

Period 1 covers the time during which the soil, dried out during the previous fallow, is rewetted. The water table rises until equilibrium is reached between percolation and drainage.

During *period 2* the ground water fluctuates around a constant level. The date of the last irrigation marks the end of this period.

Period 3 covers the number of days from the last irrigation to the harvest.
In this period the water table starts to fall as a result of continued drainage and evapotranspiration.

The end of *period 4* marks the end of the drainage period; the water level has fallen to drain level.

Period 5 covers the remaining period until the next cropping season. There is no further drain discharge and the water table may remain at drain level or fall below it. The fallow land may continue to evaporate, the upper soil layers drying out.

The calculation scheme is further divided up into five parts as follows: –

Part A is used for recording a number of basic data or assumptions to be made beforehand. According to the results obtained, these assumptions may have to be corrected later on.

– *Lines 1, 2, 3, 4:* These data should be supplied according to the average cropping scheme practised or proposed. The length of period 1 determines the peak irrigation demand and may have to be subsequently revised. The end of period 4 is still unknown.

– *Line 5:* The drains are laid out at a depth of ca. 1.80 m so that the groundwater depth at the end of period 4 is 1.80 m. It is also assumed that the water table remains at about this depth until the end of the fallow period. The average minimum ground-water depth should not be less than 80 cm.

– *Line 6:* The (ET – N)-values for the crop are known from measurements or are to be calculated from meteorological data. The values given refer to Dujailah conditions. The (ET – N)-fallow should be selected in accordance with the principles given above. In the example it is assumed that the land is used for grazing. If dry-farming methods are used the (ET – N)-values will probably be much lower.

– *Line 7:* The loss of soil moisture from the beginning to the end of the non-irrigated season is preferably calculated from moisture samplings in similar areas and for similar conditions. It should be noted that the loss in soil moisture in the non-irrigated season (240 mm) minus the (ET – N) for the same season (194 mm) represents the quantity of drainage (46 mm). But this value is also related to the fall in the water table during the same period and the volume percentage moisture draining from the saturated soil. If we assume this percentage the difference between full saturation and moisture at pF $= \pm 2$ to be 6, the maximum drainage would be 60 mm. It is a maximum value because drainage is not the only factor that makes the water table fall, the upward capillary movement being another important cause. Hence a value of 46 mm compared to a maximum of 60 mm would seem reasonable.

Part B shows the results of the calculations of the annual irrigation and drainage requirements. In the example the simplified equations 13 and 14 are used. The permissible average salinity level is assumed to be 2 mmhos in the saturation extract.

– *Line 9:* The amount of drainage after the last irrigation is related to the values selected in lines 6 and 7 and the depth over which the water table falls, as discussed above.
When the drainage requirement totals 185 mm, the remaining 139 mm should be drained during the irrigation season.

Part C summarizes the calculation of the required drain spacing. The example is based on a water level in the drains of 1.80 m below the surface, an isotropic permeable soil with a hydraulic conductivity of 1 m a day and an impervious stratum at a depth of 4 m. The calculation is made by means of the nomograph in annex VI for stationary flow although the drainage conditions in the first period and after the second period are non-stationary. Owing to the many quantitatively unknown factors which, in addition to drainage, affect the movement of the water table, the real accuracy of the results would not be improved by employing fairly complicated non-stationary calculation methods instead of stationary ones.

– *Lines 10 and 11:* Optimum drainage occurs when the ground water is at its maximum permissible level, viz. when the average hydraulic head, m or the difference between the ground-water depth and the drainage depth, is one meter for the second period. During the first period m is not constant but increasing, the m-time curve being generally convex; consequently the average hydraulic head may be calculated with reasonable accuracy by taking 2/3 of the maximum value. After the last irrigation m decreases in proportion to the moisture drained, but also as the result of evaporation and upward movement of capillary moisture. The m-time curve will be concave, for which reason the average is calculated by taking 1/3 of the maximum value. The actual shape of the time curve of the rising water table in period 1 is governed by the distribution of the irrigation supply during this period, and it may be possible to obtain a better average m-value by constructing this curve on the basis of the assumed irrigation supply, evaporation, drainage and moisture storage capacity of the soil. The actual shape of the time curve of the falling water table can only be estimated, as the combined effect of drainage, evaporation and capillary transport on the lowering of the water table is rather complex. This will not result in considerable errors since the drainage in the non-irrigated season is usually relatively small and the total drainage during this period is already known (see line 9).

– *Line 12:* Quantities to be drained according to lines 9 and 2. For period 3 + 4 this quantity depends on the still unknown length of period 4.

– *Lines 13, 14, 15, 16, 17:* The calculation of the drain spacing is now continued for the irrigation period. Lines 13, 14, 15 refer to calculations by means of the nomograph in annex VI. The resulting drain spacing (L) of 144 m is then transferred to the column of period 3 + 4 and used for calculating the average daily drainage (0.31 mm) during these periods in the reverse manner. The length of period 4 is calculated from the two quantities for the daily discharge now available, at 134 days. This value substituted for x in line 2 gives line 17.

So long as x is less than the maximum possible, which is the total number of days in periods 4 and 5 together, the required drain spacing is determined by the requirements during the irrigated season. If x is very short, the drainage after the last irrigation is of little importance compared to the total. If x reaches the maximum value (180 days in the example) the non-irrigated season makes its maximum contribution to the total drainage and consequently the most economical drain spacing would be obtained in that case. The value for x may possibly prove to be higher than the maximum possible. This indicates that the drain spacing calculated for the irrigated season is inadequate to cope with the quantity to be drained in the non-irrigated season under conditions as assumed in part A. In this case the spacing has to be calculated over periods 3 and 4 with x at its maximum value (which means that period 5 has been reduced to zero days).

Another possibility is to select a greater drain depth or not to allow the water table to fall to the initially assumed depth during the non-irrigated season but to remain above it. In both cases the system should be recalculated for the modified conditions.

Part D is used for calculating the drainage of the periods 1 and 2 separately and also provides a check on the spacing calculation. Taking the average of the hydraulic head, $\bar{\bar{m}}$ (line 11) may have introduced errors since the drain discharge is only approximately directly proportional to the hydraulic head. The total drainage for periods 1 and 2 of line 24 may therefore differ from the value given in line 9. If the difference is small the values of line 24 should be corrected in proportion. If the difference is considerable, say more than 15 %, $\bar{\bar{m}}$ (line 11) should be slightly more or less than the arithmetical mean of the value in the previous line. The correct values should be found by trial and error.

Part E shows the soil moisture balance used for analysing the irrigation needs during the various periods. The quantities of lines 25, 26 and 27 are taken from the above. The required irrigation, line 28, is found as the balance.

- *Line 28:* Heavy supplies of water are needed during the first period in order to remoisten the soil, i.e. to compensate for the amounts drained and evaporated in the non-irrigated season. In period 2 the irrigation need consists of the evapotranspiration plus a quantity for leaching and drainage. Heavy irrigations in the first part of the cultivation season, including the period of land preparation, are common in rotations with summer fallow and favourable with respect to salinity. The salts accumulated during the fallow period are leached and a salinity level below the annual average is obtained during the period of crop germination and initial development. The annual variation in soil salinity can be worked out quantitatively by the method described in paragraph 8.2. The irrigation required during the first period may prove to be unreasonably high, also with regard to the amount of irrigation water available. This means that the replenishment of moisture lost in the fallow season should be extended over a longer period than was initially assumed. Period 1 should then be longer and period 2 correspondingly shorter. This will have an unfavourable effect on the drain spacing required. Most unfavourable in this respect is when period 1 covers the whole irrigation season, i.e. when the water table does not reach an equilibrium level. This is the case for example, when in addition to the actual crop evapotranspiration a constant quantity is supplied for leaching and compensation of water evaporated and drained in the non-irrigated period. For economy in the layout of the irrigation system, a constant supply to the field may be advantageous. This may be obtained in the given example when period 1 is assumed to be of the order of $2\frac{1}{2}$ to 3 months, which means that the drain spacing required should be in the order of 135 m.

EXAMPLE VI (TABLE 46)

This case assumes a situation for example in a valley, in which the ground water is constantly fed by a subsoil supply from the surrounding higher soils. During the cropping season this seepage supply is at the rate of 0.5 mm/day and 1 mm a day during the fallow owing to the irrigation of neighbouring fields. It is also assumed that for some reason the drains cannot be laid deeper than 1.1 m, the result being that most of the seepage supply during the fallow period is evaporated by growing weeds and herbs.
The calculation method of table 46 is similar to example V, so that only the differences between the two examples will be discussed.

Part A

- *Line 5:* The water table is assumed to fall to a depth of 1.4 m in the nonirrigated period, i.e. 30 cm below the drain depth. The accuracy of this assumption is doubtful, although it would seem reasonable to assume a depth of somewhere between 1.1 and 1.8 m. However, the actual value is of minor importance.

TABLE 46. Calculation scheme example VI

Period	1	2	3	4	5	year
A. *Basic data*						
1. date	1/11	1/12	15/4	1/5	?	1/11 – 1/11
2. days	30	135	15	x	180–x	360
3. land use	fieldcrop			grazing		
4. irr. use	irrigated		non irrigated			
5. gr. water depth (cm)	140	⩾60	⩾60		110	140
6. seepage supply (mm)	15	68	7	180		270
7. ET–N (mm)	59	302	64	250		675
8. var. moist. storage (mm)	+150	0	−150			0
B. *Irrigation drainage quantities*						
9. Ir[1]) (mm)	900		0			900
10. Dr[1]) (mm)	495 − 23 = 472		23		0	495
C. *Spacing (Draindepth = 1.1 m, K = 1 m/day, impervious floor at 4 m)*						
11. $\bar{m}$ (m)	2/3 × 0.5	0.5	1/3 × 0.5		0	
12. $\bar{\bar{m}}$ (m)	0.47		0.17		0	
13. Dr (m/day)	2.86×10^{-3}		$\frac{23}{15+x} \times 10^{-3} = 0.91 \times 10^{-3}$		0	
14. K/Dr	350		1100			
15. d/$\bar{\bar{m}}$	6.2		17.1			
16. L/$\bar{\bar{m}}$	111		309			
17. L (m)	[52.5] →		52.5			
18. days (2)	30	135	15	11	169	
D. *Supplementary drainage calculations*						
19. $\bar{m}$ (11)	0.33	0.5				
20. L/$\bar{\bar{m}}$	157.5	105				
21. d/$\bar{\bar{m}}$	8.7	5.8				
22. K/Dr	518	326				
23. Dr (mm/day)	1.93	3.06				
24. Dr (mm)	58	414	23		0	495
E. *Irrigation quantities. Moisture belance*						
25. ET–N (7)	59	302	64	250		675
26. Dr (24)	58	414	23		0	495
27. Seepage supply (6)	−15	−68	−7	−180		−270
28. Var. moist. storage (8)	150	0	−150			0
29. Ir (mm)	252	648	0			900

[1]) $C_{es} = 2$.

- *Lines 6, 7, 8, 10:* Reasonable values have to be selected for the fallow evaporation and the variation in the soil moisture storage. Evaporation during periods 4 and 5 should be higher than without seepage (example V) and consists of this value plus most of the seepage quantity. The drainage during periods 3 and 4, line 10, can be derived from the values of lines 7 and 8, although it should also be proportional to the fall in the water table, as discussed above.

Part B

- *Lines 9, 10:* Owing to the seepage supply the total irrigation and drainage quantities are considerably higher than those calculated in example V.

Part C

The calculation of the drain spacing is similar to the one already discussed. We ignore the effect of the water table being below the drain depth at the beginning of period 1. In fact, the first period should start when the water table reaches drain depth and should therefore be a few days shorter. But such a correction only has a minor effect on the further calculations. Period 4 proves to be only 11 days. The contribution of the fallow to the drainage of ground water can therefore be ignored (see also line 10). The drainage layout is correspondingly expensive since the drains are only in operation for about half the year. An improvement in this respect could be obtained by deeper drainage (example VII).

Part D

The daily drainage rate of period 2 is particularly high compared to the value given in example V.

Part E

Compared to example V the irrigation required is less during period 1 and higher during period 2. Owing to seepage there is less extensive drying out of the soil profile, which explains why less soil moisture has to be replenished in period 1. The irrigation quantity of period 2 is high owing to the high annual requirement.

EXAMPLE VII (TABLE 47)

This example relates to a case similar to example VI, the difference being that, in order to intercept the supply of seepage water, the drains are installed at 2 m depth and the water table is to remain at a depth of 1.50 m or more during the fallow period. Under these conditions the seepage will not affect the evaporation from the fallow land. The data and calculations are summarized in table 48.

TABLE 47. Calculation scheme example VII

Period		1		2		3		4		year	
A. *Basic data*											
1. date	1/11		1/12		15/4		1/5		1/11		1/1
2. days		30		135		15		180		360	
3. land use			fieldcrop					grazing			
4. irr. use			irrigated				non irrigated				
5. gr. water depth (cm)	150		⩾60		⩾60		150		150		
6. seepage supply (mm)		15		68		7		180		270	
7. ET–N (mm)		59		302		64		130		555	
8. var. moist. storage (mm)		+200		0		–70		–130		0	
B. *Irrigation and drainage quantities*											
9. Ir[1]) (mm)			740				0			740	
10. Dr[1]) (mm)			262			13		180		455	
C. *Spacing (draindepth = 2 m. K = lm/l day, impervious floor at 4 m)*											
11. Dr (m/day)			1.59×10^{-3}			0.9×10^{-3}		10^{-3}			
12. $\bar{m}$[2])		0.69		0.79				0.5			
13. $\bar{\bar{m}}$, from (15) or (16)			0.77					0.5			
14. K/Dr			630					1000			
15. $d/\bar{\bar{m}}$ } from (14) and (17)			2.6					4			
16. $L/\bar{\bar{m}}$ } from (14) and (17)			114					175			
17. L			88 ←			88 ←		88			
18. gr. water depth (cm)	150		121		121		150		150		
D. *Supplementary drainage quantities*											
19. $\bar{m}$ (m)		0.69		0.79							
20. $L/\bar{m}$		127		111							
21. $d/\bar{m}$		2.9		2.53							
22. K/Dr		700		605							
23. Dr (mm/day)		1.34		1.65							
24. Dr (mm)		40		222		13		180		455	
E. *Irrigation quantities. Moisture balance*											
25. ET–N (mm)		59		302		64		130		555	
26. Dr (mm)		40		222		13		180		455	
27. Seepage supply (mm)		–15		–68		–7		–180		–270	
28. Var. soil moist. storage (mm		+200		0		–70		–130		0	
29. Ir (mm)		284		456			0			740	

[1]) $C_{es} = 2$.

[2]) $30\,\bar{m}_1 + 135\,\bar{m}_2 = 165\,\bar{\bar{m}} = 165 \times 0.77$.
$\bar{m}_1 = 0.5 + {}^2/_3\,(\bar{m}_2 - 0.5)$.
$\bar{m}_1 = \bar{m}$ period 1; $\bar{m}_2 = \bar{m}$ period 2.

Part A shows that most of the basic data are the same as for example VI. The groundwater depth required during the fallow is 1.5 m, the fallow evaporation is selected according to example V, and the variation in soil moisture storage as lying between the values of the previous two examples.

Calculation of the drain spacing shows it to be governed by the requirements of period 4, or in other words the seepage supply of 1 mm/day should be drained when the ground water has a depth of not less than 1.5 m. The corresponding average water-table depths during periods 1 and 2 are derived from the drain spacing required for period 4. It is found that these average depths are much higher than the minima required.

TABLE 48. Comparison between shallow and deep drainage in seepage areas. Examples VI and VII

drainage depth drain spacing	1.1 m 52 m	2 m 88 m
annual irrigation required	900 mm	740 mm
annual drainage required	495 mm	455 mm
average daily drain discharge		
period 1 (30 days)	1.93 mm	1.34 mm
period 2 (135 days)	3.06 mm	1.65 mm
period 3 + 4 + 5 (195 days)	0.12 mm	1.00 mm

The results of example VI and VII are a good illustration of the importance of deep drainage in seepage areas. The favourable effect of a deep drainage under such conditions is twofold (see table 48). In the first place it reduces the total annual requirements of irrigation water and quantity to be drained. Secondly, it results in a more regular distribution of the drainage discharge over the year, which means a more economic utilization of the drainage system.

9. SOME ECONOMIC ASPECTS OF RECLAMATION PROJECTS

9.1. INTRODUCTION

In order to answer the cardinal questions whether, how and when the reclamation of saline soils in Iraq is possible and desirable, it is necessary to make a study of the economic aspects of the plans as well as the technical prospects.
To give an idea of the economic feasibilities of the works a few provisional estimates have been made of the expected costs and returns of the reclamation projects. For large-scale projects as in Iraq, an investigation will no doubt always have to be made of the way in which, given the technical possibilities and given the national and regional conditions and possibilities, the maximum economic effect of the works can be secured. Special attention should be paid to the co-ordination and synchronization of all the operations which have to be undertaken for a plan to succeed. A few remarks have been made on this subject under the heading 'Programming of reclamation projects'.
Lastly some suggestions have been made with regard to the planning and execution of the reclamation projects under Iraqi conditions.

9.2. ECONOMIC FEASIBILITY OF RECLAMATION PROJECTS IN IRAQ

Although it is impossible with the available data to give an exact forecast of the cost and return of a desalinization project, the order of magnitude can be indicated, bearing in mind that this will provide an average picture. The project costs are mainly fixed by the following components in an area already under cultivation: –

1. Construction of drainage system.
   - main drainage system, including outfalls, branch drains and main drains
   - drainage pumping station
   - farm drains, comprising all farm drains and any collector drains carrying the water to the main drainage system.

2. Adaptation of irrigation system
   - if an irrigation system already exists, it will have to be adapted to new conditions.
3. Execution of the proper reclamation works
   - levelling of the parcels
   - desalinization of the soils
4. Adjustment measures for agriculture
   - education
   - improvement of farm equipment

   Adjustments in the supply of raw materials and provision of services to agriculture and in the processing of agricultural products.

The returns are formed by: -

1. Higher gross yields in agriculture resulting from
   - higher yields of conventional crops
   - the possibility of growing more kinds of crops and crop varieties
   - the possibility of cropping more land hitherto abandoned owing to salinity.
2. Increasing revenue in the ancillary industries and those that are concerned with the processing of agricultural products, provided that it does not result in attracting productive resources away from other applications having the same or an even higher productivity.
3. Enhanced purchasing power giving rise to a cumulative effect because greater purchasing power leads to an increased demand for all kinds of commodities.
   This again produces a cumulative effect on the purchasing power.
4. In addition the higher standards of living will cause hygienic conditions to improve, resulting in better and more efficient performance of the labour involved.

At this stage of the argument it is particularly difficult to give an idea of total costs and returns, because this will also depend on the complete scheme framework. There are many alternative means of improvement, and the following paragraph will revert to this point.
It is possible to make an overall estimate of costs and returns if the basic plan is a minimum one, in which case the only improvement made to the existing state of affairs is the construction of a drainage system with minimum adaptation of the irrigation system.
The effect of this plan, which also means minimum attention being paid to education, is therefore limited to increasing the yield of conventional crops.
The expenditure relating to a plan of this nature is assessed as follows. On an average, the cost of a main drainage system based on prices and conditions obtaining in the

spring of 1959 is of the order of I.D. 6/– per meshara (1 I.D. = 1 £). This figure represents the cost of all earth-moving work for the excavation of the drains plus the cost of erecting all accompanying structures, when offered in fairly large tenders.
Under the same conditions, the cost of constructing drainage pumping stations may vary from I.D.–/750 to I.D. 2/– per meshara, depending on the acreage of the drainage basin connected to the station; the bigger the acreage, the lower will be the construction cost per meshara.
The cost of a farm drainage system is even more difficult to assess, as local differences, for instance in elevation and permeability, have a marked effect on drain spacing and consequently on the cost. Nevertheless, under average conditions the cost of such a drainage system can be estimated at I.D. 12/– to I.D. 14/– per meshara.
The total of the above figures gives an overall drainage cost of approximately I.D. 20/– per meshara.
It is realized that the above distribution of cost may vary considerably, especially when the main drainage system is substantially deepened so that the drainage depth can be increased, and consequently the drain spacing. This operation raises the cost of the main drainage system, but lowers the cost of the farm drainage. But very probably the total figure of I.D. 20/– per meshara will not be greatly altered.

