Properties of saline soils in Iraq

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Summary

Analytical data of thousands of samples originating from different areas in the Lower Mesopotamian Plain in Iraq, enabled a study on several soil and salinity characteristics.
Data on soil texture, lime, gypsum, cation-exchange capacity, salinity, alkalinity, hydraulic conductivity, their interrelationships and variations are discussed. An equation expressing the relation between exchangeable Na and cations soluble in 1 : 1-extracts is presented. Special attention is paid to the question whether alkalisation and deterioration of structure will be met with in the reclamation of these soils. Gypsum contents seem to be high enough to ensure adequate replacement of Na by Ca during the leaching process, but some temporary decline in the permeability in early stages of leaching is likely to be expected as a consequence of retarded exchange reactions, caused by the nature of the clay minerals.

1. Introduction

The saline soils in the flood- and delta plain of the twin-rivers Tigris and Euphrates and problems related to the reclamation of these soils have roused the interest of the Iraqi government and researchworkers since several years. The country faces the enormous problem to secure an existence for her growing population by promoting its agricultural and industrial development.
The conditions for this development are favourable. Iraq has the most striking potential of any Middle Eastern nation. Although 75 % of its 440.000 km^2 large area has no agricultural potentiality at all, there still remains land in abundance. Compared to Egypt e.g., Iraq has three times more cultivable land and a population four times smaller. The rivers provide enough water for irrigation purposes and finally oil revenues provide the means to develop all the land that bred the Sumerian, Babylonian and Assyrian civilisations of antiquity.
Agriculture in the Mesopotamian Plain is seriously hampered by the high salt content of the soil, a situation originating from incorrect irrigation methods already applied in early Babylonian times. Moreover feudalism has, untill the revolution in 1958, more than anything else depressed the state of Iraqi agriculture and frustrated efforts toward reform.
At present measures are being studied and carried out in order to overcome salinity and salinisation by combined irrigation and drainage. In the past years several soil surveys and drainage studies were carried out by government institutions and private companies. In these studies large scale use was made of soil analysis carried out by the "Laboratory for soil- and water analysis" in Tell Mohammed, Baghdad. This

Received for publication 13th February, 1962.

laboratory forms part of the Division of soils and agricultural chemistry of the Ministry of Agriculture.
An impressive amount of data on soil- and salinity conditions in different areas of the Mesopotamian Plain has thus been accumulated.
Reports on these studies are, however, not easily accessible. Untill 1960 this laboratory analysed 40.000 odd soil samples originating from several areas; furthermore a far greater number of samples was analysed on EC_s (the electrical conductivity of a saturation paste) alone. Out of this extensive analytical material approximately 15.000 samples comprising some 150.000 single analyses were selected and used for a comparative study on a regional basis (DELVER, 1960).
The analytical methods applied by the Tell Mohammed laboratory are essentially the same as those given by the U.S. SALINITY LABORATORY (1954).
It is the objective of this paper to discuss some physical and chemical properties of soils in the Lower Mesopotamian Plain. The picture, though far from complete, may contribute to the knowledge on soils and salinity conditions in Iraq.

2. Project areas

In order to prepare a well planned system of land reclamation the government of Iraq has assigned several project areas in which the technical aspects of irrigation, drainage and soil conditions had to be studied first. As far as samples from such areas were used for this study, the location of these areas is indicated in FIG. 1. The samples originated from the following areas:

Tigris deposits: Middle Tigris left bank, Dujaila, Ali Gharbi.
Euphrates deposits: Yusufiya, Latifiah, Hilla-Diwaniya, Rumaitha, Shatra.
Both Tigris and Euphrates deposits: East-Gharraf.

The sampling depth was always known, but not the exact location of the sampling spots within an area. The greater part of the samples, however, was collected for soil- and salinity-survey purposes. Therefore, samples from one area represent fairly accurately the average conditions in the area concerned.

3. Physical and chemical characteristics of soils in the Lower Mesopotamian Plain

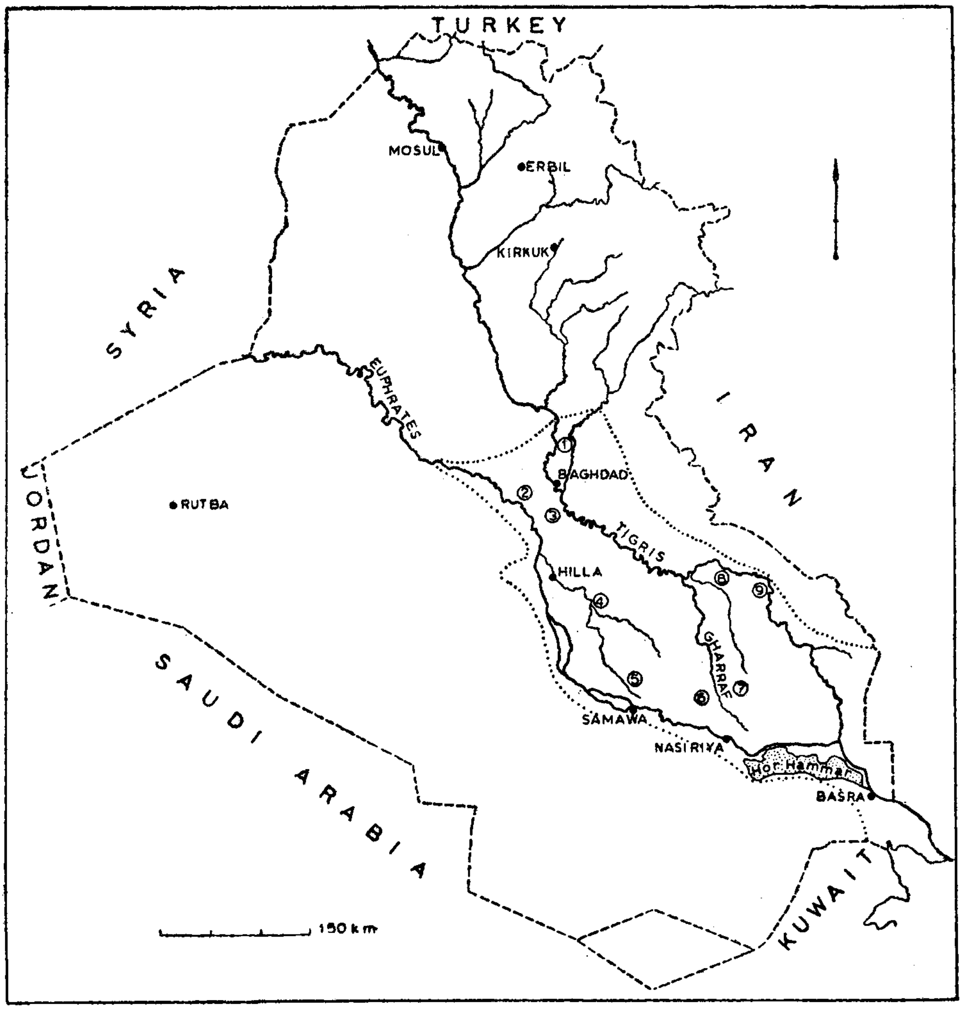
The saline soils of Iraq are almost exclusively found in the Lower Mesopotamian Plain (FIG. 1). The discussion of soil characteristics is therefore restricted to this agriculturally most important part of Iraq. Nearly all these soils, forming an enormous agricultural potential, have been sedimented under irrigation conditions. Irrigation has much influenced the physical and chemical properties of these soils.

