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LEACHING OF SALINE SOILS IN IRAQ[1])

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SUMMARY

1 A large proportion of the soils of the Lower Mesopotamian Plain are very saline. A table is given summarising the salinity data of a few project areas as reported by Consulting Engineering Firms and Government Agencies.

2. Some date are represented on the salt movement in the top-soil and the overall discharge of salt from the area. It is concluded that, even with intensive drainage and leaching operations, the sub-soil water and the drain water will remain salty for a very long period.

3. A leaching curve, figure 3, has been constructed on the basis of field experiments on the Dujailah Experimental Farm. The curve has been compared with a curve for Annanah soils and a curve for a Utah soil. The limits and the use of the curve are explained. With the aid of this leaching curve and the data on the salinity before leaching, the amount of water needed to obtain any required salinity level in the soil can be calculated. To facilitate the calculations, a leaching graph has been constructed to show the drain-water depth per unit depth of soil as a function of the salinity before leaching and of three different levels after leaching.

4. It is pointed out that the information on the amount of water required for leaching has to be considered and used in conjunction with agricultural information on the salt-tolerance of field crops and need for fertilizers, to obtain a general leaching plan for the reclamation of a given area.

CONTENTS

1 LIST OF SYMBOLS AND UNITS

meshara	local area unit	2500 m^2
EC	electrical conductivity	mmhos/cm at 25° C
EC_e	EC of the saturated soil extract	mmhos/cm at 25° C
EC_{eo}	EC_e before leaching experiment commenced	mmhos/cm at 25° C
EC_{ex}	equilibrium (minimum) EC_e	mmhos/cm at 25° C
DW	depth of leaching water	cm
DS	depth of soil over which salinity is given	cm

2 THE SALINITY PROBLEM IN IRAQ

A large proportion of the soils of the Lower Mesopotamian Plain contain excessive amounts of salts. Very roughly estimated, the total quantity of salts which is present in the upper 5 m of the soil of the area suitable for crop

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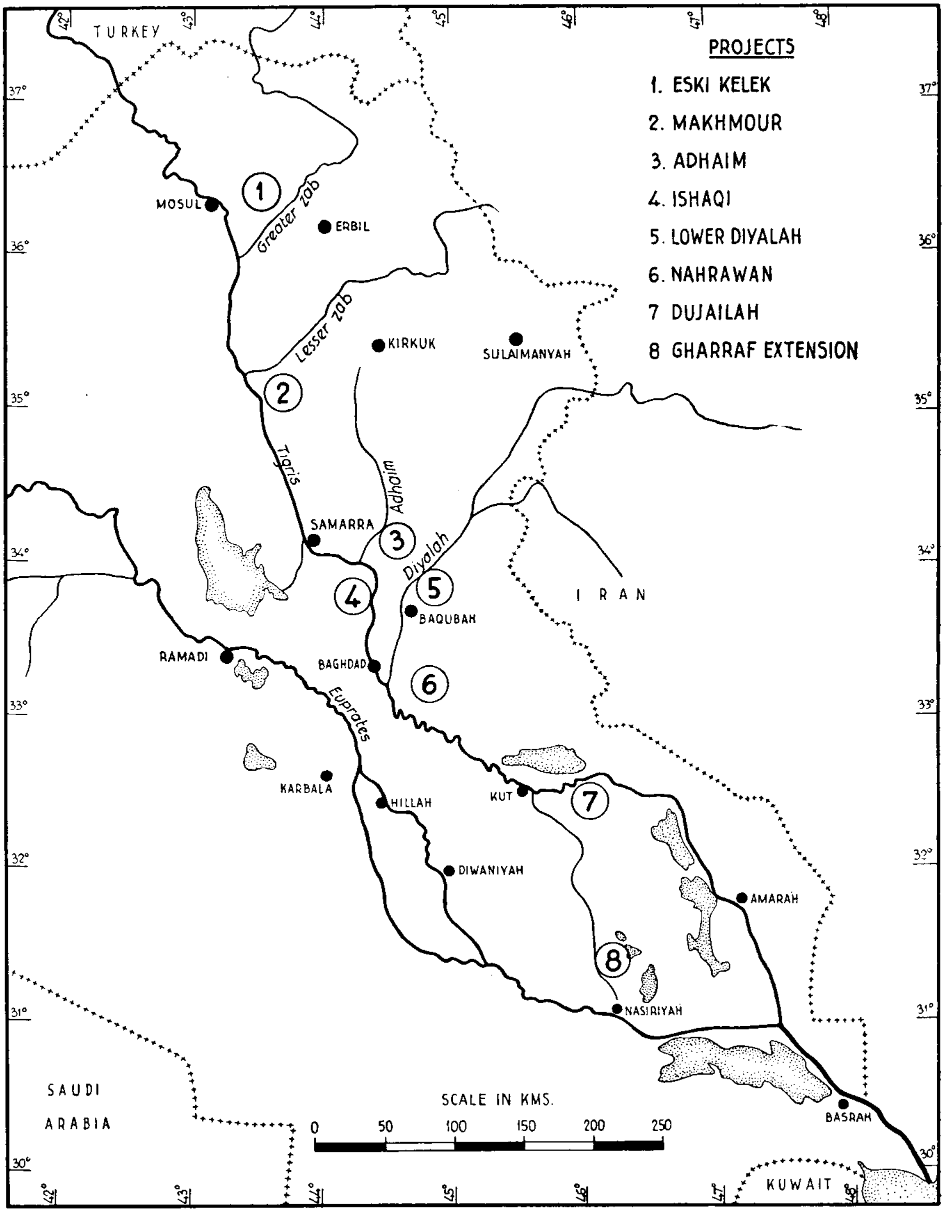