The following immediate returns may be set off against the above costs: –

– it is anticipated that under practical farming conditions the yield of barley may well increase from an average of 150 kg/meshara to 500 kg/meshara. The marketing value of this increase will pay for the whole drainage system in approximately seven years.
– by paying extra attention to proper reclamation of the soils and to extension work, etc., gross yields may be expected to rise rapidly, because the main advantages of the reclaimed land will be that other more valuable crops can be grown. Since barley is one of the poorest-paying crops it will be replaced by other more profitable crops.

9.3. PROGRAMMING OF RECLAMATION PROJECTS

As far as regards these kinds of projects there are numerous aspects which should be thoroughly studied and very carefully considered before deciding how and where to embark on a large-scale reclamation programme.
With the aid of the knowledge gained of the interrelationship of salinity, irrigation drainage and crops under the prevailing conditions, a plan will have to be drawn up that is both technically and economically justifiable. In this respect it will be necessary to reckon with the constraints resulting from national and regional conditions and possibilities.
The improvement of a great part of the saline soils in Iraq will have farreaching consequences on the economy and structure of the entire country. Studies on the cost and the outcome of the reclamation of Iraqi soils have revealed the following facts: –

- considerable investments will be required for this purpose;
- in order to make these investments profitable improvements will have to be effected in the agricultural methods hitherto employed;
- this will result in a substantial increase in the volume of agricultural produce.

The above facts affect the national economy in several ways.
On the one hand it will entail large capital investments for many years so that other activities may possibly have to be shelved. Different projects will have to be weighed against each other in order to ascertain which investments will make the greatest contributions to increasing the country's living standards.
On the other hand there will be a considerable increase in agricultural production, for which a market will have to be found. With the aid of market research it will be necessary to discover which agricultural products are most suitable for extending production. In order to avoid over-production the development plan will be carried out in accordance with the conclusions of the research.
In the 'general programming' particular attention will also have to be given to the indirect and secondary results of agricultural development plans (the movement and processing of produce, agricultural credit, etc.). The entire development programme will have to fit into the national programme of which the aim is to maximise the well-being of the country.

— *Development programme for agriculture*

In order to draw up an agricultural development programme it will be necessary to compile an inventory of the limiting factors and the possibilities: –

1. the *limiting factors* determine the limits within which the programme has to be drawn up. Starting from the premise that an agricultural development plan should fit into the general programme, it immediately follows
   - that the capital invested will have to make the largest possible contribution to the national welfare;
   - that the increase in production can be absorbed by the home and foreign market.

   In addition to these limiting marginal conditions the development possibilities are limited by the following production factors: –
   - the amount of irrigation water available
   - a specialist cadre and skilled labour.

   These scarce production factors should be used and combined in such a way that a maximum production is obtained.
   A particular aspect of the Iraqi economy is the fact that some 60 % of the population is dependent on agriculture for a living. Much of the present-day agriculture is at a low level of development owing to the unfavourable conditions (e.g. salting up of the soils). As regards the form of agriculture required to obtain a profitable production

after the soils have been improved, the majority of the agricultural population must provisionally be classified as unskilled labour.

2. The *natural possibilities* of a region determine the direction in which the development programme has to be worked out. It will be necessary to draw up an inventory of these natural possibilities. Very valuable in this connection are the data provided by soil survey and land classification[1]), experimental fields and pilot schemes, etc.
Finally it will be necessary to examine how the natural possibilities can be put to the best possible use with the scarce production factors, viz. to enable the greatest possible 'added value' to be obtained therewith. To this end alternative programmes will have to be drawn up and their cost calculated. Owing to national economic considerations these calculations will have to be based on the intrinsic value of the means of production and products by starting from accounting prices. This applies in particular to wages in connection with the unemployment.
Since the accounting wages will be low compared to the accounting prices of the capital goods the labour-intensive alternatives will be shown in a favourable light. Under the conditions obtaining in Iraq this is also the appropriate direction in which to work, unless the rate of execution greatly predominates. Moreover even simple improvements in manual execution (e.g. the use of rolling stock for transporting soil, mowing with the scythe instead of with the sickle, etc.) result in substantial improvements in labour productivity and lighten labour without any considerable capital investments being required.

— *Alternative solutions in the development of Iraqi agriculture*

There is only a limited amount of irrigation water available in Iraq. Consequently a direct relationship can be established between the water requirement per ha on the one hand and the total area to be irrigated on the other.
Hence if intensification of the land use (e.g. as a result of the elimination of fallow and/or the cultivation of crops requiring more moisture) results in an increase in the water requirement per ha, the total area to be irrigated will have to decrease.
This area determines in turn the size of the irrigation system, drainage system and road system required for providing communication facilities. Thus intensification of agriculture will result in lower costs of installing and operating the 'primary' facilities. Moreover the least productive lands can be discarded. In addition intensification of agriculture leads to a more efficient control of the irrigation water and a more effective salt control of the land. Under such conditions additional investments made by the farmers, e.g. the purchase of fertilizer and selected seed, will also give a speedier return. This in turn will open up new prospects for the cultivation of more valuable agricultural crops. Thus intensification of agriculture in Iraq could on the one hand lead to lower investment costs of land improvement works and reclamation, and on the other to higher yields as compared to the execution of such reclamation works without an accompanying intensification.

[1]) See for example: BURINGH, 'Soil and soil conditions in Iraq'.

In order to gain an insight into the problem of finding the best form of agriculture to fit into the national programme it will be necessary to calculate the cost of a number of alternative plans, taking into account the extent and rate at which the farming population will be able to adjust itself to the new agricultural conditions. It should, however, be emphasised in this connection that even the choice of the simplest plan for desalting land requires a considerable amount of adaptation on the part of the population. A rational method of controlling the irrigation water, an understanding of leaching of the soil and an applied crop rotation will be the minimum requirements for ensuring the success of the work. Moreover in many areas the existing irrigation canals, the established irrigation rights and even the parcelisation will have to be revised in order to obtain a rationally planned drainage system and a proper distribution of irrigation water.
The legal consequences of such changes, especially the irrigation rights and the parcelisation situation, will have to be considered. If this is not done the investment costs will be considerably increased, the execution will be delayed and the results unfavourably affected.

— *Rate and mode execution*

The development programme will have to include not only the technical preliminaries and the execution of civil engineering works, but also the reclamation of the land and the transmission of know-how to the land users. The weakest link in this will ultimately determine the rate of a successful plan of execution.
Experience gained in executing similar projects in various countries has shown that the weakest links are generally: making the land ripe for cultivation and the transmission of the necessary agricultural know-how to the farmers. For both sections it is necessary to have a sufficiently specialized cadre. The size of this cadre actually determines the rate of successful progress. The formation of a sufficient cadre for extension work, making the soil ripe for cultivation (desalting, levelling where necessary, etc.) and the transmission of know-how to the farmers could be done in the following way.
One or more reclamation projects of a surveyable size (depending on the number of specialists available) should be taken in hand.
The planning of the work in these projects should be such that every year the amount of land reclaimed is equal to the amount allotted as 'ripe for cultivation'. The necessary operations will have to be carried out by the land users whose land is being improved. This has two advantages. During the reclamation, which may take about three years, the land users will be in a position to earn a wage and will also be afforded an opportunity of learning the new agricultural and irrigation methods. At the same time new specialists will have to be trained and these in turn will be able to take charge of new reclamation projects. Likewise a great many specialists will be required for the extension work to be carried out in the areas already improved.
As a result of continuous cadre formation these reclamation projects will ultimately snowball.

ANNEX I

THE LAYOUT AND EXPERIMENTAL PROCEDURE OF THE DUJAILAH DRAINAGE AND LAND RECLAMATION FARM

When the first projects were being drafted many questions arose to which no answer could be given without extensive and systematic research. We need not discuss whether the establishment of an experimental farm for the reclamation of saline soils would be justified when it is considered that no systematic research on the reclamation possibilities and techniques has been undertaken either in Iraq or any of the surrounding countries with comparable soil and climatic conditions.
Moreover money is available in Iraq and large ambitious programmes for the reclamation of saline soils have been drafted and the first projects are being carried out.
The need for basic quantitative data on the drainage requirements and the procedure to be followed during the reclamation has become increasingly evident.

1. LAYOUT

The farm layout given in figure I–1 shows 8 blocks varying in size from 6 to 48 mesharas. The drain depths and spacings vary from 1.20 to 2.25 m below ground level and from 25 to 150 m respectively. The blocks were subdivided into basins and sub-basins of a carefully measured acreage to allow a sufficient number of replications.
The original farm layout included four more blocks (IX, X, XII and XIII). These were reserved for additional experiments and untreated control plots and up to 1959 were not included in the experimental programme. Before the drainage system of the other blocks of the farm had been established some initial experiments were conducted on block XI, situated near the main drain.
Since the leaching programme proved to be very successful after a few years experimenting it was planned to convert plots IX, X, XII and XIII (total area 600 mesharas) into a

demonstration farm in order to facilitate the dissemination of knowledge and new techniques worked out in the course of the experiments. Up to 1959, however, this plan had still not been implemented.

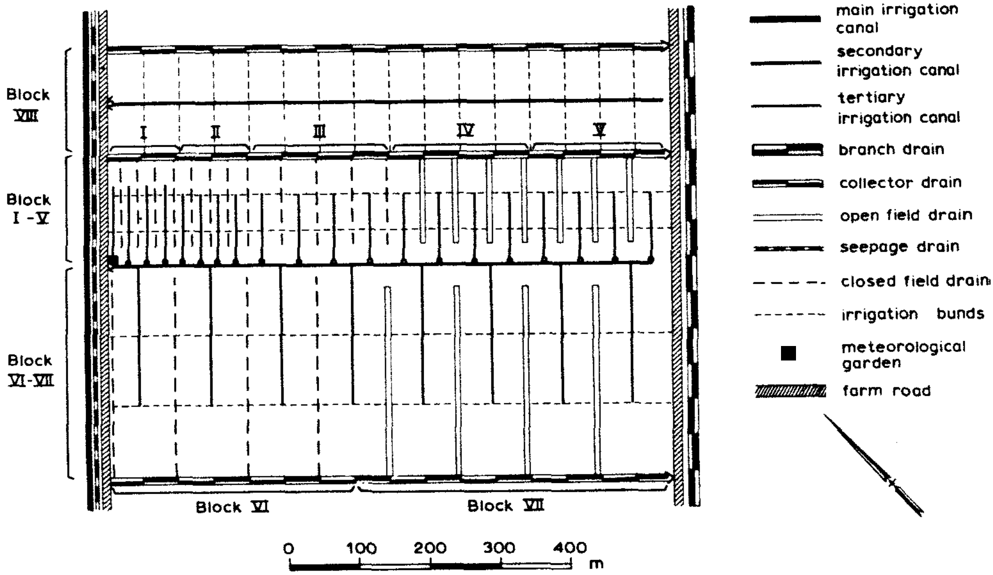


Fig. I-1. Plan Dujailah drainage and land reclamation farm

Blocks and drains of Dujailah experimental farm

Blocks	Tiles or ditches	Bottom level of drains below ground level 1 m	Spacing of drains in m	Area in mesharas
I	tiles	1.20	25	6
II	,,	1.50	25	6
III	,,	1.50	50	9
IV	,,	1.80	50	12
V	ditches	1.80	50	15
VI	tiles	1.80	100	48
VII	ditches	2.10	100	48
VIII	,,	2.25	150	48

2. SOIL CONDITIONS

Investigations carried out by TURCAN in 1952 showed the salt content of this area to be extremely high. The samples taken up to a depth of 2 m had percentages of total soluble salts of from 0.1 to 5, with an average of 1.8. More details on the salt content of the soil, assembled before the experiments started, are given in chapter 2. It may be concluded that the experimental plot was representative of the more severely salinized soils of the area. The plots had been abandoned for several years on account of the high salt content of the soil. It was only in the 1953–54 season, that some farmers tried to cultivate a small part of some of the blocks, but without much success.

Borings of up to 5 m below ground level showed that the soil profile mainly consists of silt loam with thin layers of clay, silty clay loam and sandy loam. The thickness of the clay layers increases in the direction of the main drain.

The permeability of the silt-loam, measured by the auger hole method, was 0.50 m to 1.00 m per 24 hrs, and may be classified as moderate (see table 3, chapter 2). The silty-clay loam and the clay layers are far less permeable, especially in the subsoil. The heavy clay layer, which was found at a depth of about 4 m below ground level, may be considered as impermeable.

3. EXPERIMENTAL PROGRAMME

The experimental programme has already been discussed in chapter 1 and will only be briefly summarized. It was divided in three sections, viz.: –

- a soil hydrology section in which emphasis is placed on the desalinization of the soil profile in relation to irrigation amounts, soil permeability, drain spacing and drain depth;
- an agricultural section, comprising the crop response during and after the various stages of reclamation;
- the study of reclamation procedures to be recommended for the reclamation of certain areas.

All questions and problems involved in the reclamation of saline soils may be classified under one of these groups.

The ultimate object of this programme is to investigate to what extent different types of saline lands can be reclaimed, how this should be done, and to what extent it is economically feasible. In order to include a greater number of different soil types in the investigations and to check the results obtained at Dujailah it was considered desirable to lay down trial plots of a simpler form in other project areas (Annanah, Twairij).

4. EXPERIMENTAL PROCEDURES

During the experiment measurements were taken of: –

- the quantities of water applied at each in-take
- the daily drain discharge during the discharge period
- the changes in subsoil water levels at different intervals and locations
- the changes in the salt content of soil and drain water during and after leaching at regular intervals

- the changes of soil moisture content
- the yields of cultivated basins
- various climatological data

Special blocks or combinations of basins were selected for certain investigations. For instance, for consumptive use research, undertaken on one drainage and irrigation unit, 3 basins of block 1 were selected and the detailed investigations into soil moisture throughout the summer and winter season, involving samplings every 3 days, were made at labelled locations in three different basins located in blocks I, III and IV. However, all irrigation amounts and all drain discharge of the tile drains were measured as a routine procedure.

A large number of ground-water observation wells were placed in regular patterns in blocks I, III and VI. Readings of the ground-water level were taken once every three days as a routine procedure.

Daily readings were made for special investigations and short periods. In addition a number of piezometer sets were installed in blocks I and III.

Figure I–2 shows the location of the wells and piezometers in block I. The wells, piezometers, drain water and irrigation were sampled at regular intervals and the samples analysed for salt content. Soil samples were taken before and two or three times during a heavy leaching period, and as a routine procedure before sowing and after harvesting a crop. All samples were analysed for salt content and in most cases for nitrate content as well. The samples taken at the beginning and end of the leaching period were also analysed for cations, anions, lime, gypsum, exchangeable sodium, pH etc. All samples taken from the reclaimed soil and the soils to be reclaimed by irrigation of crops but without extensive leaching before cropping were fully analysed once a year.

Cropping was carried out according to the normal agricultural practices of local farmers. It was only on some of the fully reclaimed basins that a start was made in cultivating better varieties on better prepared soil and even in introducing new crops (potatoes, groundnuts) so as to demonstrate the production potentiality of the reclaimed soil.

It was found necessary to begin fertilizer investigations, leaching and fertilizer research being closely connected. Care was taken to ensure that for reasons of comparison a sufficient number of plots were given no fertilizer.

No gypsum, sulphur or potassium were supplied, since after some initial investigations, it was noticed that the crops gave no response to these dressings.

In most cases the crops grown were the same as those grown by local farmers (barley, wheat, green gram, etc.).

The crop rotations were adapted to the stage of desalinization and reclamation of the soils. They varied from very extensive and simple rotations on the non-reclaimed soil to fairly intensive and more complex rotations on the reclaimed soil (see chapter 5).

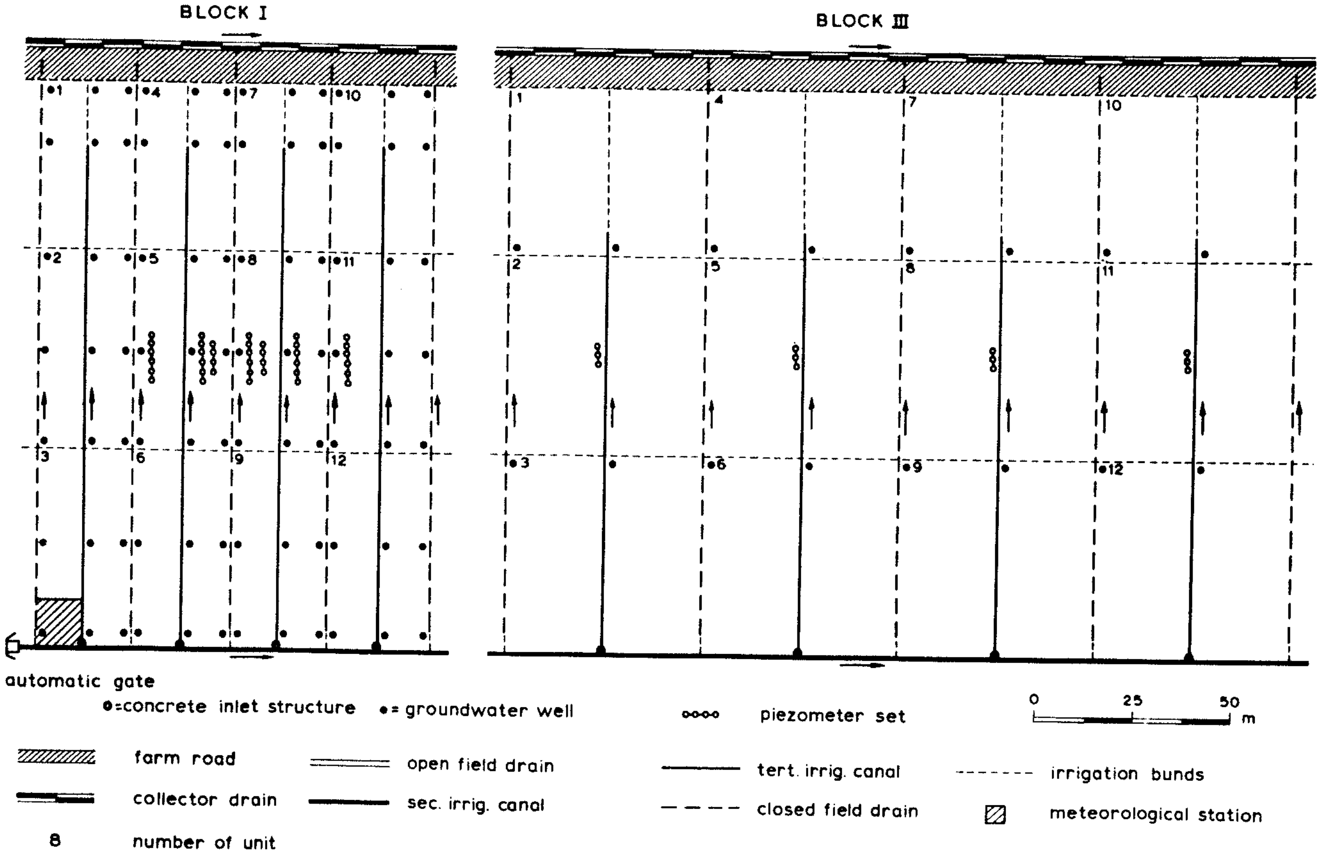


Fig. I-2. Lay-out of blocks I and III, including wells and piezometers

ANNEX II

THE ANALYTICAL METHODS EMPLOYED

Up to 1957 the soil samples were chemically analysed at the Laboratory of the Engineering College, Baghdad. Thereafter the analyses were made either at the Irrigation and Drainage Laboratory Tell Mohammad, Baghdad, or in the field laboratories on the farms. As the latter had simple equipment, it was only possible to analyse the electrical conductivity, chloride content, nitrate content and moisture percentages of the soil samples.
The Laboratory methods employed are mainly identical to those described in the U.S.D.A. AGRICULTURE HANDBOOK NO. 60 (1954), to which the numbered methods in brackets refer.