3.1. Soil textures

Soil textures in the upper few meters of the river plain show some features, which distinguish them clearly from river deposits in other parts of the world. These are:

a. A low sand content in which coarse sand is almost absent in soils not belonging to ancient river-beds or silted up irrigation canals.
b. A high silt percentage.
c. Heavy soil textures occur less frequently than in other river-plains.
d. Abrupt vertical and horizontal textural changes.

FIG. 1. Map of Iraq showing the location of project areas



.... Border of the Lower Mesopotamian Plain

1	Middle Tigris Left Bank	6	Shatra
2	Yusufiya	7	East Gharraf
3	Latifiyah	8	Dujaila
4	Hilla-Diwaniya	9	Ali Gharbi
5	Rumaitha		

The explanation of these features is given by the different sedimentation conditions of most of these soils. Since man entered the plain some 5000—6000 years ago, irrigated agriculture started to influence sedimentation. The waters of both the Euphrates and the Tigris carry large quantities of silt especially in periods of great discharge. LEES and FALCON (1952) estimated that both rivers carry $21{,}6 \times 10^6$ m^3 of silt annually. Irrigation therefore resulted in a raise of the level of the land

surface according to an artificial sedimentation pattern, a process that still continues.
Under natural conditions river-water is transported to the land by floods. The silt-load of this water sorted out by a decrease in the stream velocity, is deposited. This results in the formation of relatively coarse or medium textured river-levees and of heavier textured river-basins.

In Mesopotamia this process was dominated increasingly by sedimentation in irrigation water. Floods untill recently occurring every 3—4 years, have locally attributed to sedimentation especially in abandoned, not irrigated areas, but the general situation is that nearly all natural river-deposited soils are covered with 1—5 meters irrigation sediment. With irrigation the silt-load of the river-water looses a great part of its coarse particles during transportation in the canals and ditches. The remaining material deposited on the land is therefore characterised by a low sand content.

A further textural differentiation resulting in the formation of irrigation-levees and -basins takes place. Owing to the fact, however, that water led into small basins almost suddenly comes to a standstill, conditions under which only very fine material settles seldom occur. Very heavy clays are therefore seldom found in irrigation sediments.

Due to siltation irrigation canals were frequently abandoned and new ones were dug. Sedimentation then started anew but from a different starting point. This resulted in very stratified profiles and in sudden textural changes in horizontal direction. A detailed discussion on the influence of irrigation on soil formation in Iraq is given by SCHILSTRA (1962).

An impression about the textural distribution of irrigation sediments is given in FIG. 2 for which more than 1000 samples chosen at random from different areas and profile depths were used.

The numbers per textural class are expressed as a percentage of the total number of samples. The few sandy samples originate from old river courses and irrigation canals. This picture remains almost the same throughout the entire flood- and delta plain.

By excluding sandy samples (old river courses) the average mechanical composition of the silt-load sedimented under irrigation conditions could be calculated for a number of areas. Per area the average texture of the 0—60 cm topsoil was calculated from 200 profiles. TABLE 1 shows that the sedimented material is mostly very uniform. In the southernmost areas East Gharraf, Dujaila and Ali Gharbi, however, the soils contain somewhat less sand. These areas are situated on the transition of the delta plain to the marshy region (BURINGH, 1960), where the fall of both rivers amounts to approx. 3 cm/km. The other areas belong to the flood- and delta plain where the fall amounts to 9—5 cm/km (KNAPPEN, TIPPETS, ABBETT and MCCARTY, 1952). The somewhat lower sand content of the irrigation cover in the southern areas must therefore be attributed to the decrease in the stream velocities of the rivers, resulting in a gradual loss of the coarsest sand particles. It must therefore be expected that heavier textured soils will occur somewhat more frequently in the southern areas.

The texture properties of the upper meters of irrigation sediments are of great importance for the future reclamation possibilities. The artificial sedimentation conditions during thousands of years resulted in the formation of soils wherein heavy clay layers which possibly could impede groundwater movements seldom occur. The general opinion reflected in several reports is that most soils are moderately permeable and that nearly all soils are drainable.