Fig. 1 Map of Iraq with some projects.

production in the Central and Southern parts of Iraq, amounts to 1 milliard (10^9) metric tons over 150,000 square kms. (Dujailah exp. 6, 1959).

In table 1 the salinity data for a few project areas are summarized. These data have been taken from surveys carried out by Government Agencies and Consulting Engineering Firms. The salinity is given as the average electrical conductivity of the saturation extract, EC_e [2]), of the upper 50 to 100 cm of the soil. The location of the projects is shown in figure 1.

[2]) See list of symbols for this and other abbreviations.

Table 1 Some data on the salinity of the soils in Iraq.

Project		Km²	Latitude[1]	Percentage of project area[2]		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	2500	35.25	1	0	380	22.0	Kirkuk
	South			7	1			
Lower Diyalah		4300	33.45	87	17			
Adhaim	left	1350	34.15	54	19			
	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	Nasiriyah

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; Nasiriyah 1940—'52; (Climatological means, 1954).

It follows from the table that there is no salinity problem in the Northern districts of Iraq. These areas have little irrigation and the rainfall, although erratic, is sufficient to cause some leaching during the winter season.

The salinity of the soils increases towards the south, where irrigated agriculture becomes more prominent due to the decreasing rainfall. Below Baghdad (latitude 33.20), where the valleys of the Euphrates and the Tigris widen out to one enormously broad plain, the salt problem is most serious. These valley soils have been irrigated since early Babylonian times. Natural drainage or leaching was of no importance due to the very slight slope of the river plains and the very low rainfall. As a result, the salts from the irrigation water of some millienna has accumulated in the topsoil.

The saline soil conditions give rise to a precarious crop production and strongly influence the agricultural standards. South of Baghdad, large agricultural areas have been abandoned by the farmers and many soils are cultivated on a marginal level. Yields as low as 500 kg of barley per ha are not uncommon. The choice of crops is very restricted as the more salt-sensitive yield even less satisfactory results. Salinity is the limiting factor for the agricultural, and consequently also for the social and economical development of these areas. Any improvement scheme has therefore to start with the desalinization of the soil.