1. SATURATED SOIL PASTE

Distilled water was added to a soil sample of approximately 100 to 150 grams with stirring. When saturated the soil paste glistens as it reflects light, it flows slightly when the container is tipped, and the paste slides freely and cleanly off the spatula in the case of all soils except those with a high clay content. After the paste has been prepared it should be left to stand for an hour or more (method 2, p. 84).

2. SATURATION EXTRACT

The saturated soil paste was transferred to a Büchner funnel with filter paper and filtered in vacuo. The extract was collected in a small Erlenmeyer flask or test tube (method 3a, p. 48). Vacuum can be applied by a running water-tap pump. If no running water is available the paste can be filtered under pressure with the use of a valved pressure cooker. The Büchner funnels were placed in the cooker with their stems extending to the bottom. After the funnels had been filled with the saturated samples the lid was hermetically closed and air pressure supplied either by a hand or power pump.

3. SOIL WATER EXTRACT AT 1 : 1

A soil sample of approximately 100 grams was placed in a bottle and the same amount by weight of water added. The mixture was well shaken and allowed to reach equilibrium before filtering (method 3c, p. 88). After approximately 2 hours the mixture was filtered through a funnel with filter paper, or the supernatant liquid was carefully decanted.

4. ELECTRICAL CONDUCTIVITY OF A SOLUTION

The electrical conductivity was measured by a standard wheatstone bridge and a conductivity cell of a known cell constant (method 4a, p. 89). Two main types of bridges are available, the direct indicating bridge, giving the conductivity, and the indirect indicating bridge, giving the resistance of the solution, in which case the conductivity has to be calculated. For both instruments a temperature correction has to be made to obtain the conductivity at 25°C. Using the formula for the temperature correction in U.S.D.A. AGRIC. HANDBOOK NO. 60 a nomograph was constructed (annex IV) which was a considerable help in the calculations.

5. SOLUBLE SALTS

5.1. *Total dissolved solids (T.D.S. or T.S.S.)*

A well-filtered and weighed aliquot was evaporated to dryness, on a water bath and the residu weighed.

5.2. *Calcium and Magnesium*

The total amount of calcium and magnesium was determined by titration with versenate (method 7, p. 94).

5.3. *Calcium*

The calcium content was determined by precipitation as Ca-oxalate (method 8, p. 95).

5.4. *Magnesium*

The magnesium content was determined by direct gravimetric analysis by precipitation as Mg-ammonium phosphate (method 9, p. 95) or indirectly by subtracting the calcium content from the total calcium and magnesium content.

5.5. *Sodium and Potassium*

The sodium and potassium contents were determined by the flame photometer (methods 10a and 11a, pp. 96 and 97), using the 'internal standard' method.

5.6. *Bicarbonate*

Bicarbonate was determined by titration with acid (method 12, p. 98).

5.7. *Chloride*

Chloride was determined titrimetrically with silver nitrate (method 13, p. 98).

5.8. *Sulphate*

Sulphate was determined gravimetrically by precipitation as barium sulphate (method 14a, p. 99).

5.9. *Nitrate*

Nitrate was determined colorimetrically with diphenylamine sulphate.

6. *Exchangeable sodium*

The exchangeable sodium content was determined by shaking 5 grams of air-dry soil with 33 ml. of 1.0 N ammonium acetate adjusted to pH = 7.0. After centrifuging the supernatant liquid was collected. This procedure was repeated twice and the volume of the total amount of liquid collected made up to exactly 100 ml. In this liquid Na was measured by flame photometry, giving the sum of soluble and exchangeable sodium. By subtracting from this the quantity determined as 'soluble sodium' the value of exchangeable sodium was found (method 18, page 100). According to DELVER (1960) the value thus found may be somewhat too low as the soluble sodium should be determined in a saturation extract, viz. the narrowest soil: water ratio from which an extract should be taken on a routine scale and most closely approximating to soil moisture conditions. The wider the ratio, the more exchangeable sodium will be released in the soluble sodium extract.

7. CATION EXCHANGE CAPACITY

A sample was treated with an excess of a normal sodium acetate solution of pH 8.2 and the cation exchange capacity determined by measuring the meq. of sodium adsorbed per 100 grams of soil (method 19, p. 101).

8. pH

The pH was determined in the soil paste by an electrical pH meter with a glass electrode (method 21a, p. 102).

9. GYPSUM

All gypsum was brought into solution by progressive dilution of the soil suspension. After filtering the gypsum content was determined by precipitation with acetone (method 22b, p. 104).

10. LIME

The lime content was determined titrimetrically by treating the soil with a known quantity of hydrochloric acid and back-titrating with potassium hydroxyde (method 23c, p. 105).

11 MECHANICAL COMPOSITION

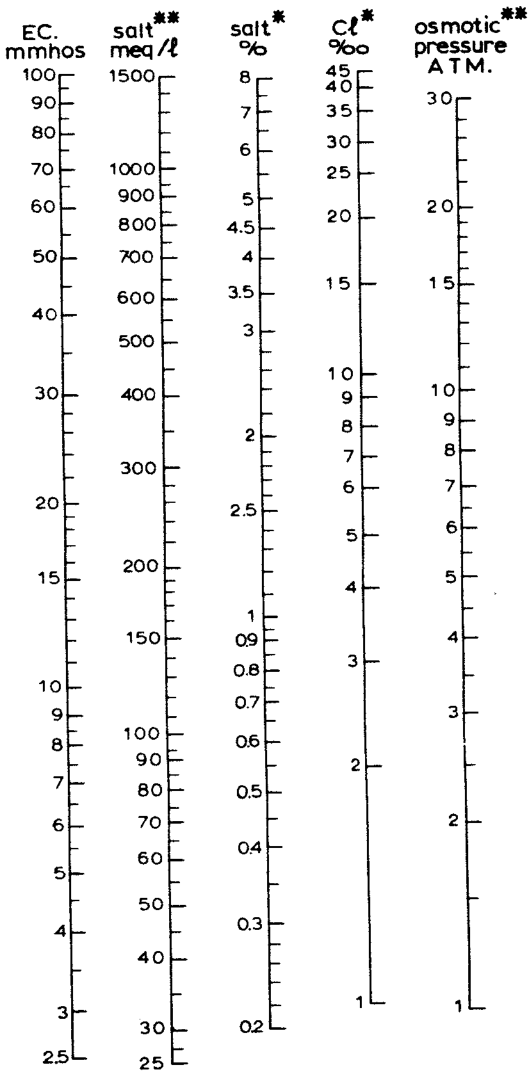
Textural analyses were usually carried out without removing lime or organic matter. The clay was dispersed by a mixture of 'calgor' (Nahexametaphosphate) and sodium-oxalate. Salts and gypsum were removed by repeated washings.
Clay was determined by the pipette method and sand ($> 50\mu$) by sieving (method 41, p. 122).

12. SATURATION PERCENTAGE

The moisture content of a saturated paste was determined by carefully filling a cup of known weight and volume with the paste and weighing (method 27c, p. 107).

ANNEX III

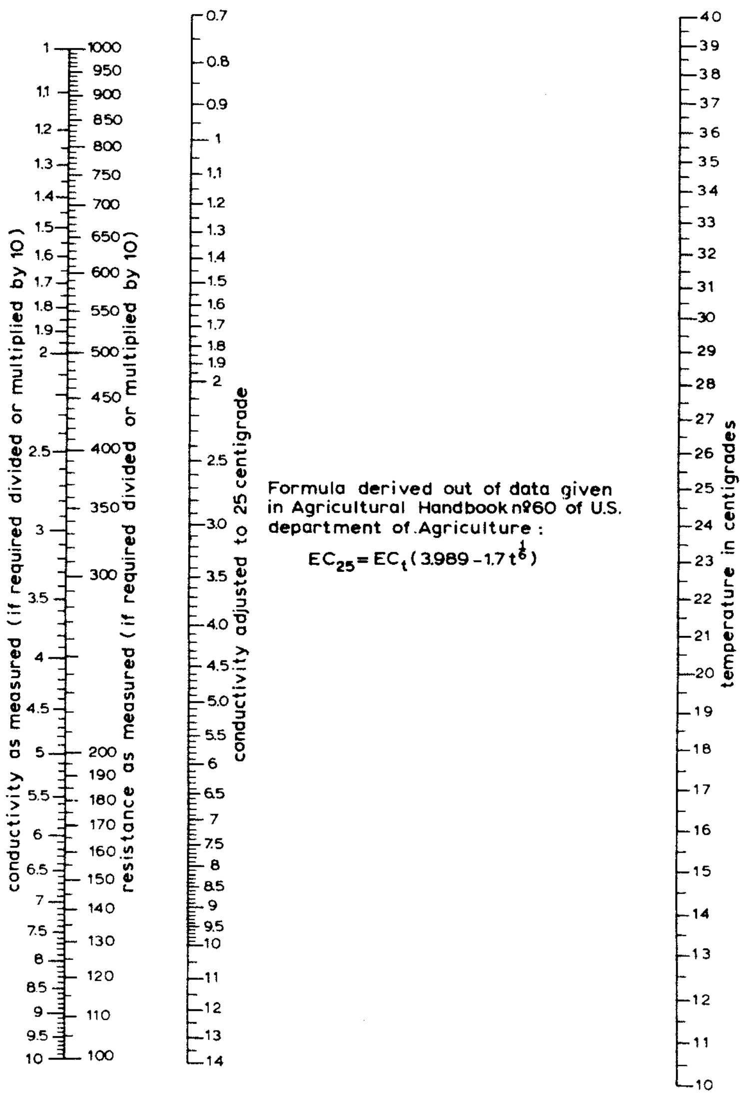
CONVERSION GRAPH FOR
CONDUCTIVITY AND SALINITY OF AVERAGE SOIL EXTRACTS



Sources:
** Agricultural Handbook No 60 U.S.D.A.
* Analytical results Dujailah Exp.

ANNEX IV

NOMOGRAPH FOR REDUCING ELECTRICAL CONDUCTIVITY OR RESISTANCE READINGS OF NATURAL WATERS OF TEMPERATURES BETWEEN 10 AND 40 CENTIGRADES TO CONDUCTIVITY AT 25 CENTIGRADES



ANNEX V

CALCULATION OF DRAIN SPACING ACCORDING TO ERNST

ERNST (1954) developed a method for calculating the drain spacing in stratified soils, built up of layers of different hydraulic conductivity. The solution of the two-layer problem only is given.

The drains may or may not cut into the second permeable layer and may consist of tiles or ditches. Figs. V–1 and V–2 show these four possible situations and the significance of the various quantities by which the system is determined. The wet perimeter U is defined as the wetted length of the cross section of the drain. For ditches with bottom width b, water depth h and side slopes 1 : 1, $U = b + 2h. \sqrt{2}$. For drain pipes with an outside diameter 2r, $U = 2\pi r$. All dimensions are in metres and days.

The available hydraulic head m difference between the groundwater level halfway between the drain and the water level in ditch or tile line) or $\bar{\bar{m}}$ when the ground water fluctuates, may be divided into a component m_v for vertical downward flow, a component m_h for horizontal flow, and a component m_r for radial flow to the drainpipe or drain ditch.

$$m = m_v + m_h + m_r$$

with

$$m_v = Dr \frac{D_1}{K_1}$$

$$m_h = Dr \frac{L^2}{8\,(K_1D_1 + K_2D_2)}$$

$$m_r = Dr \,.\, L \,.\, W_r$$

The radial resistance Wr, to be calculated as follows: –

Case Ia and Ib: –

$$W_r = \frac{0.733}{K_1} \cdot \log \frac{4d}{U} \text{ (for } K_2/K_1 \geqslant 20)$$

$$W_r = W_o + \frac{0.733}{K_1} \cdot \log \frac{0.8d}{U} \text{ (for } K_2/K_1 < 20)$$

W_o depends on D_2/D_1, K_2/K_1, and K_1 and can be read from Fig. V–3 (see page 137).

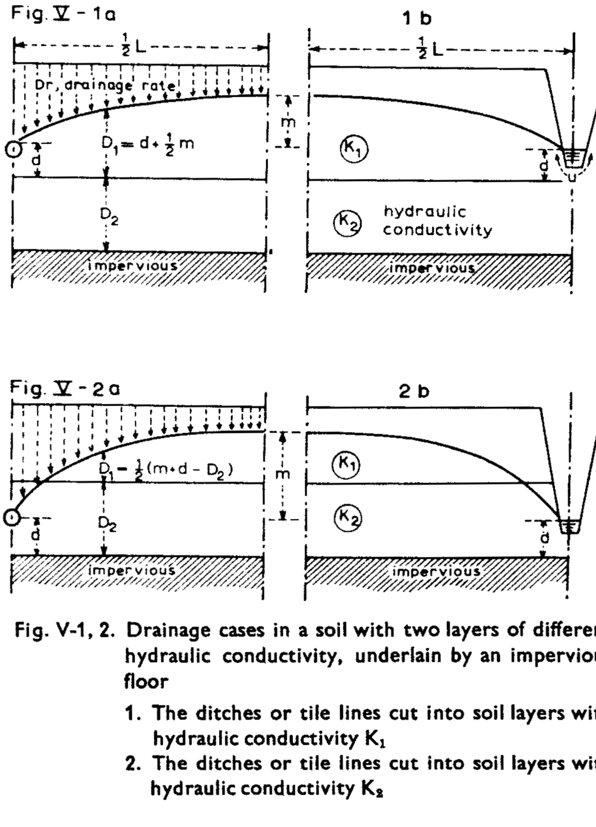


Fig. V-1, 2. Drainage cases in a soil with two layers of different hydraulic conductivity, underlain by an impervious floor

1. The ditches or tile lines cut into soil layers with hydraulic conductivity K_1
2. The ditches or tile lines cut into soil layers with hydraulic conductivity K_2

Case IIa and IIb: –

$$W_r = \frac{0.733}{K_2} \cdot \log \frac{d}{U} \text{ (for } d > U)$$

$$W_r = 0 \qquad \text{(for } d \leqslant U)$$

— *Example*

Soil profile consisting of 2 m clay loam (permeability 0.3 m/day) on 2 m sandy loam (permeability 1.5 m/day), overlying impermeable clay. Required drainage rate 1 mm/day, ground-water depth 0.6 m (minimum). Drainage with ditches 0.5 m bottom width 1 : 1 slopes, 25 cm water depth in the ditch, drain bottom depth 1.5 m.

drain depth		1.5 (m)
water level drain below surface		1.25 (m)
m	: (1.25–0.6)	0.65 (m)
Dr	:	1×10^{-3} (m/day)
U	: $(0.5 + 2 \times 0.25 \sqrt{2})$	1.2 (m)
d	: (2 – 1.25)	0.75 (m)
K_2	:	1.5 (m/day)
D_2	:	2 (m)
K_1	:	0.3 (m/day)
D_1	: (0.75 + 0.32)	1.07 (m)
D_2/D_1	:	1.87
K_2/K_1	:	5
$W_o \times K_1$	: (from Fig. V–3)	0.45
W_o	:	1.5 (day/m)
m_v	: $(1 \times 10^{-3} \times 1.07/0.3)$	3.56×10^{-3} (m)
m_h	: $L^2 \times 10^{-3}/8 \,.\, (0.3 \times 1.07 + 1.5 \times 2)$	$3.76 \times 10^{-5} L^2$ (m)
m_r	: $(1.5 - 0.73) \,.\, 10^{-3} \,.\, L$	77×10^{-5} L (m)

$$m = m_v + m_h + m_r$$

$$0.65 = 3.56 \times 10^{-3} + 3.76 \times 10^{-5} L^2 + 77 \times 10^{-5} L$$

$$L = 120 \text{ m}$$

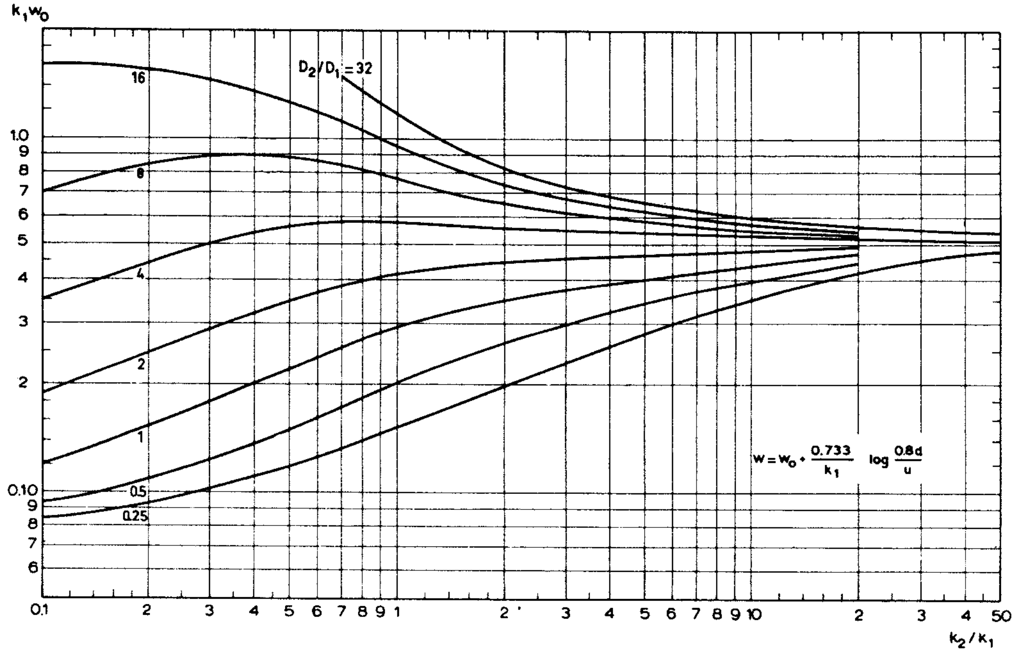


Fig. V-3. Determination of the radial resistance of an open drain having a wet perimeter $U = \pi r$, in a two-layer soil profile according to Ernst

ANNEX VI

CHARTS FOR CALCULATING THE DRAIN SPACING ACCORDING TO ERNST-BOUMANS

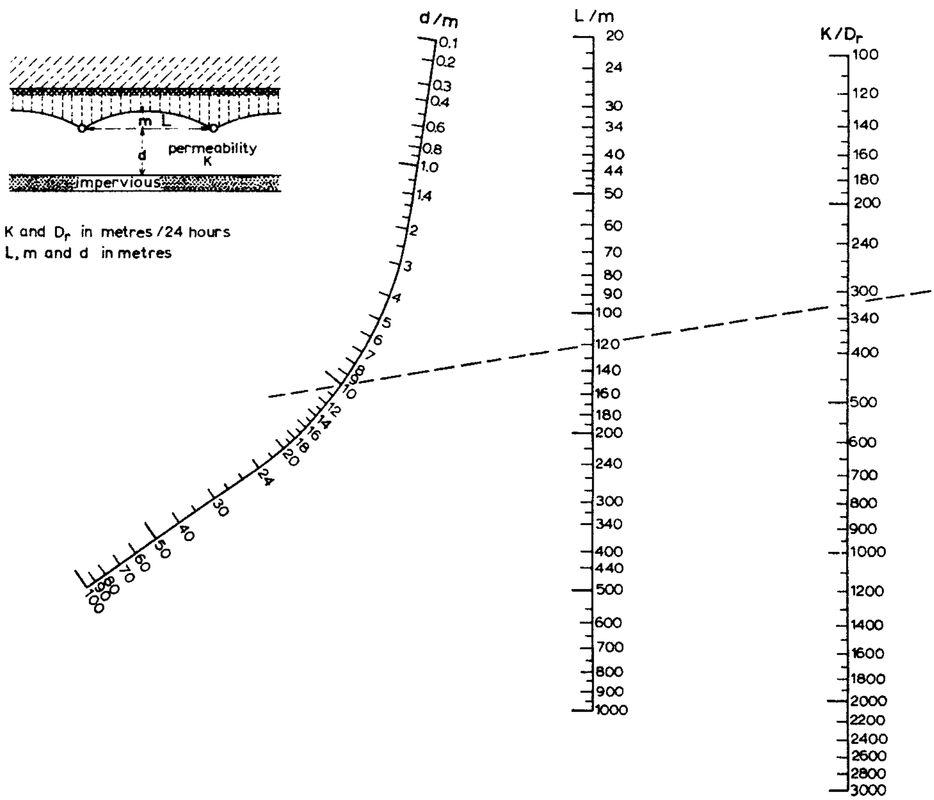


Fig. VI-1. Calculation of drainspacing for $K/D_r \geqslant 100$

ANNEX VI

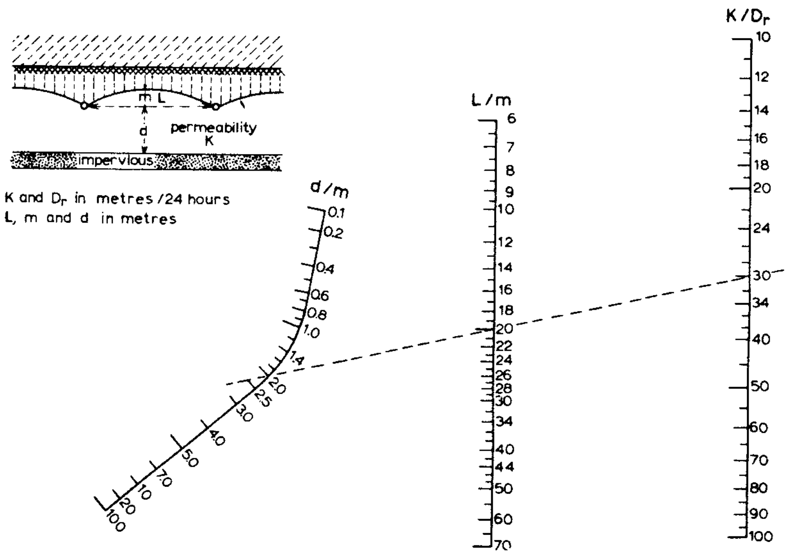


Fig. VI-2. Calculation of drainspacing for K/D_r ⩽ 100

ANNEX VII

A DRAINAGE FORMULA FOR A TWO-LAYERED ANISOTROPIC SOIL

1. EXPLANATION OF THE PROBLEM

Most of the Iraqi soils suitable for drainage are situated in the alluvial plains of the Tigris and the Euphrates. The profiles of these are particularly stratified and are hydrologically characterizable as homogeneous-anisotropic, i.e. the soil profile consists of horizontal layers of varying permeabilities.

