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Surface irrigation with saline water on a heavy clay soil in the Medjerda Valley, Tunisia

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Summary

At an early moment it was clear that the soil texture and the salinity of the irrigation water used in the Medjerda Valley would lead to a salinization problem. The Tunisian Government therefore decided to set up an experiment in the valley, where the relationships of climatological factors, irrigation with saline water, drainage, salinity of the soil, crop growth and crop rotation could be studied.
The present article gives, after mentioning some features of the Merjerda Project, the results of and the conclusions to be drawn from the experiments on salinity during the years 1962 through 1964.

The Medjerda Project

General
The Medjerda River flows from west to east in the northern part of Tunisia (Fig. 1). It rises in Algeria and runs into the Gulf of Tunis in the Mediterranean. The river is fed by many tributaries, of which Oued Mellegue, Oued Tessa, Oued Silliana and Oued Kesseb are the most important. In the upstream part the meandering river has cut a deep valley through the hills and mountains. At a distance of about 40 km westwards of the town of Tunis it enters a wide plain, which was in ancient times a part of the Gulf of Tunis. In the course of centuries the river carried so much sediment that a part of the gulf has been filled up to the present western boundary of the gulf.
A part of these low lands of fine-textured soils is topografically sufficiently high that the cultivation of some agricultural crops is possible. Other parts are too low and can be characterized as marshy areas with a high water table, especially in winter. From time to time the Medjerda River, being an intermittent stream, discharges large quantities of water, partly due to the rapid run-off of rain from the surrounding barren mountain slopes. In the valley, this meandering river on flat gradient frequently overflows its banks and floods extensive areas.
For the Tunisian government the reclamation of this vast lowland plain of 220,000 ha (1 ha = 2.47 acres) is of great importance because the present area under cultivation is not rich in good soils and newly reclaimed new lands may help to increase the food production for a rapid growing population (see also Westerhof, 1962).

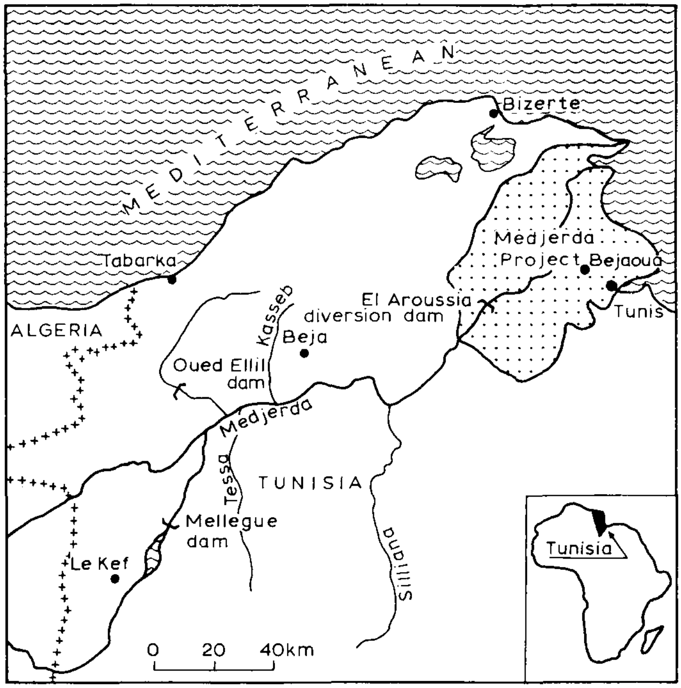

Fig. 1 Situation map of the Medjerda Project.

The Office de la Mise en Valeur de la Basse Vallée de la Medjerda (O.M.V.V.M.) in Tunis was charged with the execution of this immense task. In order to carry it out the O.M.V.V.M. invited a number of experts.

In this connection the Institute for Land and Water Management Research at Wageningen, The Netherlands, contributed by sending experts on soil salinity and drainage (see van Hoorn, 1963; van 't Leven, 1964). In this paper the investigation procedure is described and some of the results and conclusions are discussed with the exception of the work done on evapotranspiration that will be published at a later date.

Soil characteristics

As was mentioned, the soils in the plain have been deposited by the Medjerda River. In general they can be characterized as heavy clay soils (more than 35% $< 2\,\mu$). They have a high lime content (35%). The groundwater at shallow depth is saline. Before the execution of the project the groundwater table after a rainy period in winter time was at the soil surface or just below, even in the cultivated areas.

The permeability of the greater part of these soils is relatively low (0.1–0.5 m/day) if the soil is in wet condition, as in the months of February and March, during and soon after the rainy season. At this time the infiltration rate is also relatively low, in part as a consequence of the rain deteriorating the structure of the upper soil layer. During the growing season, on the contrary, with high evapotranspiration rates the soil shrinks and cracks (fissures up to 5 cm wide), increasing permeability considerably.

Table 1 Monthly precipitation at Bejaoua during 1962 and 1963, mean precipitation at Tunis-Manoubia (1901–1959) and the evapotranspiration

	Precipitation (mm)			*Potential evapotranspiration alfalfa*		*E_0 acc. Penman*
	1962	*1963*	*1901–1959*	*1962*	*1963*	*1901–1959*
Jan.	49.9	59.9	66	—	53	44
Febr.	71.4	81.6	50	—	31	62
March	48.0	43.2	42	102	112	101
April	48.2	48.4	39	105	123	132
May	11.3	18.3	22	229	214	180
June	10.3	48.9	10	288	231	222
July	0.0	20.0	2	366	310	248
August	0.0	4.2	7	248	310	220
Sept.	30.1	66.9	34	165	195	156
Oct.	122.1	39.3	56	136	127	102
Nov.	23.5	10.2	56	54	162	63
Dec.	21.4	84.2	63	53	68	44
Total	436.2	519.1	447		1936	1574

Climate

In Table 1 the precipitation during 1962 and 1963 is given for the meteorological station of Bejaoua. To compare these data with the mean precipitation for that region, the mean values for a 58 years period from 1901–1959 are indicated for the Tunis–Manoubia station of the National Meteorological Service (van Hoorn, 1961). In the last columns the potential evapotranspiration (PET) of the alfalfa is given and the E_0 according to the formula of Penman.

The precipitation in 1962 is less than the mean for the 58 years period but that of 1963 is considerably more. The months of June, July and August are very dry.

December and January are generally the months with the highest precipitation. Only the precipitation in January and February has a leaching effect, because the larger part of rainwater in December is still needed for moistening the soil profile. During 8–9 months of the year the subsequent crops need irrigation.

A number of times very high intensities of rainfall have been measured, as for example in November 1962. One shower had an intensity of 37 mm in 34 minutes. The greater part of the water of these heavy showers runs off immediately into the drainage canals and does not infiltrate into the soil. From the point of view of soil moistening or desalinization this water is lost.