FIG. 2. Diagram showing textural limits for 98 % of all samples, relative occurrence per textural class in % and lines of equal saturation percentages

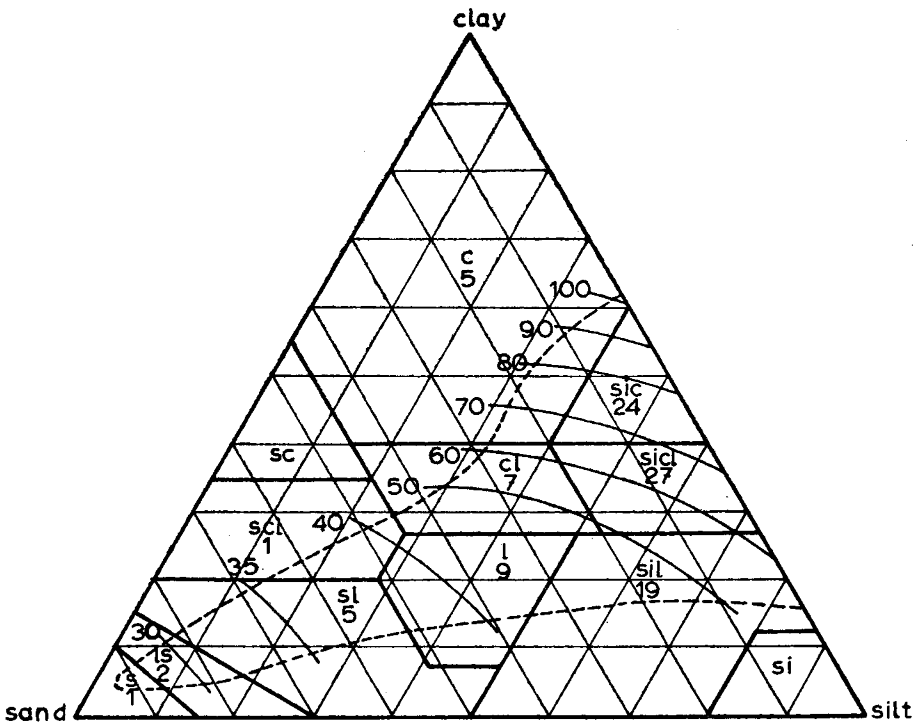


TABLE 1. Average texture of the irrigation cover (0—60 cm) in direction downstreams

Area	Euphrates deposits			Tigris deposits		
	s	si	c	s	si	c
Middle Tigris left bank				16,3	50,6	33,1
Yusufiya	15,3	50,0	34,7			
Yusufiya (200—300 cm)	15,6	50,6	33,8			
Latifiyah	17,3	47,1	35,6			
Diwaniya	15,7	50,3	34,0			
Rumaitha	14,8	50,0	35,2			
Rumaitha (200—300 cm)	15,1	50,5	34,4			
Shatra	14,5	54,4	31,1			
East Gharraf [1]	10,3	56,3	33,4			
Dujaila				11,0	—	—
Ali Gharbi				11,6	59,3	29,1

1 This area has been sedimented by both rivers.

3.2. Lime

Without exception the soils in the Mesopotamian Plain show high contents, usually 20—30 %, of lime. Since most soils also contain salt and gypsum, it may be stated that only 70 % of Mesopotamia consists of real soil. The lime originating from the northern catchment areas where soil erosion is a serious problem, was transported by the rivers mainly as part of the silt-load. Soils in the northern hills and mountains are mainly developed on limestone parent-material and may contain 40—70 % lime. In fact Mesopotamia is the result of a thousands of years old process of soil erosion.
The presence of such quantities of lime is of importance for the explanation of certain soil-physical properties such as the rather low cation-exchange capacity. Some influence on the permeability and soil structure is attributed to lime.
The variations in lime-content within a soilprofile may amount to several percents. From TABLE 2 it may be concluded that these variations are to some extent related to the soil texture.

TABLE 2. Average lime contents in percentages calculated per texture class

Area	Soil texture							
	c	sic	sicl	sil	cl	l	sl + ls	s
Latifiyah	25,6	26,3	25,3	25,5	25,4	23,2	21,5	13,6
Middle Tigris l.b.	28,6	28,3	28,2	28,0	27,0	26,4	24,2	20,5
Yusufiya	26,6	26,6	26,5	25,5	25,4	24,3	22,3	17,6
Rumaitha	25,4	25,5	25,6	25,7	26,1	24,8	22,9	17,8
Shatra	25,7	25,2	25,9	26,1	25,3	25,6	24,9	23,7
East-Gharraf	26,7	26,7	26,9	27,4	26,6	26,5	25,3	25,0

In the northern areas sandy samples clearly show lower lime contents than the finer textured samples. This difference tends to fade out in the southernmost areas Shatra and East Gharraf. This phenomenon may be explained from a difference in average size between lime and other particles in the silt-load. In the early stages of transportation where stream velocities are high, abrading forces cause a diminution of the size of the relatively soft lime particles. In this way lime particles become smaller than other particles of the silt-load (KRUMBEIN and SLOSS). If such material is deposited, coarse sediments will contain less lime than fine sediments. As transportation continues, stream velocities and abrasion of lime decrease, whereas selective transportation or the sorting out of coarse, mainly non-lime particles continues. In a later stage of transportation, more downstreams, there will be less difference between the size distribution of lime and other particles and consequently lime will be more evenly distributed over the textural classes (Shatra, East Gharraf).
TABLE 2 finally shows that the lime contents in the Middle Tigris area exceed those of other areas. This may be an indication that Tigris deposits contain somewhat more lime than Euphrates deposits and that both sediments could possibly be distinguished by their lime contents.
A part of the variations in lime content seems to be related to the profile depth. In a number of profiles from Latifiyah, lime contents were somewhat higher at approx. 1 meter above the ground-water level.

3.3. Gypsum

Like many soils in other arid regions in the world, Mesopotamian sediments contain secondary gypsum. This gypsum originates from north-eastern Iraq where the rivers flow through vast gypsumdeserts. The waters of both rivers contain 0,2—0,4 gram salt per liter, in which Ca and SO_4 predominate over Na and Cl. Some gypsum may also be transported into the plain by dust storms. A dust sample, collected in May 1958, contained 1,5 % gypsum.