The principle of desalinization is very simple. Firstly drains are required to lower the ground-water table and to discharge the saline ground-water. Secondly, the salts have to be washed downwards (leaching) from the upper soil layers at least, by means of flooding and irrigation.

A tremenduous reclamation program has been planned and partially executed in Iraq. The work up to now has mainly concentrated on the design and construction of the necessary drainage facilities. Very soon the next step, the actual desalinization or leaching of the soils, will follow. The present paper deals with some aspects of the work of this second stage.

3 Leaching experiments

In 1954, the Drainage Branch of the First Technical Section of the Development Board initiated the establishment of a Drainage and Land-Reclamation experimental Farm for the purpose of collecting basic information on the drainage and reclamation requirements of the saline soils of Iraq. The farm is located in the Dujailah Land Settlement area, about 230 km South of Baghdad. A particular saline soil was selected, with EC_e values in the top-soil often exceeding 100.

A drainage system with drains at different spacings and depths was installed on the farm. Provisions were made for measuring the irrigation supply- and drain discharge quantities (Dujailah exp. 1, 1954). The experimental work started in the spring of 1956.

The data discussed in this paper were collected from two experimental units of the Dujailah Farm, viz. block I and block III. Block I is drained by means of tiles 25 m apart and 1.2 m deep. Block III is drained by means of tiles at intervals of 50 m and at a depth of 1.5 m. By frequent soil sampling, salinity data were obtained before, during and after leaching. The samples were analysed with respect, inter alia, to the electrical conductivity of the saturation extract. The EC_e values given in this paper are averages taken over 10 to 20 soil samples while in addition each soil sample up to 60 cm depth is composed of 7 to 9 sub-samples taken by pipe auger.

Leaching was carried out by flooding the bare soil or by over-irrigating the cropped soil with different depths of water. As the actual amount of leaching water, the quantity of sub-soil water discharged by the drainage system, as measured at the drain outlets, was taken. A correction was added for the direct drain-water flow into the open collector drain. Since the area was underlain by a impermeable floor at a depth of 4 m and since boundary effects could be eliminated by a proper selection of the observation data, the water quantities thus obtained represent fairly accurately the actual amounts of effective leaching water which passed through the soil.

4 Leaching and salt balance of the soil

If a saline soil is being leached, two phenomena of the salt movement are of importance. In the first place the salts in the upper layers of the soil are washed downwards, a fact, which directly determines the improvement of the soil for agricultural use. Secondly, the ground-water table will rise and thus cause a discharge of salty 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. Some data, illustrating both aspects of the salt movement, are given in table 2.

Table 2 Dujailah experiments, salt-balance data (Dujailah exp. 6, 1959). Salts removed or added in kg per sq. metre of treated soil.

cm depth drain water	disch. by drain water	added by irr. water	Removed from soil			
			total	0–30 cm	0–60 cm	0–200 cm
20	13	1	12	20	25	
92	44	4	40	20.5	29	39
165	74	14	60	20.5	29	53
Initial amount of salt in the soil				20.7	29.2	59

According to these figures most of the salt in the top 30 cm of the soil was removed by means of 20 cm of leaching water. Further leaching had very little effect as nearly all salts had been removed. After 165 cm of leaching water had passed through, the drain was still discharging highly saline water. This means that, after the desalinization of the upper layers of the soil has been completed, the desalinization of the whole soil profile will continue for a very long period. Thus, even after the soil has been reclaimed with respect to the agricultural demands, the drains will continue to discharge salty groundwater, an aspect which 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 at least 15 to 20 years, depending on the flow pattern of the soil-water movement and the characteristics of the soil.

5 The leaching curve

In connection with the planning of the reclamation of saline areas, a reliable estimate of the amount of leaching water required to reduce the soil salinity to a level desired is of predominant interest. The purely empirical approach, with all its limitations, seems 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 results of value for practical purposes.