The minimum temperature in the months of January, February and March is low. Particularly in February and the beginning of March night frost occurs, which sometimes causes severe damage to the crops. In summer during the so-called 'Sirocco' the temperature rises up to 45 °C.

The dams

To date reservoir dams have been built in the Oued Ellil and Oued Mellegue and a diversion dam in the Oued Medjerda. The Oued Ellil is a small stream having its source in the cork-oak forests of the mountains in North Tunisia. The quality of the water in the reservoir near the village of Ben Metir was sufficiently good (200 mg total salt per litre) to use it as drinking water for the town of Tunis and its environ-

ments. The catchment basin, covering an area of 108 km², has a mean annual rainfall of 1200 mm. Any surplus is used for irrigation purposes.
The Oued Mellegue is the main tributary of the river Medjerda. The catchment basin covering an area of 10,000 km² has a mean annual rainfall of 400 mm. The capacity of the storage reservoir, near the village of Nebeur, is considerably higher than of the one mentioned above. However, the quality of the water is notably lower, the salt content is more than 2000 p.p.m.
This water is used for irrigation of the lowlands of the Medjerda.
The Oued Medjerda has a diversion dam near El Aroussia for the irrigation distribution system. The dam is built 10 km upstream from Tebourba, where the river enters the plain. The minimum discharge of the river is 15 m³/sec, of which 1 m³/sec passes the dam to supply irrigation water to the fields adjacent to the river.
It is estimated that in total 250×10^6 m³ per year is available for irrigation purposes. Besides this quantity, 650×10^6 m³ per year are still flowing into the sea.

The irrigation and drainage system
Water is distributed from the main irrigation canal to laterals and flows by gravity, or is pumped, to the irrigated parcels. The irrigation system is of the French Neyrpic type.
From the concrete irrigation flumes the water flows in 'seguias' or earthen canals. Via the seguias the water is fed into basins.
A relatively deep and narrow spaced drainage system was required because of the heavy clay soils, brackish irrigation water supply, saline groundwater and a high water table.
The average drain depth was fixed at at least 150 cm. This depth still allows discharge by gravity. Experiences elsewhere (e.g. Talsma, 1963) have indicated that this depth will reduce capillary rise in the rootzone sufficiently. The salt content of the soil will therefore be influenced favourably.
The permeability of the soil of the whole area to be irrigated was calculated with the augerhole method of Hooghoudt (van Beers, 1958). In a number of cases it was impossible to determine it because the groundwater table was too deep.
In general a drain radius of 10 cm and a drain spacing of 40 to 60 m was recommended. The latter was calculated with Hooghoudt's formula (Hooghoudt, 1934):

$$s = \frac{8k_o d m_o + 4k_b m_o^2}{L^2}$$

where:
s = discharge per 24 h, expressed as a surface layer of water in metres,
k_o = hydraulic conductivity in m/24 h of the soil below the level of the drains,
k_b = the same of the soil above the level of the drains (in our case k_o equalled k_b),
m_o = hydraulic head midway between the drains, in metres,
d = depth of equivalent layer in metres, a function of the radius of the drains r_o, of the distance H that the impermeable layer lies below the drains, and of the drain spacing,
L = drain spacing in metres.
The tile lines discharge into open drains. The saline drain water flows to the river and then to the sea. Often along the banks of the Medjerda river farmers have to use this more saline mixture of river- and drainage water.

The salinity of the water in the Medjerda River at the dam of El Aroussia

To determine the degree of salinity, water samples are taken at several places in the river and in the irrigation canals. Near the dam of El Aroussia, where the irrigation water is diverted, samples are taken every day.

Fig. 2 shows the daily fluctuations in the electric conductivity (EC) for the period 1960 to and including 1963 in mmho's at 25 °C. The monthly means of 1962 and 1963 are given in Table 2, converted from EC to grams per litre.

It should be noted that the EC of the irrigation water when it arrives at the farm is somewhat higher than at the dam due to evaporation during the transport.

During the greater part of the year the irrigation water can be used only if such precautionary measures as drainage, leaching and a good choice of medium salt tolerant crops are taken.

Table 3 shows some chemical analyses of the irrigation water from the series of

Table 2 Salt content of the water from the Medjerda River at El Aroussia before it enters the irrigation area; monthly mean in grams per litre

	1962	*1963*
January	2.434	1.442
February	0.847	0.828
March	1.391	1.351
April	1.627	1.427
May	2.105	1.736
June	2.735	2.121
July	3.098	2.781
August	2.804	2.336
September	2.716	1.815
October	1.958	2.191
November	1.570	2.574
December	1.699	1.762

Table 3 Chemical analyses of the irrigation water from the Medjerda at El Aroussia

Date	*Components in mg/l*						*EC at 25 °C (× 10³)*	*Calcul. salt content in mg/l (K = 0.66)*	*SAR*
	Cl	*SO_4*	*CO_3*	*Ca*	*Mg*	*Na*			
13-8-61	944	898	63	224	92	660	4.55	3160	9.3
26-8-61	1194	1046	66	256	107	780	5.30	3640	10.3
12-4-62	675	461	96	152	73	400	3.00	2000	6.6
24-4-62	320	288	78	76	46	200	1.70	1060	4.1
18-4-63	568	396	102	152	68	360	2.75	1820	6.0
23-4-63	142	148	102	72	24	80	0.90	590	2.0
7-8-63	568	643	84	152	68	420	2.95	1950	7.0
31-8-63	994	956	84	200	107	700	4.70	4100	10.0