The presence of gypsum is of paramount importance for the reclamation of saline-alkali soils, since it prevents deterioration of structure during leaching.

Gypsum is precipitated in the capillary zone of the soil-profile by internal evaporation of usually strongly saline ground-water. Owing to its low solubility (2 g/l), gypsum precipitates long before other salts do and therefore accumulates deeper in the soil-profile. At the same time, gypsum accumulates in the topsoil together with other salts, as is shown by the following profile from Rumaitha:

Depth in cm	EC_e mmhos	gypsum %
0—30	49	2,7
30—90	25	0,6
90—150	15	1,2
150—190	13	0,4
190—210	12	0,3
210—270	9	$<$0,3
270—300	9	$<$0,3

In general, a high salt content in the topsoil is therefore attended with a high gypsum content. For different areas the average gypsum content of the 0—30 cm topsoil was calculated for samples of different degree of salinity (TABLE 3).

TABLE 3. Average gypsum contents in % per salinity class for 0—30 cm topsoil samples

Area	Salinity class; EC_e in mmhos/cm at 25° C					
	0—4	4—8	8—16	16—32	32—64	$>$ 64
Middle Tigris l.b.	0,20	0,30	0,63	0,82	1,11	2,26
Yusufiya	0,22	0,38	0,46	0,83	1,47	no data
Rumaitha	0,16	0,30	0,96	1,41	1,82	2,74
Shatra	0,18	0,26	0,40	0,65	1,29	1,81
East Gharraf	0,21	0,40	0,50	0,83	1,97	1,70

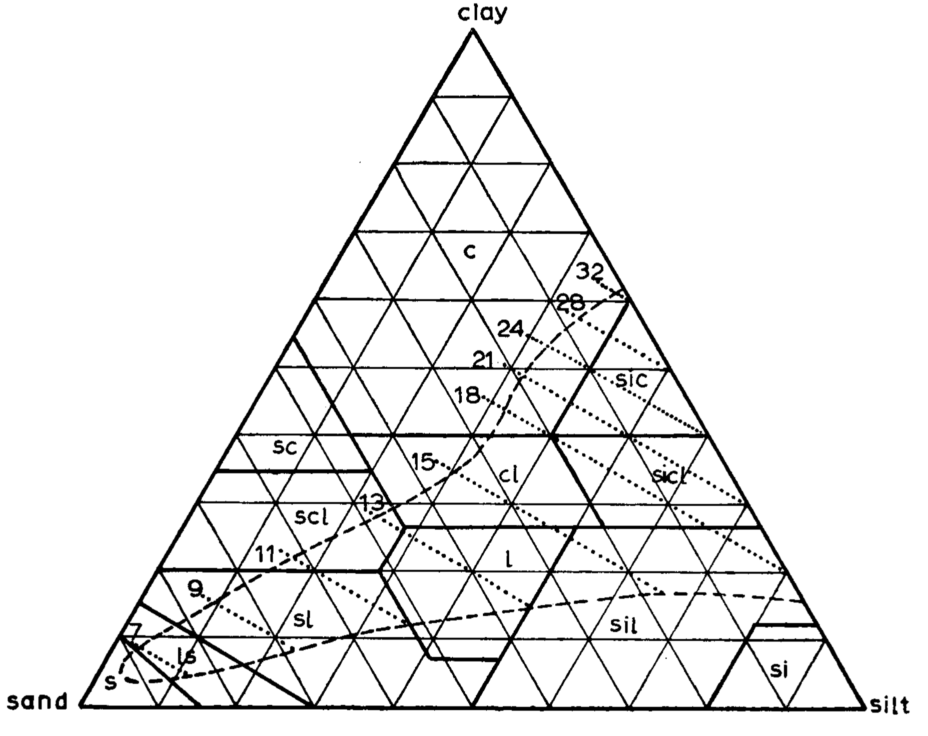
The salinity is expressed as EC_e, the electrical conductivity of the saturation extract. The importance of gypsum for the reclamation of the saline-alkali soils in these areas will be discussed later on.

3.4. Cation-exchange capacity

The remarkable shrinking and swelling, exhibited by Mesopotamian soils and the high saturation percentages found when making saturation pastes (FIG. 2), indicate that clay minerals of the expanding lattice type must be present in relatively large amounts. So far little is known about the clay minerals present in these soils. HARRIS (1958) found that montmorillonite and mica are the main constituents in gilgayed Tigris soils.

Cation-exchange capacities determined for 200 soils from Diwaniya (Euphrates deposits) were found to range from approx. 6 me per 100 g for sandy samples to 35 me per 100 g as a maximum for clay samples. These CEC-values showed a reasonable relation with soil texture. The best correlation was found between CEC and the (clay + ½ silt)-percentage. In FIG. 3 the schematic relation between soil texture and the cation-exchange capacity for the Diwaniya samples is given. Using FIG. 3 a rough estimation of CEC may be obtained for any Euphrates sample of known texture.

FIG. 3. The schematic relation between the cation-exchange capacity in me/100 g soil (CEC) and soil texture (Hilla-Diwaniya)



The degree of correspondence between estimated CEC and CEC determined in the laboratory was found satisfactory enough for calculating exchangeable sodium percentages (ESP) from exchangeable sodium data (ES in me Na per 100 g soil) and estimated CEC. By applying this method, an impression of the degree of alkalinity could be obtained for a great number of samples for which ES was determined but for which the laborious CEC-determination could not be carried out.