Figure 2 shows, in the case of our leaching trials, the decrease in the electrical conductivity of the saturated soil extract in relation to the amount of leaching water, over different soil depths. The data from block I and block III correspond very closely down to a depth of 1 m. At greater depths, the leaching in block III proceeds more rapidly than in the case of block I. This difference can be explained by a difference in the flow-line pattern in the two units as, 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.

In figure 3, the data given in figure 2 are represented in a different way, (Reeve, 1957). The depth of leaching water on the abscis is given per unit

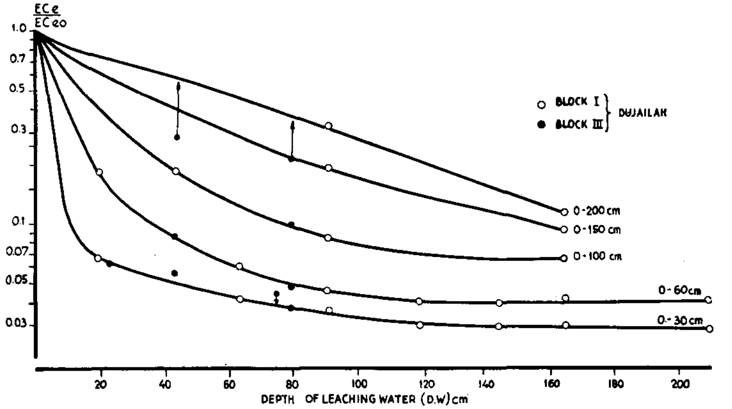

Fig. 2 Relation between soil salinity and total depth of leaching water.

depth of soil. The fraction of the initial salt remaining in the soil, represented by the ratio EC_0 / EC_{eo} , on the ordinate, has been corrected by subtracting from EC_e as well as from EC_{eo} a constant value EC_{ex} . This value EC_{ex} represents the equilibrium of salinity in the soil which will finally be obtained under the actual irrigation practices. EC_{ex} depends on the salinity of the irrigation water and the ratio between irrigation and drainage quantities. Under our experimental conditions, EC_{ex} was found to be between 2.7 and 3.0. By subtracting the equilibrium value EC_{ex} from the salinity values before and after leaching, the relationship as given in figure 3 becomes independant of the salinity of the irrigation water and the existing drainage conditions. The curve thus obtained is determined by the soil conditions only.

Besides that for the Dujailah soil, two other leaching curves are given in

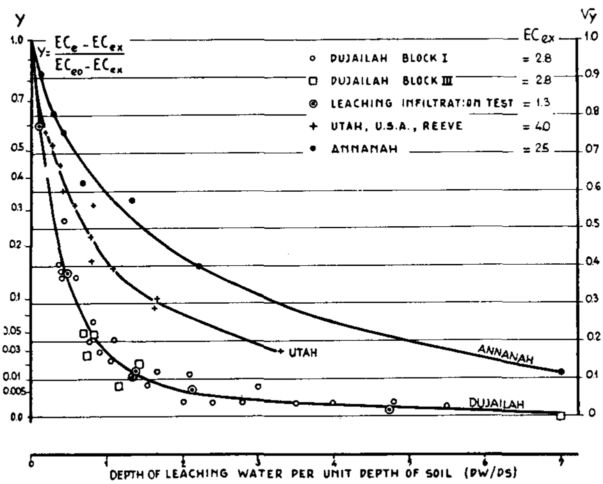

FIG. 3 LEACHING CURVES.

figure 3. 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 are not however as accurate as the Dujailah one, since estimates had to be made for the evaporation losses, which were not known in either case, to assess the actual nett amount of leaching water from the total irrigation duty. As 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 at 4.

A comparison of the three curves shows that, to leach the Annanah soil, much more water is required than for the Dujailah soil. The Utah soil holds a position in between.