As described in chapters 7 and 8 intervals of one hundred metres and more are admissible between field drains under the given conditions. For drain intervals of this order of magnitude the flow of underground water to the drains will be a few tens of metres deep. To calculate the drain distances it is therefore necessary to have available the hydrological data of the deeper subsoil. For practical and economic reasons, however, routine examination at that depth for the purpose of securing a fully differentiated picture of the hydrological characteristics of the entire profile related to the flow of ground water is quite out of the question. With the aid of a limited number of deep borings, however, where necessary accompanied by a few pumping tests, it is possible to form an average picture of hydrological characteristics.

It is also possible to make a routine examination for ascertaining the differentiated picture of the hydrological characteristics of the top few metres of the soil profile.

Here in the upper section of the soil profile which will accommodate the field drains, the ground water will flow radially to the drains. The hydraulic (loss of) head over these last few metres is thus relatively great. This makes it advisable when planning the drainage system to take into account the differentiated hydrological characteristics of the soil layers immediately below the level of the field drains.

Before drawing up general directions for the drainage investigation it proved necessary to ascertain the following: –

1. a simple method of calculating the drain distances from the permeability data of the ground layers immediately below the level of the drains and the deeper layers, bearing in mind the stratified nature of the soil profile.
2. the depth to which the permeability examination can be carried out in the upper layers, which involves taking into account the relatively important influence of the radial ground water flow in the immediate vicinity of the drain on the hydraulic head as well as the feasibility of the routine examination.
3. the density of the investigation survey used for examination of
   - the upper soil layers with the requirement that a differentiated picture be obtained of the hydrological characteristics of the topsoil at relatively short distances.
   - the deeper layers with the requirement that a differentiated picture be obtained field by field of the hydrological characteristics of the deeper subsoil.

There now follows the derivative of a drainage formula adapted to Iraqi conditions.
Furthermore a nomograph has been worked out of this formula allowing of quick computation of drain distances under varying conditions.
Points 2 and 3 are not elaborated further in this connection. As regards point 2 it should be pointed out that it has been found possible for routine examination to make boreholes by hand power to a depth of approximately 5 metres.
The following remarks may be made in connection with the intensity of the drainage examination of the upper soil layers. As a description of profile was given of every bore-hole made, the main pattern of the subsoil could be reconstructed wherever the observation survey was dense enough. Partly in view of the requirement that it was necessary to have a reasonably reliable interpolation between observation points, the required density of a drainage investigation survey of the topsoil has been defined as follows.
The average density of a drainage investigation survey with holes of about 5 metres depth should be close enough to allow of a reconstruction of the main pattern of the subsoil.
The density of the survey in the Hillah-Kifl area, including intermediate boreholes, proved to be one dot per 300 mesharas (= approximately 70 hectares).
The nature of the subsoil was examined down to depths of 10 to 15 metres. The required number of deep borings to this depth could be defined as follows: –

a. the total number of deep borings must be sufficient to base on it a reliable conclusion as regards the general nature of the deeper subsoil,
b. it must also give sufficient information about the existence of extended soil layers with relatively very high or low permeability of which a specific influence could be expected on the flow of the ground water towards the drains. In the area of Hillah-Kifl, the density of the deep borings of 10 to 15 metres was in a ratio of one to about 12 borings of 5 metres.

2. FORMULA FOR CALCULATING DRAIN SPACING

The establishment of a drainage formula where both difference in permeability of two soil layers and the homogeneous-anisotropic characteristics of the soil are taken into account is based on the formula elaborated by HOOGHOUDT for a drainage system in a homogeneous isotropic soil[1]): –

$$m = \frac{Q}{\pi K}\left(\ln\frac{S}{2r} - 0.454\right) \quad (1)$$

where

m = potential difference or hydraulic head in metres
Q = discharge in m^3 per metre drain length per 24 hours
K = hydraulic conductivity in metres per 24 hours
S = spacing of the drains in metres
r = radius of the drain under study in metres

As $0.454 = \ln\frac{\pi}{2}$, equation (1) becomes

$$m = \frac{Q}{\pi K}\ln\frac{S}{\pi r} \quad (2)$$

This formula may also be expressed as follows: –

$$m = \frac{Q}{\pi K}\left(\ln\frac{S}{\pi r_d} + \ln\frac{r_d}{r_o}\right) \quad (3)$$

where:

r_d = radius of the equipotential plane at a distance of r_d metres from the centre of the drain.
r_o = radius of the drain (wet perimeter of the drain divided by π).

It is possible by using the first term of equation (3) to calculate the loss of hydraulic head m_1 of the deeper subsoil to the equipotential plane r_d and by using the second term the loss of hydraulic head m_2 resulting from the radial flow of ground water to the drain over a distance r_d: –

$$m_1 = \frac{Q}{\pi K}\ln\frac{S}{\pi r_o} \quad (4)$$

$$m_2 = \frac{Q}{\pi K}\ln\frac{r_d}{r_d} \quad (5)$$

In order to be able to apply these formulae to a homogeneous-anisotropic system, it must first be converted to a homogeneous-isotropic system.

[1]) JAMES N. LUTHIN, Drainage of Agricultural Lands, page 86.

In the following derivative the transformation has been continued in y direction, so that measurements in x direction remain the same.
The flow problem discussed here may be regarded as two-dimensional. In a section normal to the drain the equipotentials in anisotropic soils are half ellipses.
The following symbols are used in the further derivation of the equations: –

- d = thickness of the soil stratum of which the loss of hydraulic head m_2 resulting from the radial flow has to be calculated (viz. thickness of the soil stratum below the water level in the drain of which the hydrological characteristics differentiated to short intervals are known).
- q = precipitation in metres per 24 hours ($Q = q \times S$).
- K_x = horizontal permeability in layer d
- K_y = vertical permeability in layer d
- K_h = horizontal permeability in the deeper subsoil
- K_v = vertical permeability in the deeper subsoil
- r'_o = radius of the drain after transformation of the layer d into a homogeneous-isotropic system
- r'_d = radius of equipotential after transformation etc.
- r''_d = radius of equipotential in layer d after conversion of the deeper subsoil to a homogeneous-isotropic system
- b = bottom width of drain in metres
- h = water depth of drain in metres
- n = slope

— *Conversion of equation* 4

In equation (4) after transformation[1]) $K = \sqrt{K_h K_v}$, while r''_d is obtained by calculating the equipotential at d metres under the drain after conversion and dividing by π, hence

$$r''_d = \left(\sqrt{\frac{K_x}{K_y}} + \sqrt{\frac{K_h}{K_v}}\right)\frac{d}{2}$$

Equation 4 now becomes

$$m_1 = \frac{qS}{\pi\sqrt{K_h K_v}} \ln \frac{2S}{\pi d\left(\sqrt{\frac{K_x}{K_y}} + \sqrt{\frac{K_h}{K_v}}\right)} \qquad (6)$$

— *Conversion of equation* 5

In equation (5), after transformation, $K = \sqrt{K_x K_y}$. The equipotential at a distance d under the drain becomes a circle with radius $r'_d = d\,\frac{K_x}{K_y}$, and

r_o becomes $r'_o = \frac{1}{\pi}\left(b + 2h\sqrt{\frac{K_x}{K_y} + n^2}\right)$

[1]) M. Maasland, Soil anisotrophy and land drainage (p. 216), in: Drainage of agricultural lands, ed. by James N. Luthin, 1957.

Equation 5 now becomes

$$m_2 = \frac{qS}{\pi\sqrt{K_x K_y}} \ln \frac{\pi d \sqrt{\frac{K_x}{K_y}}}{b + 2h\sqrt{\frac{K_x}{K_y}} + n^2} \tag{7}$$

Total loss of pressure thus becomes (8)

$$m = m_1 + m_2 = \frac{qS}{\pi}\left[\frac{1}{\sqrt{K_h K_v}} \ln \frac{2S}{\pi d\left(\sqrt{\frac{K_x}{K_y}} + \sqrt{\frac{K_h}{K_v}}\right)} + \frac{1}{\sqrt{K_x K_y}} \ln \frac{\pi d\sqrt{\frac{K_x}{K_y}}}{b + 2h\sqrt{\frac{K_x}{K_y}} + n^2}\right]$$

This equation may also be expressed as follows

$$\frac{\pi m \sqrt{K_h K_v}}{qS} - \ln . S = \sqrt{\frac{K_h K_v}{K_x K_y}} \cdot \ln \cdot \frac{\pi d\sqrt{\frac{K_x}{K_y}}}{b + 2h\sqrt{\frac{K_x}{K_y}} + n^2} + \ln \frac{2}{\pi d\left(\sqrt{\frac{K_x}{K_y}} + \sqrt{\frac{K_h}{K_v}}\right)}$$

or for purposes of conciseness: $A = B + C$ (9)

Nomographs have been devised for calculating drain distances S (see nomographs A and B).

By using nomograph B, B can be determined and should then be transposed to nomograph A.

A follows from B and C.

3. NOTES ON NOMOGRAPHS A AND B

In order to determine B in the equation $A = B + C$ one should begin working below nomograph B from the left. The dotted line with arrows shows the direction to be followed when reading the nomograph.

Below nomograph B and to the left three curves have been drawn relating to three different wet cross-sections of the drains; two of these curves relate to open drains and the third to a tubular drain. Curves may be plotted for other cross-sections as required. If the ratio of $\sqrt{K_x K_y}$ to $\sqrt{K_h K_v}$ is equal to unity, B may read straight off the second vertical reference axis $\left(B\sqrt{\frac{K_x K_y}{K_h K_v}}\right)$. For unequal ratios of $\sqrt{K_x K_y}$ and $\sqrt{K_h K_v}$ reading must go on up to the last vertical axis of nomograph B for the calculation of B. B must then be retraced on the B axis given in nomograph A, where it is linearly graduated.

C may be deduced from the graph on the right-hand side of nomograph A. After A has been worked out from B and C, the drain distance S may be read off by determining the value of $\frac{m}{q}\sqrt{K_h K_v}$. The value of $\frac{m}{q}\sqrt{K_h K_v}$ may generally be regarded as constant for limited areas.

Example

Calculation of the drain distance S is based on the following data
(for the meaning of the symbols see also the drawing on nomograph B): –

– Measurements of the drains. –

$b = 1$ metre
$n = 1 : 1$
$h = 0.25$ metres

– Permeability of the topsoil up to 3 metres (= d) below the 'water level of the drain': –

$K_x = 1.44$ metres per 24 hours
$K_y = 0.36$ metres per 24 hours

thus $\sqrt{\frac{K_x}{K_y}} = 2$ and $\sqrt{K_x K_y} = 0.72$ metres per 24 hours

– Permeability of the subsoil: –

$K_h = 1$ metre per 24 hours
$K_v = 0.25$ metres per 24 hours

thus $\sqrt{\frac{K_h}{K_v}} = 2$ and $\sqrt{K_h K_v} = 0.50$ metres per 24 hours.

Permissible hydraulic head $m = 1$ metre for a discharge of $q = 0.001$ metres per 24 hours.
To ascertain B from nomograph B one should begin by reading off from the bottom left $\sqrt{\frac{K_x}{K_y}} = 2$.

It follows from the drain measurements that in this case the right hand curve should be followed for the wet-cross-section. The dotted line indicates the direction in which the reading should be effected. On the first vertical axis d (top left) the curve is found for $d = 3$ metres (see dotted line for reading direction). Then find $\sqrt{K_h K_v} = 0.50$ metres per 24 hours on the third vertical axis. Next the same procedure is followed for $\sqrt{K_x K_y} = 0.72$ metres per 24 hours on the fifth vertical axis, after which B is read off on the last vertical axis ($B = 0.65$).
B is retraced on the axis provided for this purpose in nomograph A.

$$\frac{\pi m\sqrt{K_H K_V}}{q.S} - \ln S = \sqrt{\frac{K_H K_V}{K_x K_y}} \cdot \ln \frac{\pi d \sqrt{\frac{K_x}{K_y}}}{b+2h\sqrt{\frac{K_x}{K_y}+n^2}} + \ln \frac{2}{\pi d \left(\sqrt{\frac{K_H}{K_v}} + \sqrt{\frac{K_x}{K_y}}\right)} \longrightarrow A = B + C$$

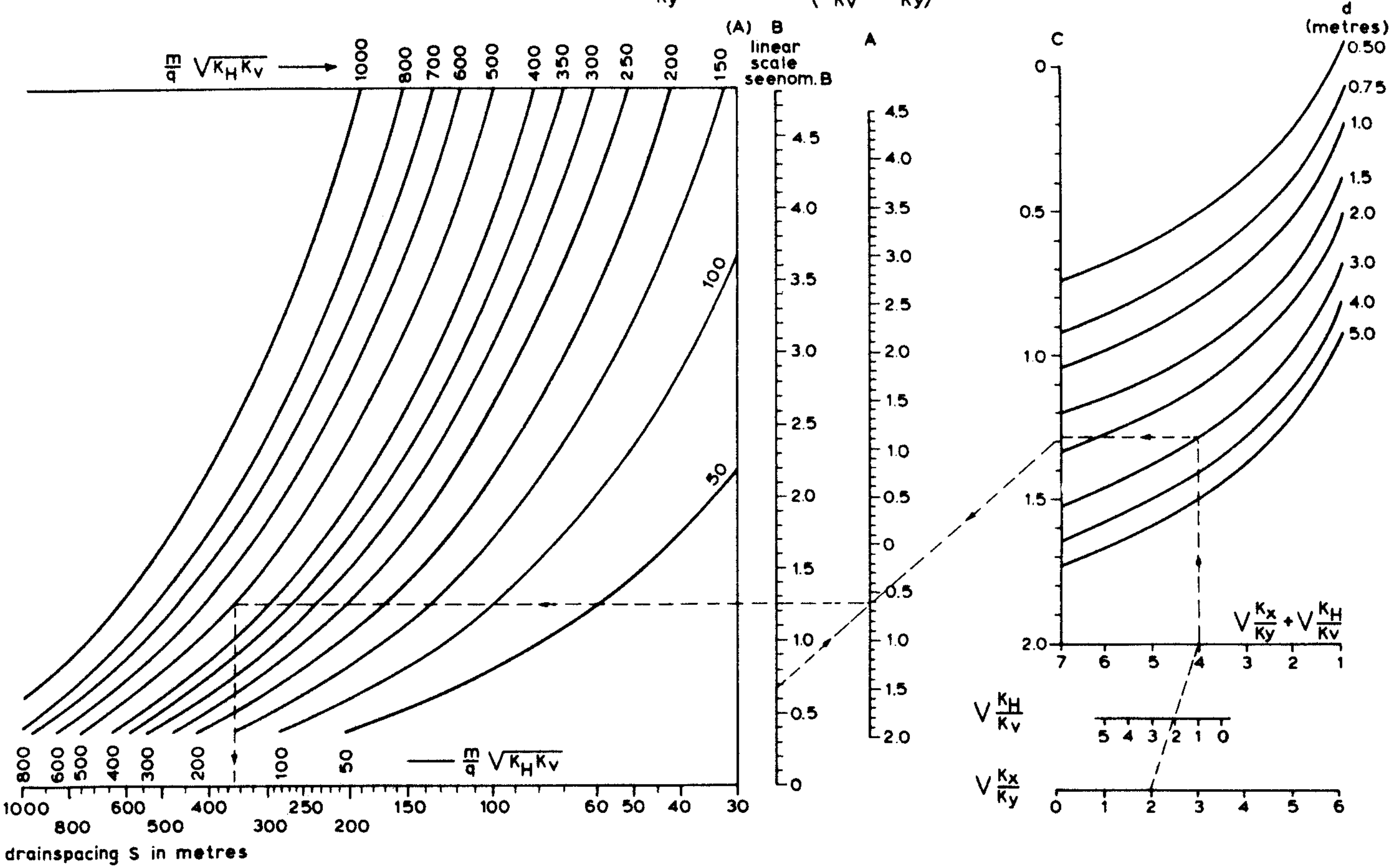


Fig. VII-1. Nomograph A for the determination of drainspacings in two-layered anisotropic soils (see Nomograph B)

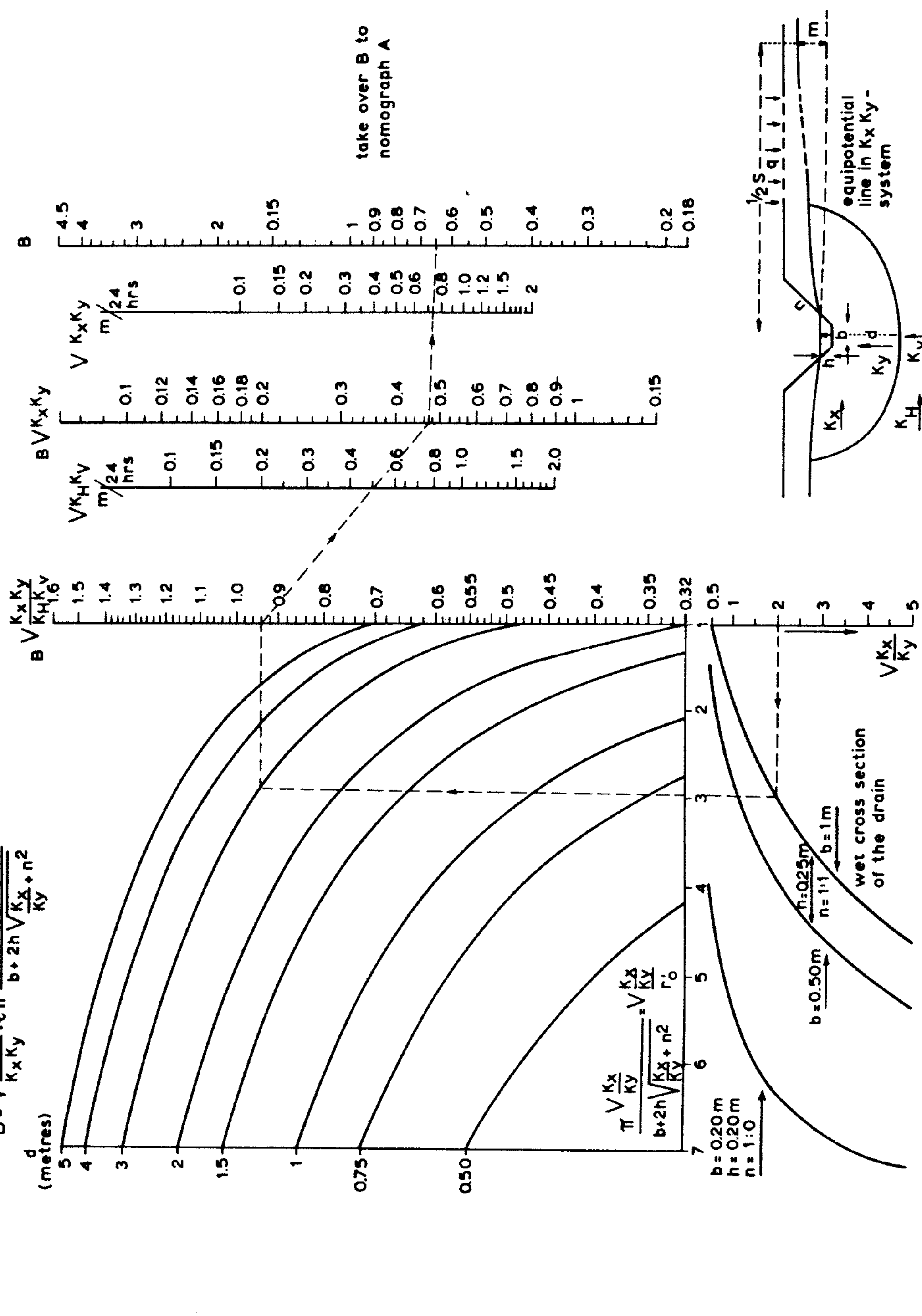


Fig. VII-2. Nomograph B for the determination of drainspacings in two-layered anisotropic soils (see Nomograph A)

To ascertain C, $\sqrt{\frac{K_x}{K_y}} = 2$ and $\sqrt{\frac{K_h}{K_v}} = 2$ have to be determined from the bottom right of the nomograph A. C can then be determined via the curve which relates to d = 3 metres (C = 1.28).
A is determined by the point of intersection of the line connecting B and C and the vertical axis A.