3.5. The soil reaction

The soil reaction expressed as pH is measured potentiometrically in saturated soil pastes. The variations in pH are known to depend upon the moisture content at which the reading is made and a number of soil characteristics, such as the com-

position and concentration of salts, the hydrogen-ion concentration, the composition of exchangeable cations, the nature of the clay minerals and the presence of lime, gypsum and organic matter.
The thousands of pH-values determined in the different Mesopotamian soils show variations between 7,2 and 8,5. Somewhat lower or higher values may sometimes be found. These variations fluctuating around an average of 7,8 (FIG. 4) are mainly caused by differences in the adsorbtion of sodium and in the degree of salinity. Some variation is related to textural differences: sandy non-saline soils usually show pH-values which are 0,2—0,3 units higher than fine-textured non-saline soils.

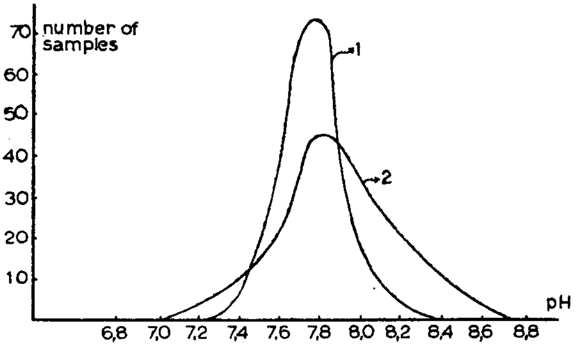


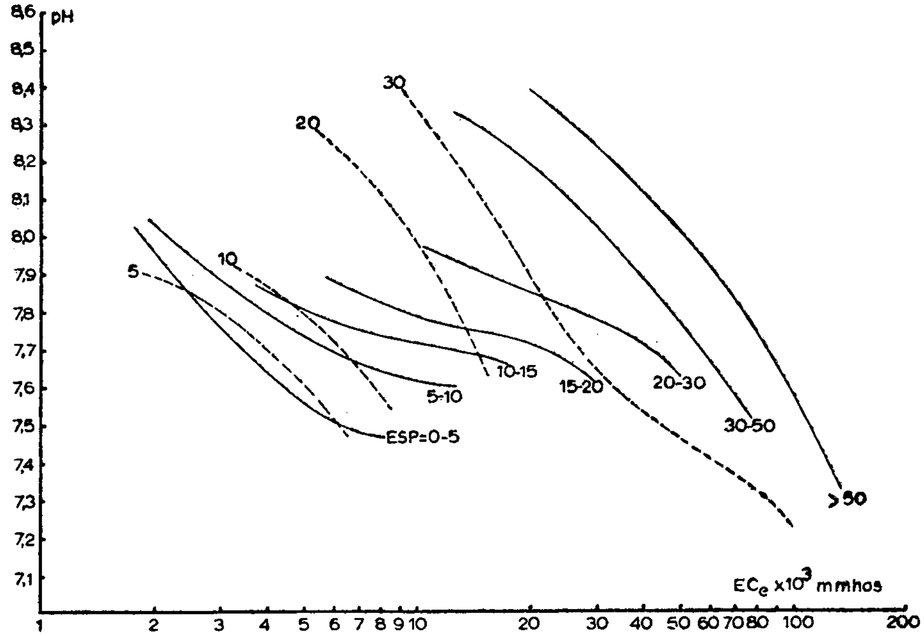
FIG. 4.
pH-distribution for saline (2) and non-saline (1) soils (Middle Tigris Left Bank)

Increasing salinity causes two opposite effects on the pH:

1. The release of hydrogen-ions as a consequence of exchange reactions causes a decrease in pH, an effect that is also known to cause seasonal pH-fluctuations in non-saline areas.
2. In the soils concerned, gypsum due to its low solubility precipitates with increasing electrolyt concentration. A higher salt concentration is therefore attended with an increase in the $\frac{Na}{Ca + Mg}$ -ratio in the soil solution. The exchangeable-sodium percentage (ESP) will therefore increase with salinity. This tends to raise the pH.

For a few hundred soils of different texture from Rumaitha, the combined effects of salinity and alkalinity have been analysed by calculating the influence of salinity changes on the pH at different levels of exchangeable sodium percentage (FIG. 5). The ESP's of these samples have been calculated by using FIG. 3 and the textural and ES-data determined in the laboratory.
Similar curves given by BOUMANS and HULSBOS (1960) for a silty clay-loam and silt-loam soil from Dujaila, agree fairly well with those for Rumaitha. These authors point out that, by using these curves, an impression of ESP could be obtained from simple pH- and EC_e -measurements. Such estimations will be rather rough however.
Extreme pH-values may be interpreted as follows:
High values of approximately 8,5 point to ESP's of at least 30, moderate salt levels of EC_e not exceeding 30—40 mmhos and a $\frac{Na}{Ca + Mg}$ -ratio in the 1 : 1-water extract of at least 3.

FIG. 5. pH as related to EC_e for different levels of ESP (Rumaitha)



------- according to BOUMANS and HULSBOS (1960) for a sicl-sil soil from Dujaila

Low pH-values of approximately 7,0 indicate extremely high salt contents of $EC_e > 80$ mmhos in which Ca- and Mg-salts predominate.
In non-saline soils, as can be seen from FIG. 4, high pH-values that could point to alkalinity do not occur.

3.6. Salinity

During thousands of years salts have been transported into the plain by river-water. The original source of these salts are exposed rocks that release ions as a consequence of processes of chemical weathering. Flood- and irrigation water, although containing only 0,2—0,4 g salt per liter, have added enormous quantities of salt to the Mesopotamian soils. Already in early Babylonian times salinisation has impaired agricultural production. DE GRUYTER (1953) estimated that each year irrigation water adds 3×10^6 tons of salt to the irrigated soils of Iraq. Due to the hot and arid climate and the limited natural drainage, these salts have accumulated in the groundwater which usually contains 3—5 % salt.
Under conditions of a high ground-water level, occurring in depressions or caused by irrigation without simultaneous drainage, salt is transported into the rootzone by capillary water. Ground-water therefore has to be considered as the direct source of salinisation.
Differences in the degree of salinity of the topsoil are strongly related to the topography of the terrain. The general tendency that salinity in the Mesopotamian plain increases in southern direction must be attributed to a decreasing depth of the

ground-water in this direction. The differences in salinity between areas of the Lower Mesopotamian Plain, as presented in TABLE 4, are influenced by the average ground-water level, the topography (levees-basins) and the presence of irrigated agriculture.