These different leaching efficiencies are related to the physical properties of the soil. The Dujailah soil consists mainly of sandy loam, 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 silty loam (Agric. Handbook No. 60, 1954). The distribution of the total pore space over pores of diffierent diameter is probably of major importance for the efficiency of leaching. In a light soil, the pores have usually a more uniform diameter than in a heavier soil in which large pores occur between and fine pores within the structural elements. In leaching a heavy soil, the part of the water which passes through the largest pores (cracks) is of little effect for leaching.

For a proper interpretation of the leaching curves, a few remarks will have to be made:

a. The EC_e values used for the construction of the curves in figure 3 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 different layers of the soil profile varies considerably (Dujailah exp. 6, 1959).
A close analysis of the field data indicates that, in all probability slightly different curves could be constructed for the different soil depths. However these differences appear to be of minor importance and can be neglected for practical purposes.

b. Leaching measurements of the different layers of the soil profile commence only after the drains start discharging water. It appears that a high subsoil water table under fieldconditions is quickly built up after irrigation starts, by water flow through cracks.
The drains start discharging before the whole soil profile is saturated. Therefore little leaching of the top layers of the soil profile occurs during the period of a rising ground water table and before the drains discharge. For the quick leaching test no such conditions prevail and a correction for water storage in the profile has to be introduced (see 6).

c. Due to the fact that the leaching curve is an empirically determined relationship, its validity is restricted to an initial salt content (EC_{eo}) within the same limits as are given by the field data from which the curve is drawn. These limits are, in the case of the Dujailah curve, an electrical conductivity of the saturation extract of between 40 and 100 and, for the Annanah curve, an EC_{eo} between 20 and 60.

d. The speed of leaching seems to be of little or no importance for the result. In block I, leaching started by flooding and was continued by means of normal irrigation. In block III, the basins were cropped, and irrigated in a normal way from the beginning. The leaching effect in both cases appeared to be related only to the total amount of leaching water which actually drained through the soil.
Hence, the manner in which the soil is irrigated and the amounts and frequency of water gifts are of little or no importance for the leaching effect.

e. The leaching curve is practically independent of the kind of soil-water extract used for the electrical conductivity determination. The salinity could also be expressed in, for instance, the percentage of salt in the dry soil, if the proper equivalent value for EC_{ex} were chosen.

f. The leaching curves are drawn for a vertical water movement and can therefore be applied only to a depth where the water movement is vertical or nearly vertical. In leaching the upper metre of the soil for agricultural crop growth, and with drain spacings of 100 m or more, this aspect can be neglected save, possibly, in the case of a strip very close to the drains where these are shallow.

6 A simple field test for determining the leaching curve

In planning the reclamation of saline land, the leaching relationship as given in figure 3 will be a useful tool in deciding whether or not desalinization is possible and economically justified and which reclamation methods are most suitable, taking into account the 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, in principle, be necessary for each reclamation project to determine the leaching curves valid for the specific conditions of that area. It does not seem feasible however, to carry out time-consuming and expensive field experiments for that purpose.

An attempt was therefore made to discover if the leaching curve could be based with sufficient accuracy on the results of a simple and quick leaching test.

The test was carried out by means of two concentric cylinders, with diameters of 50 and 70 cm respectively, 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 speed was measured for the inner cylinder. Soil samples in the inner cylinder were taken before the test started and after water had been infiltrated to a depth of about 50 and 100 cm. In each location, the test was carried out in quadruplicate. The duration of the test depends on the infiltration rate; in Iraq the test could usually be completed within two weeks.

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

The results of the tests carried out within the Dujailah experimental area are given in figure 3. Comparison with the data of the field leaching experiments in large basins, shows that both results fit very well into the same salt-leaching relationship. The leaching curve can therefore be determined, to a sufficient degree of accuracy, by means of simple leaching-infiltration tests as described above.