This is followed by the calculation of $\frac{m}{q} \sqrt{K_h K_v}$. In this case it is 500. By following the dotted line, a reading of 360 metres is obtained for the drain distance S.

SUMMARY

This paper is the result of the combined efforts of four authors who, during the period 1953–1959, worked several years as 'foreign experts' at the Ministry of Development and Development Board of Iraq, First Technical Section (subsequently in the Fourth Technical Section). It was their task among other things to report on the possibilities and methods of reclamation of salt-affected areas of Iraq.

Experimental fields were laid out in order to obtain a clear insight into the water and salt movement of the soil.

In this paper the experiments conducted on these fields are described and the results obtained set forth.

GENERAL INTRODUCTION

There is practically no salinity in the rain-fed northern districts of Iraq. But salinity increases towards the South, where irrigated agriculture becomes more prominent, and is very serious below Baghdad where the valleys of the Euphrates and Tigris widen to form a vast, broad plain (Fig. 7). Here, owing to the long, hot and dry summer and the little rain in winter (Figs. 1, 2, 3), normal agriculture requires an artificial water supply throughout the year.

As salinity was not a severe problem in ancient times, the present salinity is most probably due to the accumulation of salt from irrigation water (Euphrates and Tigris as the only sources of irrigation water for the Mesopotamian plain) over many years.

Reclamation experiments were already carried out in the Saklawiyah area, in 1927 by STRACHAN and in 1944 by TURCAN and HAWKINS. Although interesting results were obtained these researches did not lead to conclusions concerning drainage criteria, amount of leaching water required, etc. Therefore various experimental fields were laid down, again in 1954, the most important being in the Dujailah project area. Additional experiments were carried out in the Annanah and Twairij areas (Fig. 7). The object was defined broadly as the acquisition of more basic knowledge on the reclamation of saline soils with regard to soil condition, drainage and irrigation and cultivation practices. For the purpose of a systematic study, the experimental programme was divided into three parts: –

1. a soil hydrology section, especially the desalinization of the soil profile with regard to irrigation application, soil permeability, drain spacing and drain depth;
2. an agricultural section, comprising the crop response during and after the various stages of reclamation;
3. the study of the reclamation procedures to

be recommended for the reclamation of certain areas.

DATA ON THE SOILS AND SALTS OF THE DUJAILAH EXPERIMENTAL AREA

The soil profile of the Dujailah area consists of silty loam deposits (table 2), underlain by an impermeable layer at a depth of 4 m. The average permeability of the upper 4 m of soil is 70 to 80 cm per day (table 3).

The water-table before irrigation of the experimental plots varied from less than 1 m near the main feeders to more than 5 m in parts which have long been out of cultivation. After irrigation the water-table rose to above the drainage level. The salt content of the ground water was about 3% before irrigations started.

The soil, like all soils in Iraq which are saline, contains from 20 to 30% lime, which is proportionally distributed over the sand, silt and clay fractions. The gypsum content varies from zero to a few per cent. Most of the gypsum is located below a depth of 1 m in the profile.

The salt content of the Dujailah soil is high: roughly 2.5 % in the top 30 cm of soil and roughly 1.5 % in the deeper layers (Table 6, Fig. 8). About 70 % of all ions is taken by sodium and chloride ions.

For various reasons preference is given to the electrical conductivity of the saturated soil extract as an index of the salinity level of the soil. As the preparation of a saturated soil extract is rather time-consuming, all analysis since 1958 have been made in a 1 : 1 extract. For the Dujailah soils the relationship was determined between the salinity of the saturation extracts and 1 : 1 extracts, thus enabling the results to be converted.

During leaching the concentration of the different ions does not decrease proportionally (Fig. 16, Table 8). There was a marked decrease in the Na percentage to a depth of 30 cm and in the percentage of Cl to a depth of 100 cm. This means that the ion ratio changed during leaching. The Cl/SO_4 ratio, for example, which was 6 at the surface before leaching, decreased to about 1; lower down in the profile this ratio dropped to about 0.6. The disproportionate decrease of the ions can not be explained by varying 'moving capacities', but is the net result of supply and discharge of ions. It explains, at least partly, the occurrence of different types of saline soils found in the Mesopotamian plain.

LEACHING OF SALINE SOILS

Leaching was carried out by flooding the bare soil or by over-irrigating the cropped soil with varying depths of water. The quantity of water discharged by the drainage system, as measured at the drain outlets, was taken as an index of the actual amount of leaching water. The results of the field leaching experiments are shown in Figs. 17–20. These figures show that, in order to reduce the salt content of e.g. the upper 60 cm of soil to 10 per cent of the original value, some 35 cm of leaching water is required for Dujailah soil and some 190 cm for Annanah soil

As it is often not feasible to carry out time-consuming and expensive field experiments, an attempt was made to determine the leaching curves by means of two concentric cylinders, having diameters of 50 and 70 cm. The cylinders were pressed into the soil for about 5 cm and filled with water to a depth of 10 cm. Comparison with the data of the field leaching experiments shows that the results agree very well (Fig. 18). The leaching curve can therefore be determined sufficiently accurately by means of simple leaching infiltration tests.

The leaching of highly saline soils is a single operation. It may be repeated if for any reason too high a salt content accumulates in a soil once reclaimed, but a distinction is generally drawn between the leaching of excess salts which have accumulated in a soil, and the subsequent drainage of a certain amount of the added irrigation water in order to maintain the low salinity level obtained.

There is no constant soil salinity value during the cropping periods. With each irrigation the salt is moved downward, but during the intervals between irrigation it rises again owing to surface evaporation. In addition to these minor fluctuations there is an increase in salt content during the fallow periods, after the last irrigation of a crop and before the first irrigation of the succeeding crop (Figs. 20 and 21).

With a given drainage system the minimum salinity depends on the amounts of irrigation water applied and the amount of water discharged by the drain (table 9). As the irrigation supplies differ considerably, the drainage expressed as a percentage of irrigation quantities is also found to differ substantially: when there is an intensive cropping during both winter and summer, a higher discharge is required during summer. Table 10 shows the observed and the calculated leaching percentages for different seasons. There is no direct agreement between these; it is probable that not all irrigation water is effective in leaching and establishing the salt balance.

ALKALI ASPECTS OF LEACHING OF SALT-AFFECTED SOILS

Since the great majority of the saline soils in Iraq had to be classified as saline-alkali soils (terminology as proposed by the U.S. Salinity Laboratory, U.S.D.A., 1954), it was essential to know whether these soils would develop into a non-saline alkali soil as a result of leaching.

The most important considerations in this respect are as follows: –

1. Of the numerous soil samples analysed, hardly any exhibited the true alkali characteristics. This is a remarkable fact since leaching is regularly practised by the local farmers to reduce the salt content of the surface soil before planting.
2. All the soils of the Lower Mesopotamian Plain contain abundant calcium, most of it in the form of carbonates. Particularly owing to the fact that calcium carbonate occurs also in particles of 2 microns and less, it probably is of value as a source of Ca ions. Gypsum is present in most subsoils and partly in the surface soil, although in low concentrations.
3. The composition of the irrigation water is favourable (table 11).

Based on these considerations as well as on field leaching experiments (tables 12, 13, 14), the conclusion seems justified that the reclamation of the saline-alkali soils of Iraq probably does not give rise to any alkali problem.

The relationship between pH, E.S.P. and EC is plotted in Figs. 22 and 23. The graphs show the decrease of the pH with an increasing salt content, and the increase in exchangeable sodium with increasing salinity and a constant pH.

CROP YIELDS AND CROP ROTATIONS DURING RECLAMATION

A study was made of the influence of various drainage and reclamation treatments on the productivity level of the soils and the yields of some locally grown crops and varieties. The effect of salinity and fertilizer on yields is shown in tables 17 to 25, that of the soil nitrate content on yields in Figs. 24 to 27.

It proves that of the many factors influencing yield, soil salinity is the most important followed by the nitrogen level of the soil.

If the soils have been leached to a certain salinity level (approximately $EC_e = 8$), more benefit may be expected from fertilizer application than from further leaching. This was found to be true of all winter crops tested and even of legumes. However, the increase in yield resulting from nitrogenous fertilizer will differ according to the salt tolerance of the crop. This means that, in order to obtain optimum results, leaching of saline soils should be accompanied by an improvement in other growing conditions, in particular the application of plant nutrients.

The most obvious way of eliminating the salts is to preleach the soil heavily and then to start cropping. But this procedure cannot be recommended for large-scale application as it would involve, among other things, technical and economic difficulties in supplying farmers with sufficient water and fertilizer.

An attempt has therefore been made to find a reclamation procedure in which the heavy initial leaching was avoided, and leaching carried out gradually by normal irrigation or over-irrigating the land which is subjected to a certain crop rotation.

Such crop rotations are set out in tables 28 and 29.

The conclusion reached is that the best reclamation procedure should be arrived at by selecting the combination of initial leaching, legumes and length of crop rotation which will give the highest yields and best financial return under the given circumstances.

CONSUMPTIVE USE

Field measurements of the consumptive use were compared with evaporation pan records and the consumptive use according to BLANEY-CRIDDLE and PENMAN (Fig. 29, Table 32). Especially during the summer, the calculated C.U.-values were much lower than those actually measured, when the empirical coefficients proposed by the authors were applied. This disagreement may be explained by the 'desert effect' and the extreme summer climate of Iraq.

If modified empirical coefficients adapted to Iraqi conditions are used in the Penman and Blaney-Criddle calculation as well as in the evaporation pan method, they could be very useful in estimating the consumptive use for both the summer and winter seasons (tables 33, 34 and 36).

Mutual comparison of the three methods showed that their results were all equally reliable (Fig. 30). For this reason the Blaney-Criddle method is to be preferred as being the most simple one. The following coefficients are advised for use in the Blaney-Criddle formula: winter crops 0.5–0.8; summer crops 1.0–1.5.

SOME PRINCIPLES GOVERNING THE DRAINAGE AND IRRIGATION OF SALINE SOILS

Improvement of saline land consists of the reclamation period during which the excess salts are leached from the profile and the subsequent period during which resalinization has to be prevented.

The present chapter deals with the leaching and drainage problems of the second period, viz. after the soil has been reclaimed and also, of course, before the soil has been affected by salt.

Generally speaking the temporary drainage requirements of the initial reclamation period will be met by a drainage system adapted to the permanent needs of the second period. In certain cases a good temporary solution may be to construct shallow and cheap additional ditches to aid the reclamation.

Formulae are developed to calculate the leaching requirement P–G (form. 1–7) and the irrigation and drainage quantities required (form. 10–12). In these formulae a leaching efficiency coefficient (f) was introduced, the magnitude of which depends on soil physical characteristics and varies between 0 and 1. In the case of the Dujailah soils f was determined experimentally and calculated from Fig. 18 (form. 9). Both figures tally well and result in a leaching efficiency of 0.6.

SOME APPLICATIONS AND CALCULATIONS

It is realised that the actual processes occurring in the soils are much more complex than they were assumed to be in the foregoing chapter. Therefore the calculation techniques developed should never be used as purely routine methods; one should always adopt a critical attitude and be aware of the extent to which the assumptions made correspond with the

local conditions and experiences. The results of the calculations should always be considered as an approximate value.
The method of calculating the required field drainage system is illustrated by a number of examples.

SOME ECONOMIC ASPECTS OF RECLAMATION PROJECTS

The factors determining the cost and return of a project are briefly reviewed. A few provisional estimates of cost and return are also given of a minimum improvement plan. The economic feasibility of the reclamation projects do not appear to be unfavourable in the light of these conservative estimates.
The importance of the reclamation projects to the local population and the national economy is great. However, in the planning, execution and maintenance of the works, the constraints resulting from regional and national factors and possibilities will have to be taken into account. The weakest link in the process of improvement will govern its rate of progress.
A typically significant example is that the technical advance made by the farmers is such that the new possibilities arising as a result of the reclamation of land may also be exploited.
It is proposed to synchronize the planning of the land reclamation with the formation of specialists. By adapting the scope of the projects to the number of experts available and at the same time using these projects to train fresh experts, it will be possible to reclaim increasingly extensive tracts of land.

RÉSUMÉ

MISE EN VALEUR DES SOLS SALÉS EN IRAK

Cet exposé représente le résultat des efforts combinés de quatre auteurs qui, durant la période 1953–1959, ont travaillé en qualité d''experts étrangers' au Ministère Irakien du Développement, de même qu'au Conseil de Développement d'Irak, Première Division Technique (plus tard Quatrième Section Technique). Leur tâche était notamment de dresser un rapport sur les possibilités de mise en valeur des régions atteintes par une teneur en sel trop élevée du sol, et sur les méthodes appropriées susceptibles de conduire à ce résultat.

Dans le but de se faire une idée précise des mouvements d'eau et des transports de sel dans le sous-sol, ils procédèrent au tracé de terrains expérimentaux.

Ce document contient la description des expériences effectuées sur ces terrains, et l'exposé des résultats obtenus.

INTRODUCTION GÉNÉRALE

Il n'est pratiquement pas question de salinité du sol dans les régions pluvieuses du Nord Irakien. Mais à mesure que l'on se dirige en direction Sud, où prévaut davantage l'agriculture basée sur l'irrigation artificielle, la salinité augmente; elle prend des proportions très sérieuses au Sud de Bagdad, où les vallées de l'Euphrate et du Tigre s'élargissent pour former une vaste plaine très étendue (Fig. 7). C'est ici qu'en raison de la longueur de l'été sec et chaud, et de la faible pluviosité en hiver (Figs. 1, 2 et 3), la pratique de l'agriculture dans des conditions normales exige pendant toute l'année l'approvisionnement artificiel en eau.

Alors qu'aux temps anciens, la salinité ne formait pas un problème sérieux, le caractère qu'elle prend de nos jours est vraisemblablement attribuable à l'accumulation du sel provenant des eaux d'irrigation pendant de très nombreuses années (l'Euphrate et le Tigre étant les sources d'eau d'irrigation uniques dont on dispose dans la plaine de Mésopotamie).

Dès 1927, des expériences de mise en valeur avaient été effectués par STRACHAN dans la région de Saklawiyah, puis en 1944 par TURCAN et HAWKINS. Bien que des résultats intéressants fussent obtenus, ces travaux de recherche n'aboutirent pas à des conclusions définitives concernant les normes de drainage, le volume nécessaire des eaux de filtration et de lessivage, etc. C'est pourquoi l'on procéda une fois de plus, en 1954, au tracé de différents terrains expérimentaux, dont le plus important était celui qui comprenait la région du

Projet Dujailah. D'autres expériences furent effectuées dans les régions d'Annanah et de Twairij (Fig. 7). En grandes lignes, le but avait été défini comme suit: 'Acquisition d'un complément de connaissances fondamentales sur la mise en valeur des sols salins, compte tenu de la condition des sols et des méthodes locales de drainage, d'irrigation et de mise en culture.

Afin de permettre l'accomplissement d'une étude systématique, le programme expérimental fut divisé en trois parties:

1. la partie comportant l'étude hydrologique du sol, et particulièrement du dessalement de son profil en fonction de l'application de méthodes d'irrigation; d'autre part l'étude de la perméabilité du sol, de l'écartement des drains et de la profondeur de drainage.
2. la partie agricole, comprenant l'étude du rendement des récoltes avant et après les différentes phases de mise en valeur.
3. la partie comprenant l'étude des méthodes de mise en valeur à recommander d'une région à l'autre.

ÉLÉMENTS D'APPRÉCIATION SUR LA NATURE DU SOL DE LA RÉGION EXPÉRIMENTALE DU DUJAILAH, ET SUR LES DEGRÉS DE SA TENEUR EN SEL

Le profil du sol de la région de Dujailah se compose de sédiments de limon vaseux (tableau 2), reposant à la profondeur de 4 mètres sur une couche imperméable. La perméabilité moyenne de la couche supérieure de 4 mètres varie de 70 à 80 cm par jour (tableau 3).

Avant l'irrigation systématique des parcelles expérimentales, le niveau hydrostatique de la nappe aquifère variait de moins de 1 mètre à proximité des canaux d'irrigation principaux à plus de 5 mètres dans les parties depuis longtemps en friche. Après la mise en oeuvre des travaux d'irrigation systématique, ce niveau monta à tel point qu'il dépassait le niveau de drainage. Avant le début des travaux d'irrigation, la teneur en sel de la nappe phréatique était d'environ 3 %.

Comme tous les sols salins en Irak, celui de la région expérimentale contient de 20 à 30 % de chaux, répartie en proportions à peu près égales entre les parties sablonneusses, vaseuses et argileuses. Quant à la teneur en gypse, elle varie de zéro à quelques pourcents. La plupart du gypse se trouve à plus de 1 mètre de profondeur dans le profil.

La teneur en sel des terres de la région de Dujailah est élevée: près de 2½ % pour les 30 cm d'épaisseur de la couche supérieure, près de 1½ % pour les couches plus profondes (Tableau 6, Fig. 8). Près de 70 % des ions se composent d'ions de sodium et de chlorures.

Plusieurs raisons ont motivé la préférence donnée à la conductivité électrique d'un extrait saturé du sol en tant qu'indice du degré de sa salinité. Comme la préparation d'un tel extrait prend plutôt du temps, toutes les analyses depuis 1958 ont été basées sur un extrait 1 : 1. Pour ce qui est des types de sol de la région de Dujailah, le rapport fut déterminé entre la salinité des extraits saturés et celle des extraits 1 : 1, ce qui a permis la conversion des résultats.

Pendant le lessivage, la concentration des différents ions ne diminue pas proportionnellement (Fig. 16, Tableau 8). Jusqu'à la profondeur de 30 cm, une diminution sensible fut constatée du pourcentage de sodium (Na), de même que, jusqu' à la profondeur de 100 cm, du pourcentage de chlore (Cl). Autrement dit, la proportion des ions s'était modifiée durant le lessivage. C'est ainsi, par exemple, que la proportion Cl/SO_4, qui était de 6 à la surface avant le lessivage, était tombée à l'environ 1; à une certaine profondeur dans le profil, cette proportion était tombée à 0,6 environ. Cette diminution disproportionnelle des ions ne s'explique pas par leurs 'capacités migratoires' variables; par contre, elle est le résultat net de l''approvisionnement' en ions et de leur décharge. C'est ce qui explique, tout au moins en partie, le fait que différents types de sols salins ont été découverts dans la Plaine de Mésopotamie.