TABLE 4. The occurrence of salt[1] in the 0—30 cm topsoil in different areas of the Lower Mesopotamina Plain. Numbers of samples are expressed as percentages per salinity class

Area	Salinity class; EC_e in mmhos/cm at 25° C						
	0—2	2—4	4—8	8—16	16—32	32—64	> 64
Middle Tigris l.b.	27	24	10	12	9	13	5
Yusufiya	9	33	20	19	15	3	1
Rumaitha	1	10	21	16	14	25	13
Shatra	0	13	25	27	22	11	2
East Gharraf	16	16	17	16	16	11	8

[1] The degree of salinity (expressed as EC_e, the electrical conductivity of a saturation extract), has for these areas been calculated from a few thousands of EC_s data (EC_s = the electrical conductivity of a saturation paste), using a conversion method given by DELVER and KADRY (1960). The coëfficient of correlation between EC_e thus calculated and EC_e measured in saturation extracts = 0,996. Soils in which EC_e exceeds 4 mmhos are, according to international standards, considered as saline.

Since river-water contains different ions (TABLE 5), ground-water also contains different salts. Due to differences in solubilities, the capillary rise and internal evaporation of ground-water gives rise to an intricate process of vertical sorting out of these salts. This results in morphological and chemical differences in salinisation. The

TABLE 5. Water analyses of the Tigris at Baghdad in 1949 (KNAPPEN, TIPPETS, ABBETT and MCCARTY, 1952)

Ions in me/l	Jan.	June	Dec.
Ca	3,25	1,95	3,25
Mg	2,05	0,66	1,72
Na	0,96	0,52	1,52
HCO_3	3,33	2,26	2,90
Cl	0,93	0,31	1,30
SO_4	1,79	0,54	2,29
NO_3	0,04	0,02	0,06
Total conc. me/l	13,04	6,26	13,40
Total salts ppm	334	165	368

depth of salt accumulation is related to the ground-water level. Sabakh soils e.g. may be formed under certain conditions of soil texture and ground-water level (BURINGH, 1960). These soils, also reported to occur in Spain (AYERS *et al.*, 1960), appear as dark-brown oily spots and mainly contain deliquescent $CaCl_2$ and $MgCl_2$.

$Na_2SO_4 . 10H_2O$ sometimes precipitates as a fluffy salt crust, possibly under influence of high soil temperatures during accumulation. Such a crust may show the following characteristics:

Salt %	$EC_{1:1}$ mmhos	Gypsum %	cat- and anions in me/l in 1 : 1-water extract						
			Ca	Mg	Na	Cl	SO_4	HCO_3	NO_3
19,4	210	4,8	52	700	1950	696	2100	9	0

Due to the big variations in salt composition, a simple relation between the EC of a soil extract and its salt content does not exist.
For most soils, however, an average conversion factor 0,080 for 1 : 1-water extracts could be used. This means that a soil with $EC_{1:1}$ = 10 mmhos will in average contain 0,8 % salt. This factor is in good accordance with the factor given by SCHILSTRA (1960) for Latifiyah soils (f = 0,08) and by HULSBOS (1959) for soils from Dujailah.
As was mentioned before an increase in the salt concentration of soil moisture is attended with the precipitation of gypsum. A rather strong correlation therefore exists between the degree of salinity and the $\frac{Na}{Ca + Mg}$-ratio in 1 : 1-soil extracts, especially for subsoil samples (FIG. 6).

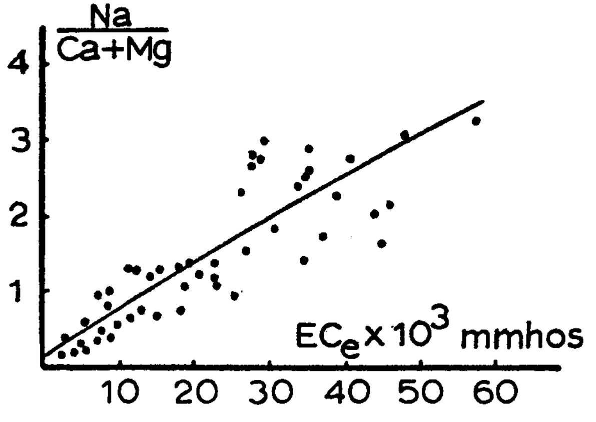


FIG. 6.
The relation between EC_e and the ratio $\frac{Na}{Ca + Mg}$ in me/l in the 1 : 1-extract for samples below 60 cm depth (Rumaitha)

With the degree of salinity the Na-adsorbtion on the clay-complex therefore increases.

3.7. The alkali problem

As a consequence of high Na-concentrations and $\frac{Na}{Ca + Mg}$-ratios in the soil moisture, many soils show high exchangeable-sodium percentages (ESP). TABLE 6 gives an impression about the level of ESP in different areas.

TABLE 6. Occurrence of exchangeable-sodium percentages (ESP) in 0—30 cm topsoil. Figures per area present percentages of the total number of samples. In alkali soils ESP exceeds 15

Area	ESP-classes						
	0—5	5—10	10—15	15—20	20—30	30—50	> 50
Middle Tigris l.b.	56	13	8	4	5	10	4
Yusufiya	58	20	9	6	4	3	0
Rumaitha	11	17	11	9	13	24	15
Shatra	25	23	19	14	12	6	1
East Gharraf	38	20	13	7	9	9	4

These data were calculated from a great number of ES-analyses and CEC-estimations. Strictly speaking CEC-estimations for the Tigris deposits in the first area could not be made since our data about the relation between CEC and texture (FIG. 3) refer to Euphrates deposits. There is no evidence, however, that a significant difference exists between Euphrates and Tigris soils as to the cation-exchange capacity. TABLE 6 shows that in many soils ESP exceeds 15 and that many soils therefore have to be classified as saline-alkali.