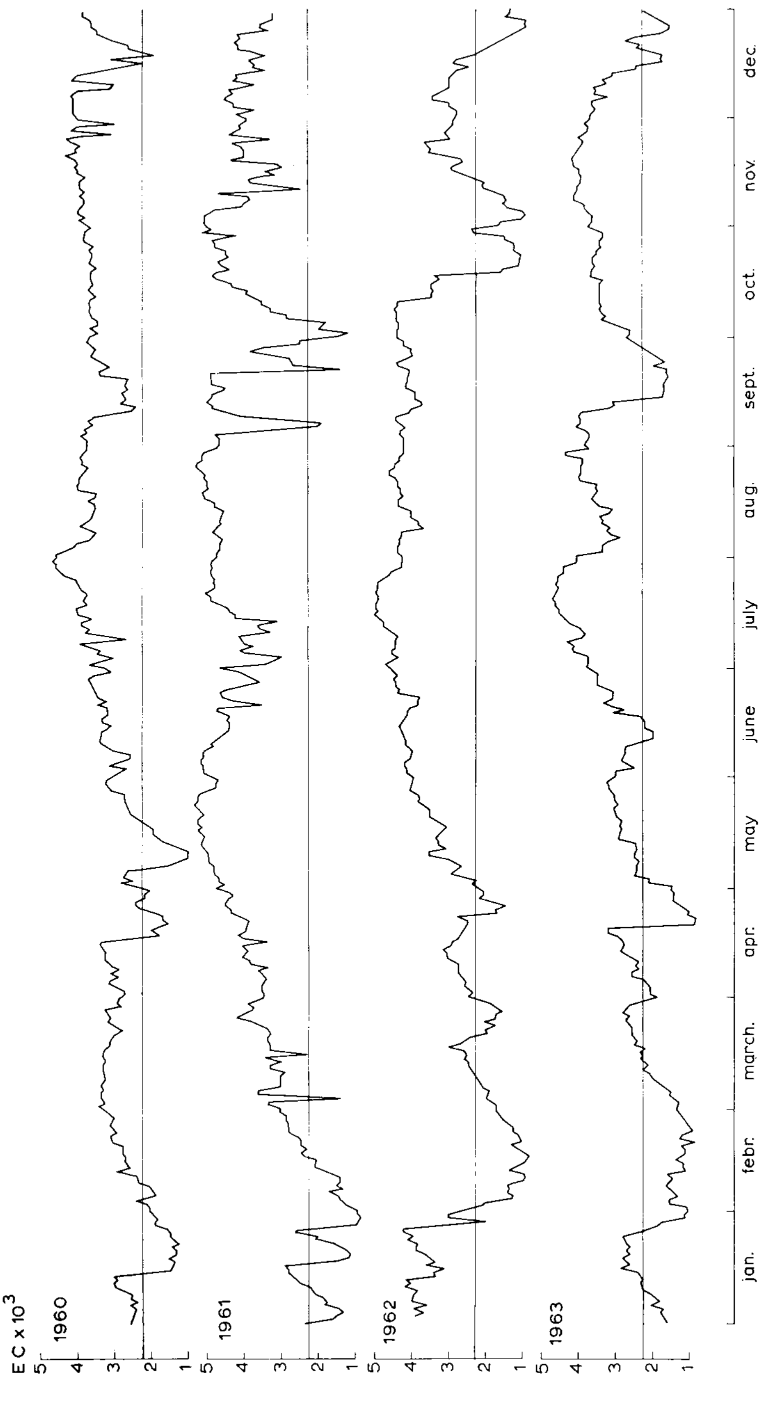

Fig. 2 Daily fluctuations of the electric conductivity of the water of the Medjerda River at the dam of El Aroussia.

points to a poor quality of the irrigation water, except at a low salt content.

$$SAR = \frac{Na^+}{\sqrt{0.5\ (Ca^{++} + Mg^{++})}} \quad \text{(in meq.)}$$

points to a poor quality of the irrigation water, except at a low salt content. Generally, the river water has a low salt content during and shortly after the rainy period in February, which holds for the whole catchment area of the river. During these rainy periods the rain water leaches salts from the top soil layer, leaving that layer with such poor structure that leaching of the entire profile is hindered.

The experiment field

General

The O.M.V.V.M. selected an experiment field where the relationships between crops, irrigation, drainage, salinity and climate could be studied (Hamdaoui et al., 1961). The experiment field is located at Bejaoua, at 17 km West of Tunis.

The experiment field covers an area of 14 ha (Fig. 3). It is divided into 4 sections (A, B, C and D), each half section drained at a distance of 30 m (A30) and the other half at 60 m (A60). On every section a specific crop rotation is practiced, in which summer- and winter fallow and non-irrigated crops play an important role.

The drain distances were chosen to be able to check the reaction of the groundwater table at distances larger and smaller respectively than the distances calculated by the formula of Hooghoudt. According to this formula a distance of 40 m was calculated, assuming that $k = 0.35$ m/day, $d = 2.65$ m ($r_o = 0.10$ m), $m_o = 0.5$ m, $s = 0.0025$ m/day and an impervious layer at a depth of 6 m.

The irrigation water was conveyed from the pumping station at Bejaoua by a concrete flume to the end of the field. From the concrete flume the water flowed through the seguias to the basins of 30×27.5 m.

A meteorological station was built, where the evaporation was measured in open pans (among these was a Class A pan) and the potential evapotranspiration was measured by lysimeters. The meteorological station is equipped with a registrating raingauge, thermograph, hygrograph, psychrometer, and a Campbell-Stokes sunshine duration recorder. From the different meteorological data the evapotranspiration was calculated according to the formulas of Penman and Blaney-Criddle.

Research programme

The research programme of the experiment field can be summarized as follows:

a) The study of the reaction of the salinity of the soil on crop, irrigation, drainage and climate. Nearly every month soil samples were taken at depths of 0–20, 20–40, 40–80, 80–120 and 120–160 cm in every drain section. The electric conductivity of the soil extract (EC_e) was measured in the laboratory, according to the method described in Agricultural Handbook nr. 60 (Richards, 1954).

b) The determination of the salt balance:

$$S_I \pm \triangle S_P - S_D = 0 \quad \text{(in kg/ha)}$$

where:

S_I = the quantity of salt added to the soil by irrigation,

S_D = the quantity of salt evacuated by the tile drains, and

$\triangle S_P$ = the difference in salt content at the beginning and the end of the period.