LE LESSIVAGE DES SOLS SALINS

Le lessivage fut effectué, soit en procédant à l'inondation du sol nu, soit en irriguant excessivement le sol cultivé en le submergeant de nappes d'eau de différentes profondeurs. Le volume d'eau déchargé par le système de drainage, tel qu'il était mesuré aux embouchures des canaux de drainage, fut pris comme indice du volume réel de l'eau de lessivage. Les résultats des expériences de lessivage effectués sont montrés aux Figures 17 à 20. L'examen de ces figures nous permet de constater que, si l'on tient, par exemple, à ramener la teneur en sel de la couche supérieure du sol, épaisse de 60 cm, à 10 % de sa valeur d'origine, il faut environ 35 cm d'eau de lessivage pour le sol de la région de Dujailah, et près de 190 cm pour le sol de la région d'Annanah.
Comme il n'est que rarement possible d'effectuer sur place des expériences coûteuses qui prennent beaucoup de temps, on s'est efforcé de déterminer les courbes de lessivage à l'aide de deux cylindres concentriques, diamètres 50 et 70 cm. Ces cylindres furent enfoncés dans le sol sur une profondeur de 5 cm, puis remplis de 10 cm d'eau. La comparaison aux données obtenues à la faveur des expériences effectuées en terrain démontre que les résultats s'accordent fort bien (Fig. 18). La courbe de lessivage peut, dès lors, être déterminée de manière suffisamment précise au moyen de simples essais d'infiltration d'eau de lessivage.
Le lessivage des sols à salinité élevée n'est effectué en principe qu'une seule fois. L'opération peut se répéter si, pour une raison ou l'autre, une accumulation trop grande de sel se produit dans un sol déjà mis en valeur. Cependant, une distinction est généralement établie entre le lessivage des sels excédentaires qui se sont accumulés dans un sol donné, et le drainage ultérieur d'une certaine partie de l'eau d'irrigation ajoutée dans le but de maintenir la salinité au faible niveau qui avait été obtenu.
Pendant les périodes de mise en culture, la salinité du sol n'est pas constante. Lors de chaque opération d'irrigation, le sel descend dans le sol; par contre, durant les intervalles qui séparent deux opérations d'irrigation successives, il remonte par suite de l'évaporation qui se produit en surface. Outre ces fluctuations de moindre importance, la teneur en sel augmente pendant les périodes de mise en jachère, qui ont lieu après la dernière opération d'irrigation d'une récolte donnée, et avant la première opération d'irrigation de la récolte suivante (Figures 20 et 21).
Quel que soit le système de drainage existant sur place, la salinité minimum dépend des volumes d'eau d'irrigation utilisés et de la quantité d'eau déchargée par les canaux de drainage (tableau 9). Comme l'approvisionnement en eau d'irrigation varie considérablement d'un endroit à l'autre, on constate que le drainage exprimé en pourcentage des volumes d'eau d'irrigation varie sensiblement, lui aussi: lorsque la mise en culture est pratiquée de manière intensive en hiver comme en été, une décharge plus importante est nécessaire pendant l'été. Le tableau 10 montre pour les différentes saisons les pourcentages d'eau de lessivage observés et calculés. Aucune corrélation directe n'existe entre ces deux; il est probable que le volume d'eau d'irrigation utilisée ne produit pas dans sa totalité un travail efficace de lessivage, et ne contribue donc pas entièrement au maintien de l'équilibre de la teneur en sel.

LES ASPECTS ALKALINS DU LESSIVAGE DES SOLS À TENEUR EN SEL EXCESSIVE

Étant donné que la grande majorité des sols salins en Irak ont dû être classifiés comme sols salino-alkalins (terminologie proposée en 1954 par le Ministère Américain de l'Agriculture, Laboratoire de la Salinité), il importait

avant tout de savoir si ces sols allaient se transformer en sols alkalins non-salins par suite des travaux de lessivage.
Dans cet ordre d'idées, les considérations majeures sont les suivantes:

1. Parmi les nombreux échantillons de sol analysés, il n'y en eut pratiquement aucun qui manifestât les véritables caractéristiques d'alcalinité. Il s'agit là d'un fait remarquable, étant donné que le lessivage est régulièrement effectué par les agriculteurs locaux dans le but de réduire, avant la mise en terre des plants, la teneur en sel du sol en surface.
2. Tous les types de sol de la Plaine Inférieure de Mésopotamie contiennent du calcium en abondance, généralement sous forme de carbonates. Or, étant donné surtout que le carbonate de calcium se présente également dans les particules de 2 microns et moins, il revêt probablement de l'importance comme source génératrice d'ions de calcium (Ca). Quant au gypse, il se trouve dans la plupart des couches en profondeur, et parfois aussi en surface, bien que, dans ce dernier cas, en faible concentration.
3. La composition de l'eau d'irrigation est favorable (tableau 11).

Sur la base de ces considérations, la conclusion selon laquelle la mise en valeur des sols salino-alcalins en Irak ne pose probablement pas de problème d'alcalinité apparaît justifiée. Cette conclusion a été en tous points confirmée par les résultats détaillés des expériences de lessivage effectuées en terrain (tableaux 12, 13 et 14).
Les rapports qui existent entre le pH, le pourcentage échangeable de sodium et la conductivité électrique sont rapportés graphiquement aux figures 22 et 23. Les diagrammes montrent la diminution du pH lorsqu'augmente la teneur en sel, et l'augmentation du pourcentage échangeable de sodium. Lorsque la salinité augmente, le pH demeure constant.

RENDEMENTS DU SOL ET ASSOLEMENTS PENDANT LES TRAVAUX DE MISE EN VALEUR

Des recherches ont été faites visant à déterminer l'influence exercée par différents systèmes de drainage et de mise en valeur sur la productivité des sols et sur les rendements de quelques végétaux et variétés végétables cultivés sur place. Les tableaux 17 à 25 montrent les effects que produisent la salinité et les engrais sur les rendements; par ailleurs, les figures 24 à 27 montrent l'influence qu'exerce la teneur en azotes sur les rendements agricoles.
La preuve est ainsi fournie que, parmi les facteurs qui influent sur le rendement des cultures, c'est la salinité du sol dont les effets se font le plus sentir, suivie par la teneur en azotes.
Lorsque les sols ont été lessivés jusqu'à ce que la salinité ait été ramenée à un degré donné (conductivité électrique $EC_e = 8$ environ), l'application d'engrais chimiques devient plus avantageuse qu'un lessivage plus poussé. Cette constatation fut faite pour toutes les cultures d'hiver soumises à l'essai, et même pour les plantes potagères et les légumineuses. Toutefois, l'augmentation du rendement dû à l'application d'engrais azotés varie selon la tolérance que manifeste à l'égard du sel la variété considérée. Ceci veut dire que les résultats optimals ne seront obtenus qu'à la condition que le lessivage des sols salins soit accompagné de mesures visant l'amélioration de différentes autres conditions exerçant leur influence sur la croissance des végétaux, en particulier l'application d'éléments nutritifs pour les plants.
Parmi les méthodes praticables d'élimination du sel, celle qui saute le plus aux yeux consiste à prélessiver rigoureusement le sol avant de commencer la mise en culture. Pourtant, ce procédé ne peut être recommandé lorsqu'il s'agit d'applications sur une vaste échelle, car en ce cas il s'accompagnerait de difficultés d'ordre technique et économique, telles que la

nécessité de pourvoir les fermiers de quantités suffisantes d'eau et d'engrais.
Dès lors, on s'est efforcé de trouver un procédé de mise en valeur permettant d'éviter le prélessivage rigoureux et d'accomplir graduellement le lessivage, soit en irriguant normalement le sol soumis à un assolement donné, soit en l'irriguant surabondamment. De tels assolements sont montrés aux tableaux 28 et 29.
La conclusion s'impose que le meilleur procédé de mise en valeur doit être recherché dans le choix de la combinaison la plus favorable de prélessivage, de variété de végétal et de longueur d'assolement, susceptible de donner les rendements et les revenus financiers les plus élevés dans les circonstances qui prévalent sur place.

EXPLOITABILITÉ DES SOLS

Les résultats de travaux de mesure effectués sur place et visant à établir l'exploitabilité des sols furent comparés aux documents relatifs aux essais d'évaporation en cuvette, de même qu'aux valeurs d'exploitabilité selon BLANEY-CRIDDLE et PENMAN (Fig. 29, Tableau 32). Il fut constaté que, si les coefficients empiriques proposés par les auteurs sont appliqués les valeurs d'exploitabilité calculées sont nettement inférieures à celles qui furent effectivement mesurées, surtout pendant la saison d'été. Cette contradiction pourrait s'expliquer par l'effet, dit 'du désert', et par le caractère extrême du climat estival d'Irak.
Si, dans les calculs de Penman et de Blaney-Criddle, de même qu'à la faveur de l'application de la méthode d'évaporation en cuvette, on se servait de coefficients empiriques modifiés et adaptés aux conditions particulières qui prévalent en Irak, ceux-ci pourraient se révéler très utiles en vue de l'évaluation de l'exploitabilité, en hiver comme en été (Tableaux 33, 34 et 36).
La comparaison des trois méthodes a conduit à la constatation que leurs résultats respectifs sont aussi sûrs les uns que les autres (Fig. 30). Dans ces conditions, la préférence doit être accordée à la méthode Blaney-Criddle, qui est la plus simple des trois. Il est recommandé de se servir, dans la formule Blaney-Criddle, des coefficients suivants: cultures d'hiver: de 0,5 à 0,8; cultures d'été: de 1,0 à 1,5.

QUELQUES PRINCIPES RÉGISSANT LE DRAINAGE ET L'IRRIGATION DE SOLS SALINS

L'amélioration des terres salines comporte deux phases successives: la période de mise en valeur, durant laquelle l'excès de sel est lessivé du profil, suivie par la période pendant laquelle il s'agit de prévenir le ressalement.
Ce chapitre est consacré aux problèmes de lessivage et de drainage de la deuxième période citée, celle donc qui suit la période de mise en valeur; il est évident que les mêmes problèmes se posent lorsque le sol n'a pas encore été atteint de salinité excessive.
D'une manière générale, il est permis de dire que les besoins provisoires de drainage pendant la première période de mise en valeur seront satisfaits par un système de drainage adapté aux besoins permanents de la deuxième période. Dans certains cas, une bonne solution provisoire pourrait être celle qui consiste à creuser à peu de frais des fossés complémentaires peu profonds afin de faciliter la mise en valeur.
Des formules ont été mises au point visant à calculer les besoins de lessivage P–G (formules 1 à 7), et les volumes nécessaires d'eau d'irrigation et de drainage (formules 10 à 12). Dans ces formules, un coefficient d'efficacité de lessivage (f) fut introduit, dont la grandeur dépend des caractéristiques physiques du sol, et qui varie de 0 à 1. Dans le cas des sols de Dujailah, ce coefficient 'f' fut déterminé expérimentalement et calculé sur la base de la Fig. 18 (formule 9). Les deux chiffres se confirment parfaitement, et se traduisent par une efficacité de lessivage de 0,6.

QUELQUES APPLICATIONS ET CALCULS

On se rendra compte que les processus qui se déroulent effectivement dans les sols sont beaucoup plus complexes qu'ils n'étaient supposés l'être au chapitre précédent. C'est pourquoi les méthodes de calcul exposées ne doivent jamais servir de méthodes de pure routine; en toutes circonstances, il y a lieu de faire preuve d'esprit critique, et d'être conscient de la mesure dans laquelle les suppositions formulées correspondent aux conditions locales d'une part, aux expériences acquises sur place d'autre part. Il importe de toujours ne voir dans les résultats des calculs que des valeurs approximatives.

La méthode propre à calculer le système de drainage des champs qu'exigent les circonstances est illustrée à la faveur d'un certain nombre d'exemples.

QUELQUES ASPECTS ÉCONOMIQUES DES PROJETS DE MISE EN VALEUR

L'exposé donne un bref aperçu des facteurs qui déterminent les frais et les profits d'un projet donné. Il comporte notamment quelques évaluations provisoires des frais et des profits engendrés par un plan d'amélioration minimum. Du point de vue économique, la réalisation pratique des projets de mise en valeur semble se présenter sous des aspects assez favorables s'il faut en croire ces évaluations prudentes.

L'importance que ces projets revêtent pour la population locale et pour l'économie nationale du pays est considérable. Cependant, lors du planning, de l'exécution et de la conservation en bon état des travaux, il convient de tenir compte des impératifs qui découlent des circonstances et des perspectives régionales et nationales. C'est en fin de compte le maillon le plus faible du processus d'amélioration qui détermine le rythme des progrès réalisés à la faveur de ces travaux.

C'est ainsi, par exemple, qu'il importe que la formation technique des fermiers soit telle qu'ils soient capables de tirer profit des possibilités nouvelles, nées de la mise en valeur des terres.

Enfin, l'exposé propose de synchroniser le planning de la mise en valeur du sol et la formation de cadres. C'est en adaptant l'ampleur des projets aux effectifs de cadre disponibles, et en profitant en même temps de l'exécution de ces projets pour former des cadres nouveaux, que l'on pourra s'attaquer à des superficies sans cesse plus grandes.

ZUSAMMENFASSUNG

URBARMACHUNG VERSALZTER BÖDEN IN IRAK

Diese Abhandlung ist das Ergebnis der gemeinsamen Bemühungen von vier Autoren, die in der Zeit von 1953 bis 1959 einige Jahre als 'Auslands-Experten' in Irak im Ministerium für Entwicklung und im Entwicklungsrat für Irak, Erste Technische Sektion (später Vierte Technische Sektion), gearbeitet haben. Ihre Aufgabe bestand u.a. darin, über die Möglichkeiten und Methoden der Urbarmachung von salzhaltigen Gebieten in Irak zu berichten.
Damit ein guter Einblick in die Wasser- und Salzbewegungen des Bodens erhalten werden konnte, sind Versuchsfelder angelegt worden. In dieser Abhandlung sind die auf diesen Feldern vorgenommenen Versuche und die erzielten Resultate beschrieben und dargelegt.

ALLGEMEINE EINLEITUNG

In den regenreichen nördlichen Landstrichen von Irak besteht eigentlich keine Salzhaltigkeit. Aber in Richtung Süden, wo die Bewässerung für die Landwirtschaft bedeutender ist, nimmt die Salzhaltigkeit zu, und unterhalb von Bagdad, wo die Täler des Euphrat und Tigris sich zu einer ungeheuren weiten Ebene ausbreiten, ist sie sehr beträchtlich (Abb. 7). Hier ist infolge des langen, heissen und trockenen Sommers und wenig Winterregen (Abb. 1, 2, 3) für die normale Landwirtschaft künstliche Wasserversorgung während des ganzen Jahres notwendig.
Da Salzhaltigkeit in früheren Zeiten kein schwerwiegendes Problem war, ist die gegenwärtige Salzhaltigkeit höchstwahrscheinlich auf die jahrelange Salzansammlung aus dem Bewässerungswasser zurückzuführen (Euphrat und Tigris sind die einzigen Quellen für Bewässerungswasser für die mesopotamische Ebene).
Urbarmachungsversuche waren bereits im Landstrich Saklawiyah vorgenommen worden, und zwar im Jahre 1927 von STRACHAN und im Jahre 1944 von TURCAN und HAWKINS. Obgleich bemerkenswerte Ergebnisse erzielt werden konnten, führten diese Forschungen nicht zu Schlussfolgerungen betreffend Dränagekriterien, erforderliche Wassermenge für das Auswaschen usw. Aus diesem Grunde wurden im Jahre 1954 wiederum verschiedene Versuchsfelder angelegt, von denen sich das bedeutendste im Gebiet des Dujailah-Projektes befand. Weitere Versuche sind in den Gebieten Annanah und Twairij (Abb. 7) durchgeführt worden. Das Ziel war allgemein umschrieben als das Erwerben von grundlegenderen Kenntnissen über die Urbar-

machung von salzhaltigen Böden in bezug auf Bodenbeschaffenheit, Dränage-, Bewässerungs- und Anbaupraktiken.

Das Versuchsprogramm ist in drei Abschnitte eingeteilt worden, um ein systematisches Studium zu ermöglichen:

1. ein Abschnitt Bodenhydrologie, insbesondere die Entsalzung des Bodenprofils in bezug auf Bewässerungsanwendung, Bodendurchlässigkeit, Dränabstand and Dräntiefe;
2. ein Abschnitt Landwirtschaft, umfassend die Fruchtreaktion während der verschiedenen Etappen der Urbarmachung und danach;
3. das Studium der für die Urbarmachung bestimmter Gebiete zu empfehlendem Urbarmachungsverfahren.

DATEN DER BÖDEN UND SALZE DER DUJAILAH-VERSUCHSFLÄCHE

Das Bodenprofil der Dujailahfläche besteht aus schlammigen Lehmablagerungen (Tafel 2), ruhend auf einer undurchlässigen Schicht in einer Tiefe von 4 m. Die durchschnittliche Durchlässigkeit der oberen 4 m Boden beträgt 70 bis 80 cm pro Tag (Tafel 3).

Vor Bewässerung der Versuchsflächen variierte der Wasserspiegel von unter 1 m in der Nähe der Hauptbewässerungsgräben bis über 5 m in Teilen, die lange nicht bearbeitet worden waren. Nach der Bewässerung stieg der Wasserspiegel über den Grundwasserstand. Der Salzgehalt des Grundwassers betrug 3 %, bevor mit der Bewässerung begonnen wurde.

Der Boden, gleich allen Böden in Irak, die salzhaltig sind, enthält 20 bis 30 % Kalk, der proportional über den Sand-, Schlamm- und Tonbruch verteilt ist. Der Gipsgehalt variiert zwischen Null und einigen Prozenten. Der grösste Teil des Gipses befindet sich unterhalb einer Tiefe von 1 m im Profil.

Der Salzgehalt des Dujailah-Bodens ist hoch: ± 2.5 % in den oberen 30 cm des Bodens und ± 1.5 % in den tieferen Schichten (Tafel 6, Abb. 8). Etwa 70 % aller Ione besteht aus Natrium- und Chlorid-Ionen.

Aus verschiedenen Gründen wird der elektrischen Leitfähigkeit des gesättigten Bodenextraktes als ein Index für das Salzgehaltniveau des Bodens der Vorzug gegeben. Da die Vorbereitung eines gesättigten Bodenextraktes ziemlich zeitraubend ist, sind seit dem Jahre 1958 alle Analysen mit einem Extrakt 1 : 1 gemacht worden. Für die Böden im Dujailah-Gebiet war das Verhältnis festgesetzt zwischen der Salzhaltigkeit von Sättigungsextrakten und 1 : 1 Extrakten, auf diese Weise die umzurechnenden Ergebnisse ermöglichend.

Während des Auswaschens verringert sich die Konzentration der verschiedenen Ione nicht proportional (Abb. 16, Tafel 8). Eine auffallende Verminderung war beim Na-Prozentsatz in einer Tiefe von 30 cm und beim Cl-Prozentsatz in einer Tiefe von 100 cm festzustellen. Das bedeutet, dass das Ion-Verhältnis sich während des Auswaschens veränderte. Das Cl/SO_4-Verhältnis z.B., das 6 an der Oberfläche betrug vor dem Auswaschen, verringerte sich auf etwa 1; tiefer unten im Profil sank dieses Verhältnis auf etwa 0.6. Diese unproportionale Verminderung der Ione kann nicht aus variierenden 'Bewegungseigenschaften' erklärt werden; aber sie ist das Nettoergebnis von Zu- und Abgang von Ionen. Sie erklärt zumindest teilweise das Vorkommen verschiedener Arten salzhaltiger Böden in der mesopotamischen Ebene.