Since the adsorbtion of cations on the clay-complex is largely determined by the composition and concentration of ions in the soil moisture, various scientists have proposed cation-exchange equations for expressing the relationship between soluble and exchangeable cations. A method has been given by the U.S. SALINITY LABORATORY (1954) for estimating ESP from the sodium-adsorbtion ratio. This ratio is defined as

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\tfrac{1}{2}\,(\mathrm{Ca} + \mathrm{Mg})}}$$

wherein Na, Ca and Mg refer to the concentration of soluble cations in saturation-extracts in me/l. A linear equation empirically determined gives the relation between SAR and the exchangeable-sorium ratio:

$$y = -0{,}0126 + 0{,}01475\ \mathrm{SAR}$$

in which y = exchangeable-sodium ratio $= \dfrac{\mathrm{ES}}{\mathrm{CEC} - \mathrm{ES}}$

ES = exchangeable Na in me/100 g of soil.

ESP can then be calculated from

$$\mathrm{ESP} = \frac{100\ y}{1 + y}$$

The advantage of estimations of ESP from this equation is that the laborious determinations of CEC and exchangeable Na can be omitted since the analysis of a saturation-extract suffices for the calculation of SAR.

From Mesopotamian soils only analyses of 1 : 1-extracts were available. Although the above given method gives the best estimation of ESP if SAR is determined in the narrowest soil : water ratio extractable, i.e. in a saturation-extract, a similar relation between y and SAR could be drawn up for 1 : 1-extracts. The difference in ion ratios and -concentrations between saturation- and 1 : 1-extracts is for many soils relatively small as a consequence of the high saturation percentages in Mesopotamian soils.

If SAR is calculated from analyses in 1 : 1-extracts, the following equation

$$y = -\ 0{,}032 + 0{,}0232\ \mathrm{SAR}$$

gives a reasonable good correlation between SAR and the exchangeable-sodium ratio, and ESP can then be estimated as indicated above.

The high exchangeable-sodium percentages often found in the saline soils of the Lower Mesopotamian Plain, have given rise to the question whether *alkali* soils perceptible in deteriorating structures and decreasing permeabilities, will be formed during leaching. In leaching experiments on a saline-alkali soil in Dujailah, BOUMANS and HULSBOS (1960) have observed that due to the presence of gypsum, Na on the clay-complex is readily exchanged by Ca and that the infiltration rate during leaching remains practically constant. These authors therefore state that in the reclamation of saline-alkali soils in Iraq no difficulties by the formation of sodium-clay structures will be met with. Since these results depend on the presence of gypsum, the question could be put whether this statement has a general validity for all soils in the Mesopotamian Plain.

From experiments with gypsum amendments it is known that per milliequivalent Na per 100 g of soil to be replaced by Ca 1,7 tons of gypsum per acrefoot of soil would be required if the efficiency in the replacement of Na is 100 % (U.S. SALINITY LABORATORY, 1954). For five areas we calculated the average ESP per salinity class in the topsoil, and from these data we calculated the me exchangeable Na per 100 g of soil to be removed if ESP has to be reduced to 10 (TABLE 7).

TABLE 7. Milliequivalents exchangeable Na per 100 gram of soil, to be replaced per salinity class, if ESP has to be reduced to 10

Area	Salinity class; EC_e in mmhos/cm at 25° C					
	0—4	4—8	8—16	16—32	32—64	> 64
Middle Tigris l.b.	0	0	0,35	2,45	4,90	7,53
Yusufiya	0	0	0,18	1,78	3,03	no data
Rumaitha	0	0	0,90	3,42	6,12	9,18
Shatra	0	0	0,18	1,80	3,60	5,94
East Gharraf	0	0	0,38	2,47	4,18	6,46

From TABLE 7 and the formula

$$\text{GR (gypsum-requirement)} = 1,7 \text{ NaX}$$

in which NaX represents the number of milliequivalents exchangeable Na to be replaced per 100 g of soil, the percentage gypsum required for an adequate replacement of Na during the leaching process was calculated for the 0—30 cm topsoil. In these calculations a 10—50 % loss in efficiency of the replacement of Na by Ca for high, respectively low ESP's was taken into account.

TABLE 8 represents the required gypsum percentage per salinity class. This table, compared with the actual situation as given in TABLE 3, shows that the topsoil in all areas and at any degree of salinity in average contains 2—3 times as much gypsum as, according to the above calculations, is required for an adequate replacement of sodium. This margin seems sufficiently large to justify the conclusion that in general no alkalinity problem exists in the areas considered. Indeed, amongst the many thousands or samples no examples of non-saline alkali soils were found.

TABLE 8. Average gypsum percentage in 0—30 cm topsoil, required per salinity class if by leaching ESP has to decrease to 10

Area	Salinity class; EC_e in mmhos/cm at 25° C					
	0—4	4—8	8—16	16—32	32—64	> 64
Middle Tigris l.b.	0	0	0,07	0,29	0,58	0,78
Yusufiya	0	0	0,04	0,21	0,36	no data
Rumaitha	0	0	0,17	0,40	0,72	0,95
Shatra	0	0	0,04	0,21	0,43	0,61
East Gharraf	0	0	0,07	0,29	0,49	0,67