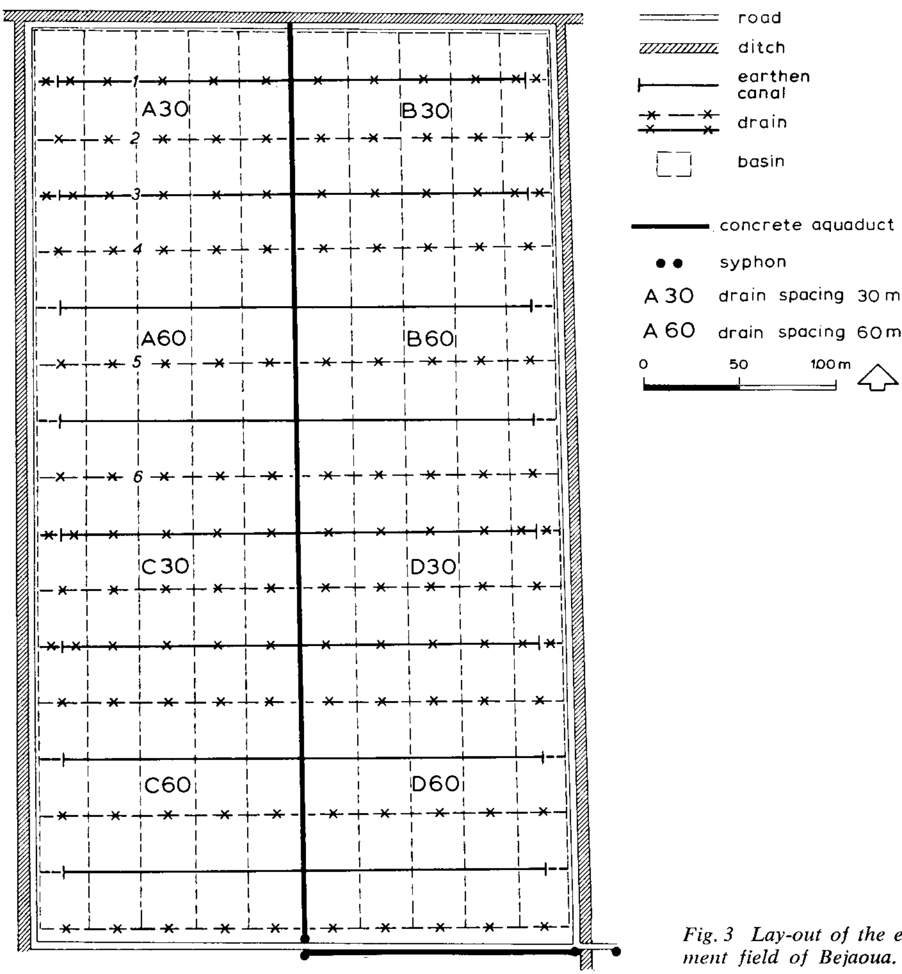

Fig. 3 Lay-out of the experiment field of Bejaoua.

All factors of the salt balance were measured with approximately equal accuracy. An eventual difference in the balance can be attributed amongst other things to the discharge of water to the drainage canals through the subsoil outside the tile drains. The salt content of the irrigation- and drainwater was calculated from EC using the coefficient K = 0.66.

The real evapotranspiration (RET) to be calculated from the water balance:

$$RET = P + I - D \pm \Delta C \quad \text{(in surface millimetres per time unit)}$$

where :

P = precipitation measured at the meteorological station of Bejaoua,

I = the amount of irrigation water given via the model X-30; the constant supply level is checked a couple of times a day,

D = the mean depth of drainage discharge calculated from three measurements a day; for some periods readings were taken every 3 hours,

$\triangle C$ = the change in storage of moisture in the profile; soil samples were collected monthly from the following depths 0–10, 10–20, 20–30, 30–40, 40–60, 60–80, 80–100, 100–120, 120–140 and 140–160 cm below the surface.

A drawback of the water balance is, that all errors accumulate in the evapotranspiration, for example if the quantity of seepage water is not exactly known.

a) The fluctuations of the water table to be measured in a large number of piezometers, installed in a line perpendicular to the tile drains to a depth of 2.5 m. The water levels were measured once a week, and after an irrigation, or after a rainy period daily.

b) The potential evapotranspiration (PET) to be measured in the lysimeters and calculated according to the equation PET = P + I — D (in surface millimeters).

The quantity of soil moisture was brought to field capacity as much as possible by nearly daily replacing the evaporated water.

c) To compare the RET and the PET with the open pan evaporation as well as with the E_0 of Penman as the E of Blaney-Criddle.

The following sections will deal with the salt balance factors, with soil salinity and with the fluctuations of the water table. Further particulars on the water balance will be published elsewhere.

Salinity regime

Irrigation

The irrigation practice of the experiment field was based on the following principles.

1) To avoid high seepage losses of water in the earthen canals, and improve uniformity of application, a delivery as quick as possible was made, namely 30 l/sec. In some cases, for example in irrigating artichokes and tomatoes, a lower flow was used. Later on it appeared necessary to spread the water over several basins at one time in order to prevent soil erosion.

2) To determine as exact as possible the time of irrigation. For this purpose samples were taken of the upper 20 cm of the soil with a short auger and the moisture content was estimated.

3) To stop delivery at the moment the water arrives at the end of a basin.

The quantity of water consumed per irrigation period depended on the available moisture in the soil, the time of the year, and the development of the crop.

Table 4 gives the minimum and maximum quantities of irrigation water given per irrigation during the two years of the experiment. The minima are in several cases due to a sudden change in weather conditions, in consequence of which the irrigation was stopped. The maximum was approximately 200 mm, very well comparable with the water holding capacity of the soil between pF 2.0 and pF 4.2 (see Table 9). Such maximum applications are often supplied after a period of rest of the crop (artichokes in July) or after a fallow period (section A 1963–1964).

During the vegetative period, the intake of water into these heavy clay soils diminishes due to deterioration of the structure. This problem occurs especially with such crops as alfalfa, which remain in the field more than one year. It is in this case necessary to provide a shallow tillage as soon as the soil is sufficiently dry to be walked on.

Table 4 The quantity of water applied per irrigation (mm)

	Artichoke 1961–1963 section A, B, D	*Alfalfa 1961–1963 section C*	*Tomato 1963 section B*	*Corn 1963 section D*	*Broad beans 1963–1964 section A*
January	50–70				
February	35–80				
March	55	110			
April	60–160				
May		120–240			
	rest period				
June		100–200	110	55–125	
July	100–195	130–195	130–190	65–90	
August	65–85	95–160	110–135	75–115	
September	50–100	90		45	
October	40–55	90–105			
November		105			fallow
December					200

Table 5 Total depth of irrigation water applied in the growing season (mm)

	Section A		*Section B*		*Section C*		*Section D*	
	A 30	*A 60*	*B 30*	*B 60*	*C 30*	*C 60*	*D 30*	*D 60*
Alfalfa								
1962					1186	1235		
1963					1172			
Artichoke								
1961–1962	211	208	122	40			195	204
1962–1963	530	493					572	569
Tomato								
1963			(1046)	(1031)				
Corn								
1963							493	482
Broad beans								
1963–1964	206	199						

In Table 5 the total depths of water applied per crop and per growing season are summarized. The alfalfa had been irrigated both years with about 12,000 m^3 per ha. The artichokes were given in the first year 2,000 m^3/ha, and the second year, when they are fully developed some 5,500 m^3/ha. This difference was chiefly caused by a more favourable distribution of the rainfall in the winter of the first year, but also because of the differences in the vegetation stage. The corn received 5,000 m^3/ha. The broad beans received a pre-irrigation, as a consequence of lack of rain. The tomatoes were irrigated according to the available data with 10,000 m^3/ha. This is very high, probably there was a loss of water from the irrigation flume directly to the drainage system.