AUSWASCHEN VON SALZBÖDEN

Das Auswaschen ist entweder durch Überfluten des unbebauten Bodens oder durch Über-Bewässerung des bebauten Bodens mit verschiedenen Wassertiefen durchgeführt worden. Die aus dem Dränagesystem abfliessenden Wasserquantitäten, die an den Dränausgängen gemessen wurden, galten als Index für die tatsächliche Menge des Auswaschungswassers. Die Ergebnisse der Feldauswaschversuche sind in den Abbildungen 17–20 dargestellt. Aus diesen Abbildungen geht hervor, dass etwa 35 cm Auswaschungswasser für den Dujailah-Boden und etwa 190 cm für den Annanah-Boden erforderlich sind, um den Salzgehalt z.B. der oberen 60 cm des Bodens auf 10 Prozent des ursprünglichen Wertes zurückzubringen.

Da es häufig nicht möglich ist, zeitraubende und kostspielige Feldversuche durchzuführen, ist ein Versuch gemacht worden, die Auswaschungskurven mit zwei konzentrischen Zylindern mit Durchmessern von 50 und 70 cm zu bestimmen. Die Zylinder wurden 5 cm in den Boden gedrückt und bis zu einer Tiefe von 10 cm mit Wasser gefüllt. Vergleiche mit den Daten der Feldauswaschversuche zeigen, dass die Ergebnisse sehr gut miteinander übereinstimmen (Abb. 18). Die Auswaschungskurve kann darum genügend genau durch einfache Auswaschinfiltrationsprüfungen festgesetzt werden.

Bei dem Auswaschen von hochsalzhaltigen Böden handelt es sich um einen Arbeitsvorgang, der wiederholt werden kann, wenn sich aus irgendeinem Grunde ein zu hoher Salzgehalt in einem einmal urbar gemachten Boden ansammelt; aber im allgemeinen wird ein Unterschied gemacht zwischen den Auswaschen von Salzüberschuss, der sich in einem Boden angesammelt hat, und der anschliessenden Dränage einer bestimmten Menge des zusätzlichen Bewässerungswassers, um den erreichten niedrigen Salzhaltigkeitsstand aufrechtzuerhalten.

Während der Bebauungszeiten ist der Bodensalzhaltigkeitswert nicht konstant. Mit jeder Bewässerung wird das Salz abwärts bewegt, aber es steigt wieder infolge der Oberflächenverdunstung während der zwischen den Bewässerungen liegenden Zeiträume. Ausser diesen geringen Schwankungen nimmt der Salzgehalt zu während des Brachliegens nach der letzten Bewässerung einer Frucht und vor der ersten Bewässerung der folgenden Frucht (Abb. 20 und 21).

Mit einem bestimmten Dränagesystem ist die Mindestsalzhaltigkeit abhängig von den für die Bewässerung verwendeten und von den aus dem Drän abfliessenden Wassermengen (Tafel 9). Es hat sich erwiesen, dass – wenn die Bewässerungsmengen beträchtliche Abweichungen zeigen – die Dränage, ausgedrückt als ein Prozentsatz der Bewässerungsquantitäten, ebenfalls wesentlich abweicht. Wenn sowohl im Winter als auch im Sommer verstärkt angebaut wird, ist während des Sommers ein höherer Abfluss erforderlich. Tafel 10 zeigt für verschiedene Jahreszeiten die beobachteten und die berechneten Auswaschungsprozentsätze, zwischen denen keine unmittelbare Übereinstimmung besteht; wahrscheinlich ist nicht jedes Bewässerungswasser im Auswaschen und Festsetzen des Salzgleichgewichts effektiv.

ALKALI-ASPEKTE BETREFFS AUSWASCHEN VON SALZHALTIGEN BÖDEN

Da die überwiegende Mehrheit der Salzböden in Irak als Salz-Alkali-Böden (Terminologie vorgeschlagen vom Salzlaboratorium–Salinity Laboratory, USDA, 1954) klassifiziert werden musste, war es wichtig zu wissen, ob diese Böden sich aufgrund des Auswaschens zu nichtsalzhaltigen Alkali-Böden entwickeln würden.

Die bedeutendsten Erwägungen in dieser Hinsicht waren die nachstehenden:

1. Von den zahlreichen analysierten Bodenproben wies kaum eine die wirklichen Alkalimerkmale auf. Dies ist ein bemerkenswerte Tatsache, da Auswaschungen regelmässig von den örtlichen Bauern vorgenommen worden sind, um den Salzgehalt der Bodenoberfläche vor der Bepflanzung herabzusetzen.
2. Alle Böden der Ebene von Niedermesopotamien enthalten reichlich Kalzium, meistens in Form von Karbonaten. Besonders auf grund der Tatsache, dass Kalzium-Karbonat ebenfalls in Partikeln von 2 und

weniger Mikronen vorkommt, ist es wahrscheinlich wertvoll als Quelle für Ca-Ione. Gips findet sich, wenn auch in einer geringen Konzentration, meistens im Untergrund des Bodens und teilweise an der Bodenoberfläche.

3. Die Zusammensetzung des Bewässerungswassers ist vorteilhaft (Tafel 11).

Gestützt auf diese Überlegungen erscheint die Schlussfolgerung gerechtfertigt, dass die Urbarmachung der Salz-Alkali-Böden in Irak wahrscheinlich keine Alkali-Probleme mit sich bringt. Diese Feststellung ist voll bestätigt worden durch die detaillierten Ergebnisse der Feldauswaschversuche (Tafeln 12, 13, 14). Das Verhältnis zwischen pH, E.S.P. (Vertauschbarer Natrium Gehalt) und EC (Elektrische Leitfähigkeit) ist in den Abbildungen 22 und 23 aufgezeichnet. Die graphische Darstellung zeigt die Verminderung von pH bei einem zunehmenden Salzgehalt und die Zunahme von vertauschbarem Natrium bei zunehmender Salzhaltigkeit und einer konstanten pH.

BODENERTRAG UND FRUCHTFOLGE WÄHREND DER URBARMACHUNG

Es ist eine Untersuchung vorgenommen worden über den Einfluss verschiedener Dränage- und Urbarmachungsbehandlungen einerseits auf das Produktivitätsniveau der Böden und andererseits auf die Erträge von verschiedenen örtlich angebauten Früchten und Varietäten. Die Wirkung von Salzhaltigkeit und Kunstdünger auf Erträge ist auf den Tafeln 17 bis 25 und die Wirkung des Bodennitratgehalts in den Abbildungen 24 bis 27 aufgezeigt.

Es stellt sich heraus, dass von den vielen Faktoren, die den Bodenertrag beeinflussen, die Bodensalzhaltigkeit der bedeutendste ist, gefolgt von dem Stickstoffniveau des Bodens. Wenn die Böden bis zu einem gewissen Salzhaltigkeitniveau ausgewaschen worden sind ($EL_e = 8$ ungef.), dürfte von der Kunstdüngerverwendung mehr Nutzen zu erwarten sein als von weiterer Auswaschung.

Dies hat sich bei allen geprüften Winterfrüchten als richtig erwiesen, sogar bei Hülsenfrüchten. Die Zunahme des Bodenertrags resultierend aus stickstoffhaltigem Kunstdünger wird jedoch entsprechend der Salztoleranz der Frucht unterschiedlich sein. Das heisst, dass zur Erreichung optimaler Ergebnisse das Auswaschen von salzhaltigen Böden mit der Verbesserung anderer Anbaubedingungen verbunden sein sollte, insbesondere mit der Verwendung von Pflanzennährstoffen.

Die am besten geeignete Art und Weise zur Salzaussonderung besteht darin, den Boden im Vorwege gut auszuwaschen und dann mit dem Anbau zu beginnen. Aber dieses Verfahren kann nicht zur Anwendung in weitem Umfang empfohlen werden, da der Versorgung der Bauern mit genügend Wasser und Kunstdünger technische und wirtschaftliche Schwierigkeiten entgegenstehen.

Daher wurde nach einem Urbarmachungsverfahren gesucht, bei dem das Auswaschen im Vorwege vermieden wird und durch normales Bewässern oder Überbewässern des Landes, für das eine bestimmte Fruchtfolge eingehalten wird, das Auswaschen nach und nach erfolgt.

Vorschläge für derartige Fruchtfolgen finden sich auf den Tafeln 28 und 29.

Es ist zu folgern, dass als das beste Urbarmachungsverfahren die Wahl der Kombination von vorherigem Auswaschen, Hülsenfrüchten und Dauer der Fruchtfolge anzusehen ist, wodurch unter den gegebenen Umständen sowohl der höchste Bodenertrag als auch der beste finanzielle Gewinn erreicht werden können.

VERBRAUCHSNUTZEN

Feldmessungen zur Feststellung des Verbrauchsnutzens sind verglichen worden mit Abdampfgefäss-Registrierungen und dem Verbrauchsnutzen gemäss BLANEY-CRIDDLE und PENMAN (Abb. 29, Tafel 32). Insbesondere im

Sommer lagen die berechneten VN-Werte viel niedriger als die tatsächlich gemessenen Werte, wenn die von den Autoren vorgeschlagenen empirischen Koeffizienten verwendet worden waren. Ursache dieser Abweichungen können der 'Wüsteneffekt' und das aussergewöhnliche irakische Sommerklima sein.
Falls modifizierte, an die irakischen Verhältnisse angepasste empirische Koeffizienten sowohl für die Penman- und Blaney-Criddle-Berechnungen als auch für die Abdampfgefässmethode verwendet werden, könnten sie für die Schätzung des Verbrauchsnutzens für die Sommer- und Wintersaison sehr nützlich sein (Tafel 33, 34 und 36).
Bei wechselseitigem Vergleich der drei Methoden zeigte sich, dass die Ergebnisse alle gleichermassen zuverlässig waren (Abb. 30). Aus diesem Grunde ist die Blaney-Criddle-Methode als das einfachste Verfahren zu bevorzugen. Die folgenden Koeffizienten werden für die Verwendung in der Blaney-Criddle-Formel empfohlen:
Winterfrüchte 0.5–0.8, Sommerfrüchte 1.0–1.5.

EINIGE GRUNDSÄTZE BETREFFS DRÄNAGE UND BEWÄSSERUNG VON SALZHALTIGEN BÖDEN

Verbesserung von salzhaltigen Böden erfolgt in der Urbarmachungszeit, in der die Salzüberschüsse aus dem Profil entfernt werden, und im folgenden Zeitraum, in dem das Entstehen neuer Salzhaltigkeit verhindert werden muss.
Das vorliegende Kapitel befasst sich mit den Auswasch- und Dränageproblemen des zweiten Zeitraumes, nachdem der Boden urbar gemacht worden und natürlich auch noch nicht salzhaltig ist.
Allgemein ausgedrückt, den zeitweiligen Dränageerfordernisse der ersten Urbarmachungszeit wird entsprochen durch ein Dränagesystem, das an die ständigen Bedürfnisse der zweiten Periode angepasst ist. In gewissen Fällen könnte eine gute vorübergehende Lösung darin bestehen, seichte und billige zusätzliche Gräben zu ziehen, um die Urbarmachung zu erleichtern.
Zur Berechnung der Erfordernisse für das Auswaschen P–G (Form. 1–7) und der erforderlichen Bewässerungs- und Dränagequantitäten (Form. 10–12) sind Formeln entwickelt worden. In diesen Formeln ist für die Auswaschleistung ein Koeffizient (f) eingesetzt worden, dessen Grösse von bodenphysikalischen Kennzeichen abhängig ist und die zwischen 0 und 1 variiert. Im Falle der Dujailah-Böden wurde f versuchsweise bestimmt und gemäss Abb. 18 (Form. 9) berechnet. Beide Ziffern stimmen gut miteinander überein und ergeben eine Auswaschleistungsfähigkeit von 0.6.

EINIGE ANWENDUNGEN UND BERECHNUNGEN

Es hat sich herausgestellt, dass die gegenwärtigen in den Böden vorkommenden Prozesse viel komplizierter sind als in dem vorhergehenden Kapittel angenommen wurde. Darum sollten die Berechnungsarten niemals als reine Routinemethoden angewandt werden; man sollte stets kritisch eingestellt sein und sich des Umfangs, in dem die gegebenen Voraussetzungen mit den örtlichen Verhältnissen und Erfahrungen übereinstimmen, bewusst sein. Die Ergebnisse der Berechnungen sollten immer als ein ungefährer Wert angesehen werden.
Die Methode der Berechnung des erforderlichen Felddränagesystems ist an einigen Beispielen erläutert worden.

EINIGE WIRTSCHAFTLICHE ASPEKTE DES URBARMACHUNGSPROJEKTES

Es wird eine kurze Übersicht gegeben über die Faktoren, die die Kosten und den Gewinn eines Projektes bestimmen. Von einem minimalen Verbesserungsplan werden einige vorläufige Voranschläge über Kosten und Gewinne gegeben. Die wirtschaftliche Möglichkeit des Urbarmachungsprojektes erscheint

aufgrund dieser vorsichtigen Schätzungen nicht ungünstig.
Das Urbarmachungsprojekt ist für die örtliche Bevölkerung und die nationale Volkswirtschaft von grosser Bedeutung. Man wird jedoch bei der Planung, Ausführung und Instandhaltung der Arbeiten die regionalen und nationalen Verhältnisse und Perspektive berücksichtigen müssen. Das schwächste Glied im Verbesserungsprozess bestimmt schliesslich das Tempo des Fortschreitens der Verbesserungen.
Wichtig ist zum Beispiel, dass die technische Ausbildung der Bauern so ist, dass die durch die Urbarmachung des Bodens gegebenen neuen Möglichkeiten auch genutzt werden können.
Es wird vorgeschlagen, die Planung der Urbarmachung mit der Ausbildung eines geeigneten Personalstamms zu verbinden. Dadurch, dass der Umfang der Projekte an den zur Verfügung stehenden Personalstand angepasst und gleichzeitig während der Ausführung der Projekte neues Personal ausgebildet wird, können stets grössere Oberflächen in Angriff genommen werden.

RESUMEN

RESCATE DE TERRENOS SALINOS EN IRAK

El presente informe es el resultado de la colaboración de cuatro autores quienes, en el período de 1953 a 1959, estuvieron por algunos años al el servicio del Ministerio de Desarrollo y el Consejo de Desarrollo de Irak, Primera Sección Técnica (más tarde Cuarta Sección Técnica) como 'peritos extranjeros'. Su tarea consistía, entre otras, en presentar un informe sobre las posibilidades y los métodos de rescate de las regiones de terreno salino de Irak.

Se prepararon algunos campos de prueba, con objeto de estudiar los movimientos de agua y sal en el suelo. En el artículo que sigue se describen los experimentos en estos campos y se presentan los resultados obtenidos.

INTRODUCCIÓN GENERAL

Los distritos septentrionales de Irak, donde la precipitación es elevada, prácticamente no presentan salinidad. En cambio, hacia el Sur, donde predomina la agricultura por riego, la salinidad va aumentando, para llegar a ser muy grave al Sur de Bagdad, donde los valles del Tigris y del Eufrates se ensanchan, formando una llanura vasta (fig. 7). En estas partes, debido al verano prolongado, caliente y seco y a la precipitación escasa en invierno (fig. 1, 2, 3), la agricultura normal requiere el abastecimiento artificial de agua por todo el año.

Puesto que en la antiguedad la salinidad no constituía problema grave, la salinidad actual probablemente se debe a la acumulación de sal del agua de riego – el Eufrates y el Tigris como única fuente de agua de riego para la cuenca de Mesopotamia – en el curso de muchos años.

Ya se habían llevado a cabo unos experimentos de puesta en cultivo en el área de Saklawiyah: en 1927 por STRACHAN y en 1944 por TURCAN y HAWKINS. Con ser muy interesantes los resultados obtenidos, aquellos experimentos no permitieron conclusiones referentes a las normas de drenaje, la cantidad de agua de lavado necesaria, etc. De ahí que en 1954 volviesen a prepararse varios campos experimentales, el más importante de los cuales se halla en el distrito del proyecto de Dujailah. Unos experimentos adicionales se llevaban a cabo en los distritos de Annanah y Twairij (fig. 7). La finalidad se definió en términos generales como la adquisición de mayores conocimientos básicos sobre el rescate de los suelos salinos por lo que se refiere a la condición del suelo, el drenaje y las prácticas de riego y cultivo. Con objeto de llegar a un estudio sistemático, el programa de los experimentos fue dividido en tres partes:

1. una sección de hidrología de suelos, especialmente la desalinización del perfil del terreno en relación a la aplicación de riego, la permeabilidad del terreno, la distancia de los tubos de drenaje y la profundidad de drenaje.
2. una sección agrícola que comprendía la reacción de la cosecha durante y después de las diferentes fases de rescate.
3. el estudio de los procedimientos de rescate a recomendar para la puesta en cultivo de ciertas regiones.

DATOS RELATIVOS A LOS SUELOS Y LAS SALES EN EL AREA EXPERIMENTAL DE DUJAILAH

El perfil del suelo del área de Dujailah se compone de depósitos de arcilla limosa (cuadro 2) sobre una capa impermeable a 4 metros de profundidad. La permeabilidad de los 4 m de suelo superior es de 70 a 80 cm por dia de promedio (cuadro 3).

Antes del riego de los terrenos experimentales, el nivel del agua variaba desde menos de 1 metro cerca de los canales de riego principales hasta más de 5 m en las partes que se dejaron de cultivar hace mucho. Después del riego, el nivel del agua ha subido por encima del nivel de drenaje. Antes de empezarse el riego, el contenido en sal de las aguas freáticas era de un tres por ciento.

Igualmente que todos los terrenos salinos de Irak, el suelo contiene de 20 a 30 por ciento de cal, distribuida proporcionalmente sobre las fracciones de arena, limo y arcilla. El contenido en yeso varía de cero a un poco por ciento. La mayor parte del yeso se halla situada a profundidades de más de un metro.

El contenido en sal del suelo de Dujailah es elevado: $\pm$ 2,5 % en los 30 cm de arena superiores y $\pm$ 1,5 % en las capas más profundas (cuadro 6, fig. 8). Un 70 por ciento de todos los iones se compone de sodio y de cloro.

Por varias razones se ha preferido la conductibilidad eléctrica del extracto saturado del suelo como criterio del nivel de salinidad del terreno. Ya que la preparación de un extracto saturado del suelo pide mucho tiempo, desde 1958 todos los análisis se han hecho a partir de un extracto 1 : 1. Para los suelos de Dujailah se determinó la relación entre la salinidad de los extractos saturados y los extractos 1 : 1, a fin de permitir la conversión de los resultados.

Durante el lavado del suelo, la concentración de los diferentes iones no disminuye proporcionalmente (fig. 16, cuadro 8). Había una disminución notable del porcentaje de sodio hasta 30 cm de profundidad y del porcentaje de cloro hasta una profundidad de 100 cm. Esto implica un cambio de la relación iónica durante el lavado. La proporción de Cl/SO_4, por ejemplo, que antes del lavado era de 6 a la superficie, cayó a 1 aprox.; a mayor profundidad del perfil esta proporción disminuyó a aprox. 0,6. La reducción desproporcional de los iones no puede explicarse por 'capacidades de movimiento' variables, sino que constituye el resultado neto del abastecimiento y de la descarga de iones. Este fenómeno constituye una explicación parcial de la existencia de tipos diferentes de suelos salinos que ocurren en la cuenca de Mesopotamia.

EL LAVADO DE LOS TERRENOS SALINOS

El lavado del suelo se llevó a cabo por inundación del suelo desnudo o por riego excesivo del terreno en cultivo con varias alturas de agua. Como criterio de la cantidad práctica de agua de lavado se tomó la cantidad de agua evacuada por el sistema de drenaje, medida a las salidas. Los resultados de los experimentos de lavado en el campo se hallan presentados en las fig. 17 a 20. Estas figuras hacen aparente que, por ejemplo, para obtener una reducción del contenido en sal de los 60 cm superiores del terreno al 10 por ciento del valor primitivo, hacen falta unos 35 cm de agua de lavado para el suelo de Dujailah y unos 190 cm para el de Annanah.