Some remarks have to be made however, since the above calculations are based on certain assumptions as to the efficiency in the replacement of Na by gypsum. In soils containing montmorillonite and mica, exchange reactions are preceded by the penetration of ions between the sheets of the clay mineral. Such exchange reactions require more time than if the replacement of sodium by Ca occurs only on the external surfaces of particles such as kaolinite. The favourable effect of gypsum in replacing sodium may then be somewhat retarded and the exchange reaction is completed more slowly than the leaching of salt. This results in a temporary decline in the permeability in the initial stage of leaching. That this may be the case in Mesopotamian soils is demonstrated by FIG. 7 in which the relation between the hydraulic conductivity and the degree of salinity, calculated for a few hundred samples from Rumaitha, is given.
The permeabilities were measured after 20 hours of percolation, at a moment when in strongly saline samples salt is not yet adequately leached out and still may have

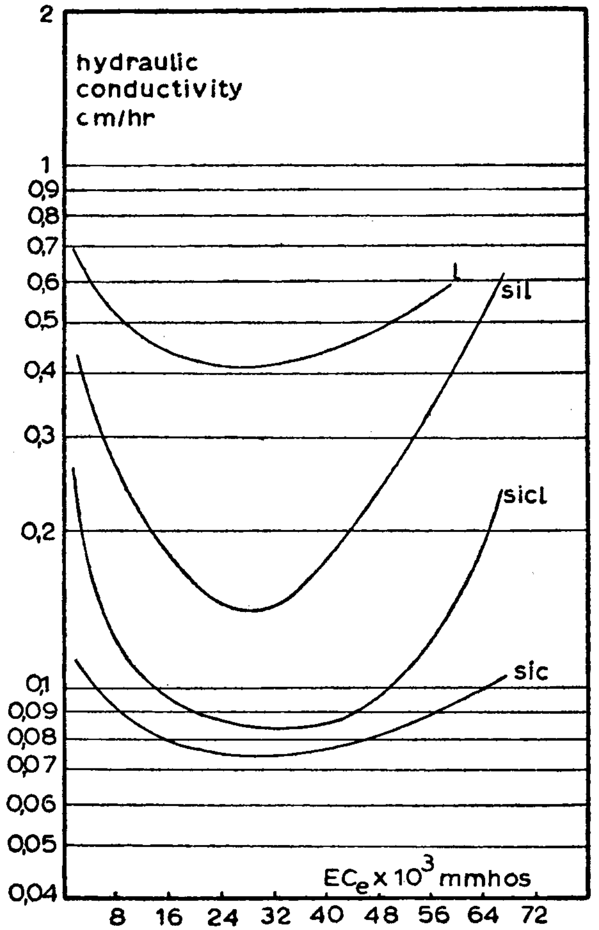
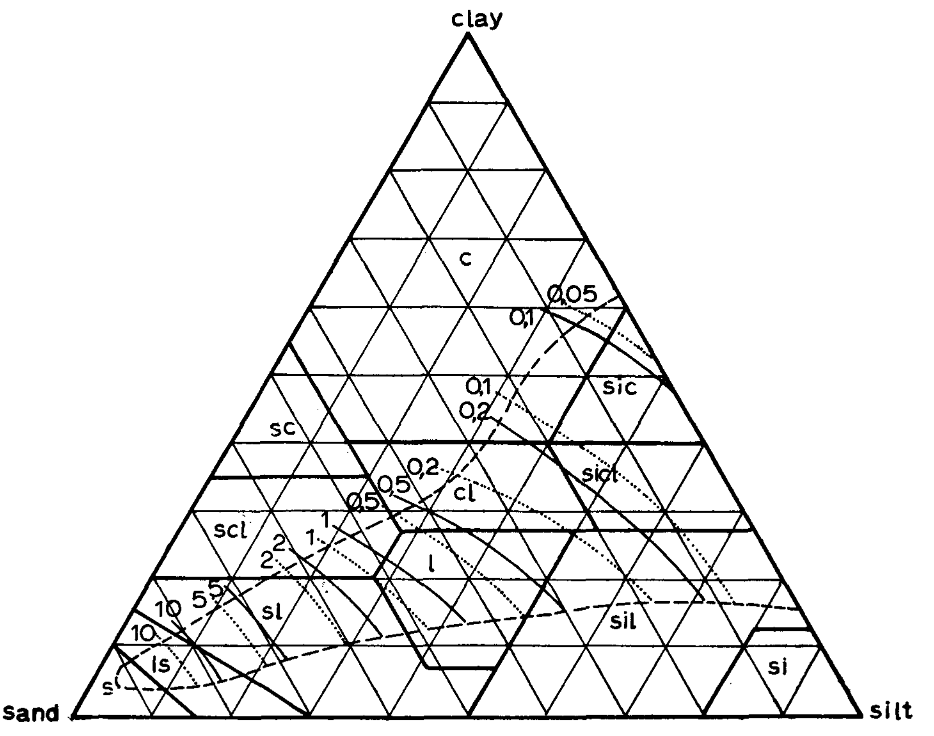


FIG. 7.
The relation between hydraulic conductivity determined after 20 hours percolation and EC_e (Rumaitha)

a flocculating effect. From these curves the conclusion seems justified that during leaching some decrease in permeability takes place at a certain stage of desalinisation, but this permeability will be restored in a later stage of leaching.
A difference in hydraulic conductivity after 20 hours percolation is also found when samples with ESP < 15 are compared with samples of which ESP exceeds 15. For these two groups the relation between hydraulic conductivity and texture is given in FIG. 8.
It is evident that in the early stages of leaching, alkali samples will show somewhat lower permeabilities than samples with low ESP-values. During leaching, the flocculating effect of a high electrolyt concentration is apparently replaced by a temporary dispersing effect of high exchangeable Na.
The slight decrease in infiltration rate in the initial stages of leaching experiments, in some cases observed by BOUMANS and HULSBOS (1960), has possibly to be attributed to the above mentioned process. That a lasting, serious deterioration of the structure was not observed however, is in accordance with the process suggested by FIG. 7.

FIG. 8. Lines of equal hydraulic conductivities in cm/hr determined after 20 hours percolation (Rumaitha)



.... for samples with ESP > 15
——— for samples with ESP < 15

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