In irrigating, a certain amount of salt is added to the soil, depending on the salt content of the irrigation water and the depth applied.

Table 6 Total quantity of salt (S_I in kg/ha) added to the soil by irrigation

	A 30	*A 60*	*B 30*	*B 60*	*C 30*	*C 60*	*D 30*	*D 60*
1962	15,905	15,669	1,534	935	34,814	31,924	18,791	18,338
1963	7,812	5,840	11,345	10,167	26,822	27,842	11,663	11,850
Total	23,717	21,509	12,879	11,102	61,636	59,766	30,454	30,188

Table 7 Increase in EC_e (mmho's/cm) under irrigation if there is no leaching

Section	*Depth of soil layer*					
	120 cm			*160 cm*		
	1962	*1963*	*total*	*1962*	*1963*	*total*
A 30	2.65	1.30	3.95	2.00	0.95	2.95
A 60	2.60	0.95	3.55	1.95	0.70	2.65
B 30	0.25	1.90	2.15	0.20	1.40	1.60
B 60	0.15	1.75	1.90	0.12	1.30	1.42
C 30	5.80	4.50	10.30	4.30	3.30	7.60
C 60	5.30	4.60	9.90	3.95	3.50	7.45
D 30	3.10	1.95	5.05	2.30	1.45	3.75
D 60	3.05	1.95	5.00	2.25	1.45	3.70

Table 6 summarizes these quantities for the years 1962 and 1963. The total salt amount added by irrigation of the alfalfa rises to more than 60 ton/ha, in contrast to section B, which rises to 12 ton/ha.

There is no doubt that these quantities will influence the salt content of the soil. To make clear that the danger of salinization is high when irrigation is practiced with saline water without an adequate and well-cleaned drainage system, the influence of salt added on the EC_e is given in Table 7. It is presumed that no salt migrated from the upper layer of the soil into the subsoil. The conversion of the amount of salt into a mean EC_e per soil layer is done by the formula :

$$EC_e = \frac{S_I}{64 \times d \times d_b \times P_w}$$

where :

S_I = kg/ha of salt added to a certain soil layer on dry weight base (Table 8),
d = depth of soil layer in metres,
d_b = bulk density = volume weight in kg/l (1.43),
P_w = percentage of water in the soil on dry weight base (55 % for Bejaoua), and
EC_e = mean electric conductivity in the entire soil layer (mmho's/cm at 25 °C).

It appears that the irrigation of alfalfa leads very quickly to salinization of the soil, whereas irrigation as applied to section B is considerably less dangerous.

It is interesting to plot the results on the scale given in the Agricultural Handbook nr. 60 (Richards, 1954) and to see what the consequences of the irrigation during the past two years would be if there had been no leaching (Table 8).

Table 8 Increase in EC_e-values due to irrigation during two years without leaching

	I	*II*	*III*	*IV*	*V*	
EC_e (mmho's/cm)	0	2	4	8	16	etc.
Total salt (g/l)	0	1.32	2.64	5.28	10.56	
Section A			III → IV			
Section B			III → (between III and IV)			
Section C			III → V			
Section D			III → (between IV and V)			

I = salinity effects mostly negligible
II = yields of very sensitive crops may be restricted
III = yield of many crops restricted
IV = only tolerant crops yield satisfactorily
V = only a few very tolerant crops yield satisfactorily

Table 9 Amount of available water (mm) between pF 2.0 and pF 4.2

	0–10	*10–20*	*20–30*	*30–40*	*40–60*	*60–80*	*80–100*	*100–120*	*120–140*	*140–160*
Per layer	14.8	17.7	15.7	14.7	30.0	31.4	30.0	22.2	28.4	29.6
Total to bottom of layer	14.8	32.5	48.2	62.9	92.9	124.3	154.3	176.5	204.9	234.5

Soil profile

The soil is the buffer in both the water and the salt balance.
Fig. 4 shows the pF-curve, or moisture characteristic, of the soil in question. It is the mean pF-curve of 10 soil layers from 0–160 cm below the surface, since the various curves were in good agreement with each other. If the soil dries out to a suction of pF 4.2, which is possible in summertime during fallow or a rest period of the crop, the deficits are as indicated in Table 9.
In the case of pF 0.4 there is 291.6 mm more than at pF 4.2 and in proportion for shallower layers.
It is now clear that the maximum irrigation applications were of the order of 200 mm, and it is beyond doubt that these amounts do not contribute appreciably to the quantities of water drained off.
If the EC_e, the bulk density (d_b) and the percentage water (P_w) in the soil are known, the total salt in a soil layer can be calculated from:

$$P_{ss} = \frac{0.064\ EC_e P_w}{100} \quad \text{and} \quad S_{P(20)} = 2.10^4 d_b P_{ss}$$

or:

$$S_{P(20)} = 200\ (0.064)\ .\ EC_e\ .\ P_w\ .\ d_b$$

where:

$S_{P(20)}$ = kg/ha of salt in a 20 cm soil layer,
P_{ss} = per cent salt in soil on dry weight base,
P_w = percentage water in the soil on dry weight base (55% for Bejaoua), and
d_b = bulk density of the soil = volume weight in kg/l.

The bulk density for the soil layers 0–20, 20–40, 40–80, 80–120, 120–160 cm below soil surface were 1.33, 1.41, 1.48, 1.46 and 1.45, respectively.
In Table 10 the quantities of salt are given to a depth of 160 cm below surface at 4-11-1963 for the different drain sections.
The total quantity of salt stored in the soil to a depth of 160 cm below the surface is in general much higher than that added to the soil profile by irrigation (see Table 6).

Drainage
The experiment field is drained from the middle to both sides. The slope is 20 cm on 140 m, the tile is at a depth of 140–160 cm below the soil surface. As mentioned the field is divided into 4 sections (A, B, C and D), every section is subdivided into two plots drained with 30 and 60 m spacing, respectively (Fig. 3).