En vista de que muchas veces es impracticable llevar a cabo una serie de experimentos en el campo, gastándose mucho tiempo y dinero, se trató de determinar las curvas de lavado por medio de dos cilindros concéntricos cuyos diámetros eran de 50 y 70 cm, respectivamente. Los cilindros fueron empujados en el suelo por unos 5 cm y llenados de agua hasta una profundidad de 10 cm. De la comparación de los experimentos de campo se hace aparente que existe una coincidencia satisfactoria, de manera que la curva de lavado puede determinarse con precisión suficiente mediante sencillas pruebas de infiltración.

El lavado de los terrenos altamente salinos es una operación singular. Puede repetirse si por cualquier causa en un terreno rescatado se acumula una concentración excesiva de sal, pero por regla general se distingue entre el lavado de excesos de sal acumulados en un terreno y el drenaje subsiguiente de cierta proporción de agua de riego para mantener el bajo nivel de salinidad obtenido.

Durante los períodos de cultivo no existe nivel constante de salinidad del terreno. Cada riego hace disminuir el contenido en sal, pero en los intervalos entre dos riegos vuelve a subir debido a la evaporación a la superficie. Aparte de estas fluctuaciones menores, hay un crece del contenido en sal durante los períodos de barbecho, entre el último riego de una cosecha y el primer riego de la cosecha siguiente (fig. 20 y 21).

Con un determinado sistema de drenaje, la salinidad mínima depende de las cantidades de agua de riego aplicadas y de la cantidad de agua descargada por los drenes (cuadro 9). Ya que el abastecimiento de riego es bastante variable, también el drenaje expresado como porcentaje de cantidades de riego presenta diferencias notables: donde el cultivo es intensivo tanto en invierno como en verano se requiere una descarga mayor en verano. El cuadro 10 presenta los porcentajes de lavado observados y calculados para estaciones diferentes. No hay correspondencia directa y es probable que sólo parte del agua de riego es efectiva en el lavado y el establecimiento del equilibrio de salinidad.

ASPECTOS ALCALINOS DEL LAVADO DE TERRENOS SALINOS

Puesto que la aplastante mayoría de los terrenos salinos en Irak habían de clasificarse como suelos salino-alcalinos (según la terminología propuesta por el Laboratorio de Salinidad estadounidense en 1954), era esencial de saber si como resultado del lavado estos suelos se convertirían en suelos alcalinos no-salinos.

He aquí las consideraciones más importantes en este respecto:

1. Casi ninguna de las numerosas muestras de suelos analizadas presentaba las verdaderas características de alcalinidad. Es éste un hecho notable, ya que los agricultores locales suelen lavar el suelo regularmente antes de plantar, con objeto de reducir el contenido en sal de la capa superficial.
2. Todos los terrenos de la Cuenca Baja de Mesopotamia contienen una abundancia de calcio, por su mayor parte en forma de carbonatos. Particularmente debido al hecho de que el carbonato de calcio se presenta también en partículas de 2 micras y menores, probablemente tendrá valor como fuente de iones Ca. La mayor parte de los subsuelos contienen yeso y ocurre también en parte de las capas superficiales, aunque las concentraciones son bajas.
3. La composición del agua de riego es favorable (cuadro 11). A partir de estas consideraciones, parece justificada la conclusión de que el rescate de los terrenos salino-alcalinos de Irak probablemente no acarreará problema de alcalinidad. Los resultados detallados de los experimentos de lavado en los campos han confirmado esta conclusión completamente (cuadros 12, 13, 14).

La relación entre pH, P.S.I. y conductilibidad eléctrica se halla expresada gráficamente en las fig. 22 y 23. Estas figuras muestran la disminución de pH a medida que aumente el contenido en sal, y el aumento de sodio intercambiable con salinidad creciente y pH constante.

RENDIMIENTO DEL SUELO Y ROTACIÓN DE COSECHAS DURANTE EL RESCATE

Se llevó a cabo una investigación de la influencia de varios tratamientos de drenaje y rescate en el nivel de productividad de los suelos y el rendimiento de algunas cosechas y variedades de cultivo local. La influencia de la salinidad y los abonos en los rendimientos se halla expresada en los cuadros 17 a 25, en tanto que las fig. 24 a 27 representan el efecto del contenido en nitrato del suelo en los rendimientos.

Estos datos prueban que de entre los muchos factores que influyen en el rendimiento, la salinidad del suelo es más importante, seguida por el nivel de nitrógeno del terreno. Si los suelos han sido lavados hasta cierto nivel de salinidad ($EC_e = 8$ aproximadamente), cabe esperar mayor provecho de la aplicación de abonos que no de un lavado continuado. Esto ha resultado ser válido para todas las cosechas invernales probadas e incluso para los legumbres. Sin embargo, el crece del rendimiento que resulta de la aplicación de abonos nitrogenados varía según la resistencia a la sal de la cosecha. Es decir que a fin de obtener resultados óptimos hay que acompañar el lavado de los suelos salinos con el mejoramiento de otras condiciones de crecimiento, particularmente la aplicación de elementos nutritivos de las plantas.

El modo más obvio de eliminar las sales consiste en un lavado preliminar intensivo del suelo comenzándose después el cultivo. Sin embargo, este procedimiento no puede recomendarse para la aplicación a gran escala, puesto que acarrearía dificultades técnicas y económicas, entre otras el abastecimiento de agua y abonos a los agricultores en cantidades suficientes. De ahí que se haya tratado de hallar un procedimiento de rescate sin lavado inicial intensivo, efectuándose el lavado del suelo gradualmente por riego normal o excesivo del terreno en que se mantiene cierta rotación de cosechas. Los cuadros 28 y 29 contienen algunas proposiciones de rotaciones.

La conclusión es que se obtendrá el mejor procedimiento de rescate por selección de la combinación de lavado inicial, legumbres y extensión de la rotación de cosechas que produzca el rendimiento mayor y los mejores resultados financieros en las condiciones existentes.

CONSUMO NORMAL

El consumo normal medido en el campo fue comparado con los datos registrados a base de tachos de evaporación y el consumo normal según BLANEY-CRIDDLE y PENMAN (fig. 29, cuadro 32). Particularmente en verano, los valores de consumo normal calculados eran mucho más bajos que los medidos en realidad, aplicándose los coeficientes empíricos propuestos por los autores. Esta discrepancia puede explicarse quizás por el 'efecto de desierto' y el clima de verano extremo de Irak.

Al emplearse coeficientes empíricos modificados y adaptados a las condiciones locales, tanto en el cálculo de Penman y Blaney-Criddle como en el método del tacho de evaporación, tales coeficientes podrían ser útiles para estimar el consumo normal tanto para la temporada de verano como para la de invierno (cuadros 33, 34 y 36).

De la comparación mutua de los tres métodos ha resultado que los datos proporcionados son igualmente seguros (fig. 30). Por tanto ha de preferirse el método de Blaney-Criddle, por ser más sencillo. Recomiéndanse los coeficientes siguientes para aplicarse a la fórmula de Blaney-Criddle: cosechas invernales 0,5–0,8; cosechas de verano 1,0–1,5.

ALGUNOS PRINCIPIOS QUE RIGEN EL DRENAJE Y EL RIEGO DE LOS TERRENOS SALINOS

La puesta en cultivo de terrenos salinos comprende la fase de rescate, en que se lavan las sales excesivas del perfil, y el período subsiguiente, durante el cual ha de prevenirse la resalinización. En el presente capítulo se tratan los problemas de lavado y drenaje del período segundo, o sea después del rescate del suelo y antes de que sea afectado de nuevo por la sal.

Por regla general cabe decir que las exigencias temporales de drenaje en el período inicial de rescate serán satisfechas por un sistema de drenaje adeptado a las necesidades permanentes del período segundo. En ciertos casos una buena solución provisoria puede ser la construcción de unos canales baratos, de poca profundidad, para facilitar el rescate.

Se han elaborado fórmulas para calcular el lavado necesario P–G (fórmulas 1–7) y las cantidades requeridas de riego y de drenaje (fórmulas 10–12). En estas fórmulas se ha introducido un coeficiente de eficacia de lavado (f), cuya magnitud depende de las características físicas del suelo y que varía entre cero y 1. En el caso de los suelos de Dujailah, el valor f se determinó experimentalmente y se calculó a partir de fig. 18 (fórmula 9). Ambos valores coinciden satisfactoriamente, dando por resultado una eficacia de 0.6.

ALGUNAS APLICACIONES Y CALCULOS

Nos damos perfecta cuenta de que los procesos verdaderos que se desarrollan en los terrenos son mucho más complejos de lo que han sido representados en el capítulo precedente. De ahí que nunca haya que aplicar las técnicas de cálculo elaboradas como unos métodos meramente rutinarios: siempre hay que adoptar una actitud crítica, considerando hasta qué punto los supuestos hechos correspondan a las condiciones y experiencias locales. Los resultados de los cálculos siempre han de considerarse como valores aproximados.

El método para calcular el sistema de drenaje del campo necesario está ilustrado por una serie de ejemplos.

ALGUNOS ASPECTOS ECONÓMICOS DE LOS PROYECTOS DE RESCATE

Se presenta un breve resumen de los factores que determinan los gastos y provechos de un proyecto. A juzgar de estas estimaciones cuidadosas las posibilidades de practicabilidad económica de los proyectos de rescate no parecen desfavorables.

La importancia de los proyectos de rescate para la población local y la economía nacional es grande. Sin embargo, al proyectar, llevar a cabo y mantener las obras habrán de tenerse en cuenta los constreñimientos consiguientes de las condiciones y perspectivas nacionales y regionales. A final de cuentas el ritmo del progreso de los mejoramientos es determinado por el eslabón más débil en el procedimiento de rescate.

Es de suma importancia, por ejemplo, que el desarrollo técnico de los agricultores sea suficiente para que se puedan aprovechar las nuevas posibilidades creadas por el rescate de los terrenos.

Se propone una sincronización del proyecto de rescate con la formación de una plantilla técnica. Adaptando la envergadura de los proyectos al núcleo de peritos disponible y aprovechando los mismos proyectos para la formación de un núcleo nuevo, se podrá emprender el rescate de superficies siempre mayores.

REFERENCES

ALI, HASSAN MOHAMMAD, Land reclamation and settlement in Iraq. Baghdad, 1955.

ANNANAH EXPERIMENTS, Development Board and Ministry of Development, Iraq. Mimeographed reports, Report 1, The results of leaching and the first summer crops. 1958.

ANTIPOV-KARATAEV, I. N., L'amélioration des solonetz en U.S.S.R. Trans. 6th Congr. Int. Soc. of Soil Sci., 1956.

BEERS, W. F. J. VAN, The auger hole method. Internat. Inst. for Land Reclamation and Improvement, Wageningen (Netherlands), 1958.

BINNIE, DEACON and GOURLEY, Z. A. D., Irrigation projects, vol. I, II, III, 1956.

BLANEY, H. F. and CRIDDLE, W. D., Determining water requirements in irrigated areas from climatological and irrigation data. U.S. Soil Cons. Serv. Techn. Publ. 96, 1950.

BOUMANS, J. H. and HULSBOS, W. C., The alkali aspects of the reclamation of saline soils in Iraq, Neth. Journal of Agric. Sci., Vol. 8, 1960.

BOWER, C. A., Cation-exchange equilibria in soils affected by sodium salts. Soil Sci. 88, 1959.

BURINGH, P., Soils and soil conditions in Iraq. Baghdad, 1960.

CLIMATE AND MAN, Yearbook of Agriculture U.S.D.A.. Washington D.C. 1961.

DELVER, P., Saline soils in the Lower Mesopotamian Plain. Division of soils and agricultural chemistry. Abu Ghraib (Iraq) 1960. (mimeographed).

DRAINAGE AND LAND RECLAMATION, SEMINAR 1958. Development Board and Ministry of Development, Iraq. (mimeographed).

DRAINAGE MANUAL. Provisional report on proposed tile drainage manual. Imperial Valley, Cal., U.S.D.A., S.C.S., 1947.

DUJAILAH EXPERIMENTS, Development Board and Ministry of Development, Iraq.
Report 1, Detailed proposals to start experimental work, (1954).
Report 2, Results of leaching of some soils along the main drain (1955).
Report 3, Summary of some results over 1955 and 1956 (1957).
Report 4, Results of a leaching test on 6 mesharas tile drained salty land (1957).
Report 5, Crop yields and reclamation (1958).
Report 6, Salts in agricultural soils (1959).
Report 7, Consumptive use of crops (1959).
(Mimeographed Reports).

DUMM, L. D., Drain spacing formula. Agr. Eng. 35, 726–730, 1954.

ERNST, L. F., Het berekenen van stationnaire grondwaterstromingen, welke in een vertikaal vlak afgebeeld kunnen worden. Landbouw-proefstation en Bodemkundig Instituut T.N.O., Groningen, Rapport IV, 1954 (in Dutch).

ERNST, L. F., A new formula for the calculation of the permeability factor with the augerhole method. T.N.O., Groningen (Neth.), 1950, translated by H. BAUER. Cornell Univ. Ithaca, New York, 1955.

GARDNER, W. R. AND BROOKS, R. H., A descriptive theory on leaching. Soil Sci. 83, 1957.

GOVERNMENT OF IRAQ, Climatological means for Iraq, publication no. 10, Baghdad, 1954.

HILMY BEY, U., Reclamation of waste lands in the northern part of the Delta (Egypt), Proc. Conf. M. E. Agr. Dev. Cairo. M. E. Supply Centre. Agric. Rep. no. 6, 1944.

HULSBOS, W. C. AND BOUMANS, J. H., Leaching of saline soils in Iraq. Netherlands Journal of Agric. Sci. Vol. 8, 1960.

JANITZKY, P., Salz und Alkaliböden und Wege zu ihrer Verbesserung. Ein Vergleich russischer und amerikanischer Forschungsergebnisse. Gieszen, 1957.

KELLY, W. P., Alkali soils, their formation, properties and reclamation. New York, 1951.

KNAPPEN – TIPPETS – ABBETT – MC CARTHY, Report on the development of the Tigris and Euphrates river system, New York, Baghdad, 1952.

KOHLER, M., NORDENSON, T. J., and FOX, W. E., Evaporation from pans and lakes, U.S. Department of Commerce Weather Bureau, Washington, 1955.

KOVDA, V. A., The use of drainage to prevent salinization of irrigated soils. Trans. 3rd. Congr. on irrigation and drainage, 1957.

KRAIJENHOFF VAN DE LEUR, D. A., A study of non-steady ground-water flow with a special reference to a reservoir coefficient. De Ingenieur 70, 1958: 87–94.

LUTHIN, J. N., Drainage of agricultural lands. Vol. VII of Agronomy, Amer. Soc. of Agronomy, Madison, Wisconsin, 1957.

MAGISTAD, O. C., and CHRISTIANSEN, J. E., Saline soils, their nature and management. U.S.D.A. circular 707, 1944.

MAKKINK, G. F., Stencilled communication (in Dutch).

McDONALD and partners, Dujailah and Middle Tigris Projects, Government of Iraq, Baghdad, 1958.

MOLEN, W. H. VAN DER, Desalinization of saline soils as a column process. Soil Sci., 81 (1956).

MOLEN, W. H. VAN DER, The exchangeable cations in soils flooded with seawater. 's-Gravenhage, Staatsdrukkerij, 1958.

NEDECO, Hillah-Diwanyah Drainage Study. Baghdad-The Hague, 1959.

PASCAUD et MINART, Corrélation entre le pH, salinité et alcalinité. Communication pour le colloque UNESCO sur les problèmes de salinité dans des régions arides, Téheran, 1958.

PENMAN, H. L., Natural evaporation of open water, bare soil and grass. Proc. R. Soc. Agr. 193, London, 1948.

PENMAN, H. L., Evaporation; introductory survey. Neth. Journ. Agr. Sci. 4, 1956.

REEVE, R. C., ALLISON, L. E. and PETERSON, D. F., Reclamation of saline-alkali soils by leaching, Delta Area, Utah. Utah Agr. Exp. St. Bull. 335, 1948.

REEVE, R. C., The relations of salinity to irrigation and drainage-requirements. Trans. 3rd Congr. on irrigation and drainage, 1957.

SCHILFGAARDE, J. VAN, KIRKHAM, D., and FREVERT, R. K., Physical and mathematical theories of tile and ditch drainage and their usefulness in design. Iowa Agr. Exp. St. Res. Bull. 436, 1956.

SMITH, R., The relationship between water quality and drainage characteristics of some Iraq soils. Trans. 3rd Congress on Irrigation and Drainage, 1957.

SMITH, R., and ROBERTSON, V. C., A classification of the saline soils of the old irrigated lands of the Middle Tigris valley. Trans. 6th Congress Int. Soc. of Soil Sci., 1956.

THORNE, D. W., and PETERSON, H. B., Irrigated soils, New York, 1954.

TIPPITS-ABBETT and MCCARTHY-STRATTON, Symposium: Drainage problem in connection with irrigation projects of Southern Iraq, Baghdad, 1957.

TURCAN, J. S., Report on a project for drainage and reclaiming land adjoining the Aqgar Quf. Irrigation Department, Baghdad, 1945.

TWAIRIJ EXPERIMENTS, Development Board and Ministry of Development, Iraq. Report I, Results of the first season. Mimeographed Reports.

U.S.D.A., Diagnosis and improvement of saline and alkali soils. Agriculture Handbook, no. 60, 1954.

VISSER, W. C., Tile drainage in the Netherlands. Neth. Journ. Agr. Sci., Vol. 2, 1954.

WARRINER, D., Land reform and development in the Middle East. London 1957.

WARTENA, L., The climate and the evaporation from a lake in central Iraq. Wageningen, 1959.

SYMBOLS, ABBREVIATIONS AND TERMS

EC	electrical conductivity in millimhos/cm at 25° C unless otherwise specified
EC_e	electrical conductivity of a saturation extract
$EC_{1:1}$	electrical conductivity of the extract from a 1 : 1 soil-water suspension
EC_{iw}	electrical conductivity of irrigation water
EC_{dw}	electrical conductivity of drainage water
EC_{eo}	initial salt content of the soil, expressed as electrical conductivity of a saturation extract
EC_{ex}	equilibrium level of salinity (electrical conductivity of the saturation extract) obtained under normal irrigation and drainage practices
mmhos/cm	millimhos per cm = reciprocal ohm × 10^3
meq/l	milliequivalent per liter
E.S.P.	exchangeable sodium percentage
SAR	sodium adsorption ratio
T	depth of soil layer in question
I	irrigation supply in water depth/period
C_i	salt concentration of irrigation water
G	moisture supply from below to the soil layer in question in water depth/period
C_g	salt concentration of water supply G
P	percolation water draining from the soil layer in question in water depth/period
C_p	salt concentration of percolation water P
N	effective precipitation/period
ET	evapotranspiration
C.U.	consumptive use = evapotranspiration
D	depth of drainage water (discharge of field drains) per period
Dn	natural drainage in water depth/period
S	seepage supply (subsoil waterflow towards the unit in question) in waterdepth per period
Dr	drainage requirement in water depth/period
Ir	irrigation requirement in water depth/period
F.C.	field capacity
M	soil moisture content

ΔM	difference in moisture stored in the soil
M_{fc}	soil moisture content at field capacity
C_{sm}	salt concentration of soil moisture
M_{ex}	moisture content of the soil-water mixture from which the extract is to be obtained
C_{ex}	salt concentration of the extract M_{ex}
C_{es}	salt concentration of the saturation extract
f	coefficient of leaching efficiency
L	drain spacing
m	available hydraulic head: difference between ground-water level halfway between the drains and water level in ditch or tile line
$\bar{n}.\bar{\bar{m}}$	same as m, but averages
m_v	hydraulic head required for vertical downward flow
m_h	hydraulic head required for horizontal flow
m_r	hydraulic head required for radial flow
W_r	radial resistance
U	wet perimeter of ditch or tile line
2r	outside diameter of tiles
b	bottom width of ditch
h	water depth in ditch
k	hydraulic conductivity
d	distance from ditch-bottom or tile line to impervious floor
meshara (mesh)	local area unit: 2500 m^2
donum	local area unit: 2500 m^2
saifi crop	summer crop
shitwi crop	winter crop
sabakh	saline soil with brown efflorescents which contain a high percentage of magnesium and calcium chloride
mash	phaseolus acornbifolius (green gram)
masri	lens culinaris (lentils)
lubia	vigna spec. (cow peas)