7 Use of the leaching curve

Leaching can be carried out in various ways, the main difference being the application of leaching water on bare soil or in combination with a chosen follow up of crops, adapted to the changing salinity status of the soil. Legume crops need our special attention in this connection as, when the harmful salts are leached, valuable plant nutrients – mainly the readily soluble nitrogen nad potassium components – are washed down also (Dujailah exp. 5, 1958; Seminar on drainage and land reclamation, 1958).

The leaching method which is to be preferred in a specific case, depends on many factors such as the need of a crop return during the reclamation period, the availability of a large discharge of irrigation water, the effect of leaching on the soil fertility, the possibilities of applying fertilizers and the technical abilities of the farmers. In short the selection of the proper leaching method is not only a chemico-physical soil problem, since economical and agro-social aspects are also intimately involved in the reclamation of an area.

If, for various reasons, a certain reclamation procedure seems advisable, it is possible, with the help of the leaching curve, to plan more accurately the different steps of the procedure and to see what the consequences will be with respect to the water requirements and the time needed to complete the reclamation. This will be illustrated by an example.

Let us suppose that the average EC_e of the Dujailah soil is 50 for the upper 30 cm and for the upper 60 cm. The plan is to flood the soil until the EC_e of the upper 30 cm has dropped to 10, than to follow with one or more years of legumes until the EC_e from 0–60 cm is below 4. After this the soil can be considered to be 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/day.

According to figure 3, 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%, thus $DW/DS = 0{,}47$, hence $DW = 14$ cm. Flooding will thus take 7 days. The total water-use including evaporation and moistening 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 6.6 and 3.8. Thus 7 days of flooding and 2 years of legumes – e.g. biennial sweet clover – will be required to reclaim this Dujailah soil.

If the same assumptions are accepted for the Annanah soils, except EC_e = 2.5, a similar calculation shows: leaching water required to lower the EC_e 0–30 cm from 50 to 10 will be 68 cm. The number of days of flooding will be 34 and the total amount of irrigation water required 150 cm.

The EC from 0–60 cm after one year of legumes will be 15, after tw

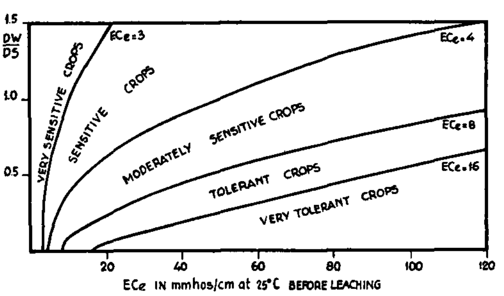

FIG. 4 LEACHING GRAPH FOR DUJAILAH SOILS.

years 11, after three years 9 and after four years 8. Thus the Annanah soil will need 34 days of flooding with a total water use 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 8.

It may be mentioned here that, from the examples given, it should not be concluded 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, figure 4 has been constructed on the basis of the leaching curve for the Dujailah soil. In this graph the depth of leaching (drain) water is given as a function of the salinity before leaching and of three different levels after leaching.

References

Dujailah experimental reports, 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 maindrain (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).

Annanah experimental reports, Development Board and Ministry of development, Iraq:

Report 1, The results of leaching and the first summer crops (1958).

Seminar on drainage and land reclamation. Development Board and Ministry of Development, Iraq (1958).

Climatological means for Iraq, publication No. 10 (1954).

GARDNER, W. R. and R. H. BROOKS: A descriptive theory on leaching. *So. Sci.* 83 (1957).

MOLEN, W. H. VAN DER: Desalinization of saline soils as a column process. *So. Sci.* 81 (1956).

REEVE, R. C., L. E. ALLISON and D. F. J. PETERSON: Reclamation of saline-alkali soils by leaching. Delta area Utah. *Utah agr. exp. sta. Bull.* 335 (1948).

— —: The relation of salinity to irrigation and drainage requirements. Trans. 3d. Congr. on irrigation and drainage (1957).

U.S.D.A. Diagnosis and Improvement of Saline and Alkali soils. Agriculture Handbook No. 60 (1954).