Table 10 Quantity of total salt (kg/ha) in the soil layers at 4-11-1963

Depth (cm)	*A 30*	*A 60*	*B 30*	*B 60*	*C 30*	*C 60*	*D 30*	*D 60*
0– 20	3,400	3,165	5,120	4,701	3,775	4,934	4,795	3,865
20– 40	3,257	3,406	4,639	4,738	5,478	7,058	4,047	3,702
40– 80	7,874	8,185	8,185	8,910	15,437	18,025	8,081	8,482
80–120	8,994	9,914	8,686	9,709	17,170	18,294	11,548	11,957
120–160	11,470	18,574	15,935	17,763	18,473	18,879	18,676	18,473
Total	34,995	43,244	42,565	45,821	60,333	67,190	47,147	46,479

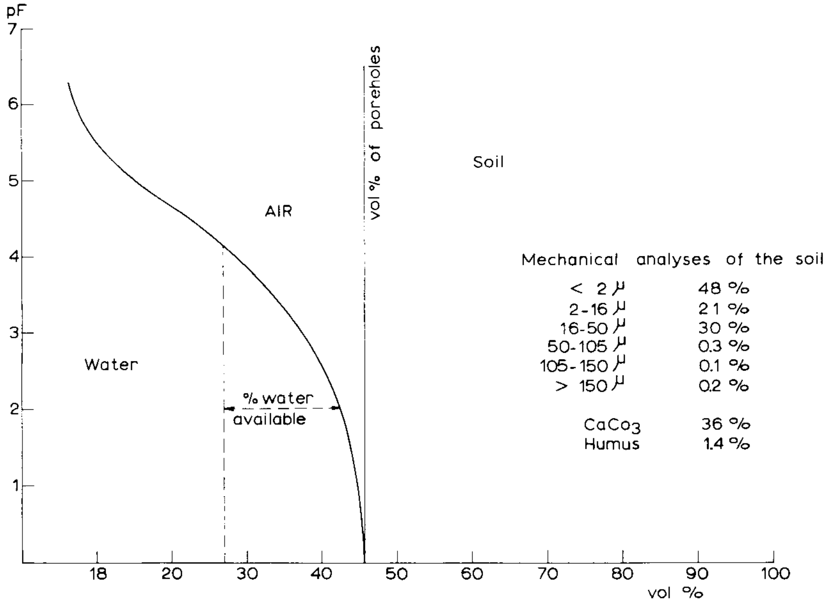

Fig. 4 Moisture retention curve (expressed as pF = negative logarithm of the suction in cm water) and the mechanical analyses of the soil at Bejaoua.

During discharge periods, the discharge was generally measured three times a day. Some drains were measured with recorders (Wesseling, 1957), others with a subsurface drain discharge meter (van der Weerd and Visser, 1964) or with a bucket. In Fig. 5, discharge curves are shown for the drains of section A in August 1962 during and after irrigation, measured every 3 hours during the whole discharge period. From this figure it can be seen that:

- The drains work subsequently from one earthen canal to another.
- The discharge increases very fast, and decreases more slowly immediately after irrigation.
- The maximum discharge of the drains of the 30 m plots is considerably higher than those of the 60 m plots.
- The discharge period of the 30 m drains is much longer than that of the 60 m drains.
- There is only a short period of maximum discharge.

It can be seen that the total amount of water discharged from the 30 m plots is much higher than that of the 60 m plots. This result was not expected. It is probable that in particular on the 60 m plots the irrigation water in part flows directly through the subsoil into the open drainage system.

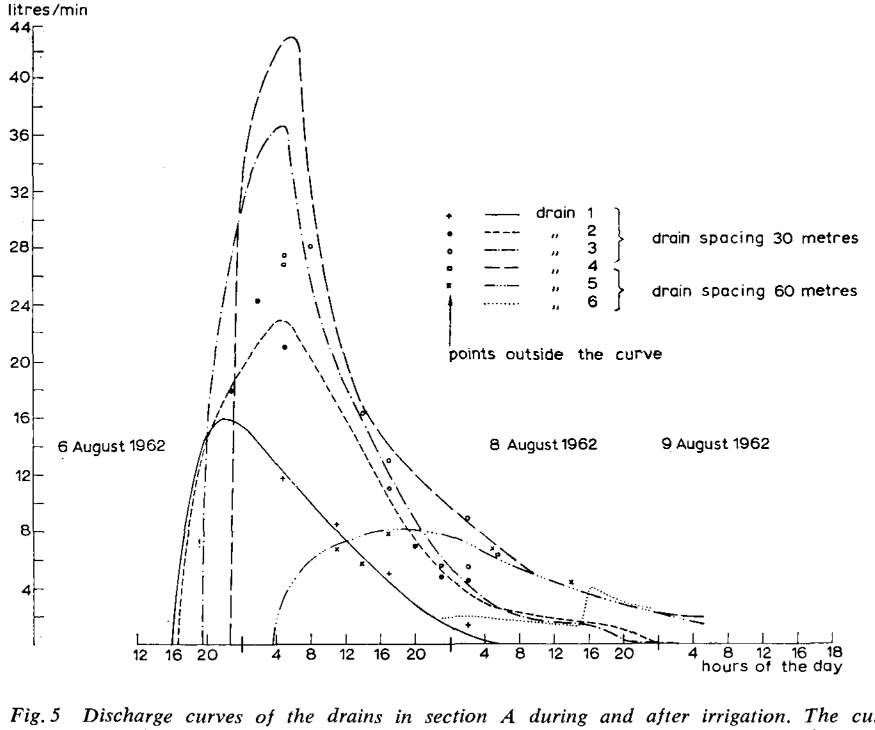

Fig. 5 Discharge curves of the drains in section A during and after irrigation. The curves have been strictly drawn through almost all available points. In the figure these points have, for clarity sake, not been drawn in, only those points not falling on the relevant curves are given.

In Table 11 examples are shown of the total drain discharge per month during the years 1962 and 1963, of the total quantities and of the discharge during the winter 1962–1963 in mm depth of water. The drain discharges are in general small. The total discharge of the 30 m drained plots is more than the discharge of the 60 m plots. It can be concluded once more that possibly in the 60 m plots a relatively larger discharge takes place through the subsoil tot the open drainage system, or that the evapotranspiration on the 60 m plots was higher.

The discharge in section C in 1962 during May and June was chiefly due to the irrigations of 250 and 280 mm per month, respectively. In February 1963 there was 81.6 mm precipitation.

Simultaneously with measuring the drain discharge, a water sample of the drainage water was taken of which the EC was determined in the laboratory. The result multiplied by 0.66 gives the weight of the total salts in grams per litre.

In Table 12 an example is given of the electrical conductivity of the drain water in section A from 17–21 July, 1962. The differences between the EC's of one drain in the course of the period are small. The EC's of the various drains lie in the same range of values. The same holds for other sections and other periods.

In comparing the results of the whole year it appears that there are also only small differences, probably due to the buffering subsoil salinity.

In the period of 17–21 July a salt content of about 4.5 g/l is found, whereas the irrigation water contained 3 g/l. From the small fluctuation in the salt content of the drain water it can be concluded that the efficiency of leaching of the soil by rain water is much higher than that by the irrigation water, since the fluctuation over the year of the salt content in the drain water is only very small.

The total quantity of salt evacuated by drainage is shown in Table 13. These quantities are very low when compared with the quantities added by the irrigation (up to 60,000 kg in 2 years).

Table 11 Drain discharges during 1962 and 1963 (mm depth)

	1962 artichokes		*1962 artichokes*		*1962 alfalfa*		*1963 alfalfa*	
	A 30	*A 60*	*B 30*	*B 60*	*C 30*	*C 60*	*C 30*	*C 60*
April	19.7	13.9	5.8	3.0	0	0	15.7	0.9
March	13.0	11.7	—	17.0	10.7	2.7	31.8	18.3
May	0	0	0	0	0	0	17.0	11.7
January	0	0	0	0	0	0	0	0
February	0	0	0	0	20.0	17.6	1.5	3.3
June	0	0	0	0	22.9	37.4	4.1	4.9
July	3.1	0.7	0	0	1.4	2.9	6.2	4.5
August	15.6	2.5	0	0	5.2	7.0	7.4	(7.9)
September	3.3	0.2	0	0	2.4	4.2	0	0
				bersim				
October	(10.9)	(5.0)	(3)	(3)	(17.9)	(17.9)	6.2	4.2
November	11.0	7.7	—	5.0	10.5	6.4	0.8	15.6
December	0.1	0	0	0	0	0	1.6	1.7
Total	76.7	41.7	(8.8)	28.0	91.0	96.1	92.1	73.0
Sept.–March incl. 1962–1963	129.0	54.6	55.0	36.0	93.3	59.4		

Salt balance
The salt balance can, as mentioned under *Research programme,* be written as follows:

$S_I + \triangle S_P - S_D = 0$ (in kg/ha)

In Table 14 an example is given of the balance for a long period of time, 30-11-1961 up to 4-11-1963. In five plots the quantity of stored salt decreased when compared with the amounts on 4-11-1963. In the sections C 30 and C 60, the most heavily irrigated parts of the experiment field, the quantity of stored salt increased considerably. It appears from the last column that more salt disappeared out of each plot than was evacuated by the tile drainage system.
There are two possibilities: a) the salt was stored below sampling depth in the subsoil; b) the salt was evacuated by a subsoil flow of water directly into the open drain system.

Table 12 Electrical conductivity of the drain water from the drains in section A, in July 1962

Date	*Hour*	*Drain*					
		1	*2*	*3*	*4*	*5*	*6*
17-7	16.00	6.90					
	20.00	6.50					
	23.00	6.80	7.00				
18-7	02.00	6.80	6.80				
	05.00	7.00					
	08.30	7.00	6.05	7.05			
	10.30	7.00	6.40				
	12.30	6.40	6.50	7.00			
	14.30	6.50	6.55				
	16.30	6.50	6.40	6.20			
	18.30		6.90	6.00			
	20.00		6.90	6.60			
	23.00		6.70	6.35	6.70		
19-7	02.00		7.10	6.30	7.10		
	05.00		6.80	6.35	7.00		
	08.30		7.10	6.60	7.10		
	10.30		7.10	6.70	7.00		
	12.30			6.60	7.00		
	16.30			6.40	7.10		
	20.00			6.30			
	23.00			6.20	7.00	7.25	
20-7	02.00			6.50	6.35		
	05.00			6.05	6.80	7.20	
	08.30			6.60	6.70	7.25	
	10.30			6.10	6.40	7.20	
	12.30			6.50	6.70	7.30	
	14.30			6.50			
	16.30				6.90	7.00	
	20.00				7.00	7.10	
	23.00				7.10	7.10	
21-7	02.00				7.10	6.90	
	05.00				6.90	7.00	6.50
	08.00					7.00	
	14.00						
	16.00				7.10		

Table 13 Total quantity of salt (kg/ha) evacuated by drain water

	A 30	*A 60*	*B 30*	*B 60*	*C 30*	*C 60*	*D 30*	*D 60*
1962	2,963	1,839	696	783	4,208	4,362	2,910	2,022
1963	3,726	3,194	2,349	2,154	4,704	2,964	3,313	1,276
Total	6,689	5,033	3,045	2,937	8,912	7,326	6,223	3,298

Table 14 Salt balance from 30-11-1961 to 4-11-1963

Section	*Quantities of salt (in kg)*						
	irrigation water	*profile*				*drainage*	
	S_1	*30-11-61*	*4-11-63*	*change* $\triangle S_P$	*total*	*drain* S_D	*subsoil* S'_D
	1			*2*	*1–2*	*3*	*1–2–3*
A 30	18,601	38,735	34,995	— 3,740	22,341	8,169	14,172
A 60	17,184	41,926	43,244	+ 1,318	15,866	4,174	11,692
B 30	12,879	49,727	42,565	— 7,162	20,041	3,045	16,996
B 60	11,102	47,608	54,821	— 1,787	12,889	2,937	9,952
C 30	58,969	45,857	60,333	+ 14,476	44,493	8,800	35,693
C 60	57,115	52,446	67,190	+ 14,744	42,371	7,224	35,147
D 30	30,454	54,089	47,147	— 6,942	37,396	6,223	31,173
D 60	30,188	60,387	46,479	—13,908	44,096	3,298	40,800

Concerning the subsoil storage no data are available, but certainly a part of the total evacuated quantity of salt will have been stored there, as Table 10 and 11 indicate. Even below 160 cm there are still fluctuations in salt content in the deeper layers.
There are some indications, that groundwater is flowing directly to the open drainage system outside the sphere of influence of the drains. These indications are:
- Iron sedimentations at the bottom and sides of the drainage canals.
- Glistening sides of the canals, indicating seepage of groundwater through the pores.
- The quantity of water drained by the 30 m plots is considerable higher than that of the 60 m ones.
- The total quantity of drainage water is surprisingly low in summer as well as in winter.

It is possible to get an indication of the amount of saline water that is draining to the deeper subsoil or directly to the open drainage system. If the EC_e of the water in question was known, the amount of water could be calculated with the aid of the last column of Table 14.
When taking a certain EC_e, extrapolated from the values as found in the higher subsoil (see Table 10 and 11), the following formula will give the equivalent amount (as a depth) of water evacuated outside of the drainage system:

$$A = \frac{S'_D}{10.\,K.\,EC_e}$$

where: A = amount of water expressed as a depth in mm,
S'_D = salt balance deficit (the salt lost to subsoil or directly to open system), and
K = transformation coefficient of EC_e into g/litre (here taken at 0.66).

In Table 15 the equivalent amounts are given in the cases that the EC_e of the deeper subsoil is the extrapolated value from Table 11 at a depth of 2 m, and the higher values of 15 and 30 mmho's/cm.
If this number of millimetres (A) is divided by the number of effective days, that is to say the number of days of irrigation- and rainy periods, an estimation of the number of millimetres of flow per day to the open drainage system will be found. The results of this procedure are not entirely in agreement with the differences found in the drain discharges for the 30 and 60 m sections, respectively. This is due to the difficulty in getting a reliable mean of the salt content of the soil profile.

Table 15 Calculation of the equivalent water depth (A) of the salt balance deficit (S'_D) for different EC_e's of the subsoil

Section	S'_D	Subsoil $EC_e (\times 10^3)$	A						Number of effective days
			per period for EC_e			per day for EC_e			
			variable acc. column 3	15	30	variable acc. column 3	15	30	
A 30	14,172	9	240	143	72	0.57	0.34	0.17	420
A 60	11,692	10	177	118	59	0.42	0.28	0.14	420
B 30	16,996	12	215	171	86	0.48	0.38	0.19	450
B 60	9,952	12	126	100	50	0.28	0.22	0.11	450
C 30	35,693	12	452	360	180	0.64	0.51	0.26	700
C 60	35,147	12.5	429	355	178	0.61	0.50	0.25	700
D 30	31,173	12.5	380	314	157	0.63	0.52	0.26	600
D 60	40,800	13	474	408	204	0.79	0.68	0.34	600

Influence of crop rotation on soil salinity

At a certain salinity level in the soil the yields of crops decrease depending on the tolerance of the crop concerned. On account of the salinity of the irrigation water it was obvious that not every crop could be grown in the Medjerda Valley. It was necessary therefore to choose crops which can be expected to prosper under these circumstances. Amongst these there are some crops familiar to the Tunisian farmer and some new crops that could be introduced. Important vegetable crops are artichokes, melons and watermelons. According to the general experience in North Africa these crops can be compared with tomatoes and cucumbers, respectively, from the viewpoint of salinity resistance.
Among the forage crops alfalfa is the most promising crop for the Medjerda Valley. The most interesting field crops are barley and wheat.
The electrical conductivity of the soil was determined from the extract of saturated soil samples. The mean saturation percentage at Bajaoua was 55 %.
The crop rotation depends on the soil salinity, at the beginning of the sowing period as well as the development of the EC_e during the growing season.
In Fig. 6 two examples are given of the fluctuations in the EC_e-values of the different soil layers from 1961 through 1963. It should be emphasized that the results were obtained without artificial leaching by irrigation water.

In Table 16 the crop rotation on the experiment field of Bejaoua, the irrigation intensity and the general conclusion on salinity trends are given.

Table 16 Crop rotation for the sections of the experiment field

	Section A	*Section B*	*Section C*	*Section D*
End 1961	artichokes	artichokes	alfalfa	artichokes
Winter 1961–1962	artichokes	artichokes	alfalfa	artichokes
Summer 1962	artichokes	fallow	alfalfa	artichokes
Winter 1962–1963	artichokes	bersim	alfalfa	artichokes
Summer 1963	fallow	tomatoes	alfalfa	corn
Winter 1963–1964	beans	barley	alfalfa	fallow
Irrigation:	fairly intensive	extensive	intensive	fairly intensive
Salinity:	stable	slight improvement	slight deterioration	stable

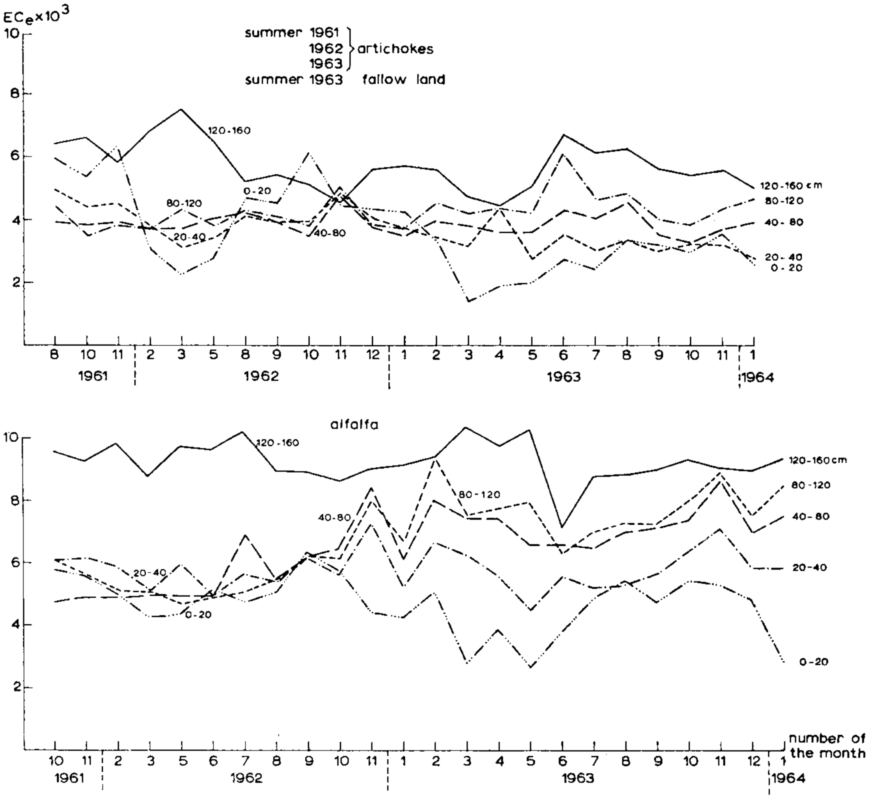

Fig. 6 Fluctuation in salinity of the various soil layers of sections A 30 (top) and C 60 (bottom) during the period of investigation at Bejaoua.

Conclusions and recommendations

From the information given above and from other available information on the given subject, the following conclusions and recommendations can be given.

1) There is no big difference in the salt content of the soil of the two different plots of one section, drained at 30 and 60 m, respectively. In Fig. 7 the mean of all samples taken in the period of August 1961 through December 1963 is given.

2) The subsoil of the sections A and B is less saline than that of C and D, probably due to the influence of the open drainage system on three sides (Fig. 1).

3) After 2 years of growing artichokes in section A, no harmful effect was observed from irrigation with brackish water. The dying of a number of cuttings was due to the method of planting. The wet soil caked hard over the plant upon drying, preventing emergence. In total this section was irrigated with some 700 mm of water. In the upper 120 cm of the soil profile the EC_e was seldom higher than 5. For artichokes it was as regards soil salinity an acceptable environment.

4) In section B there was only a slight difference in salinity between the different layers of the two plots. The crop rotation was irrigation extensive. Only during the summer of 1964 this section grown with tomatoes was irrigated abundantly. Especially in 1962 and in spring 1963 an improvement in soil salinity was found. In this section the EC_e fluctuated between 4 and 6, which means that many crops could be grown.

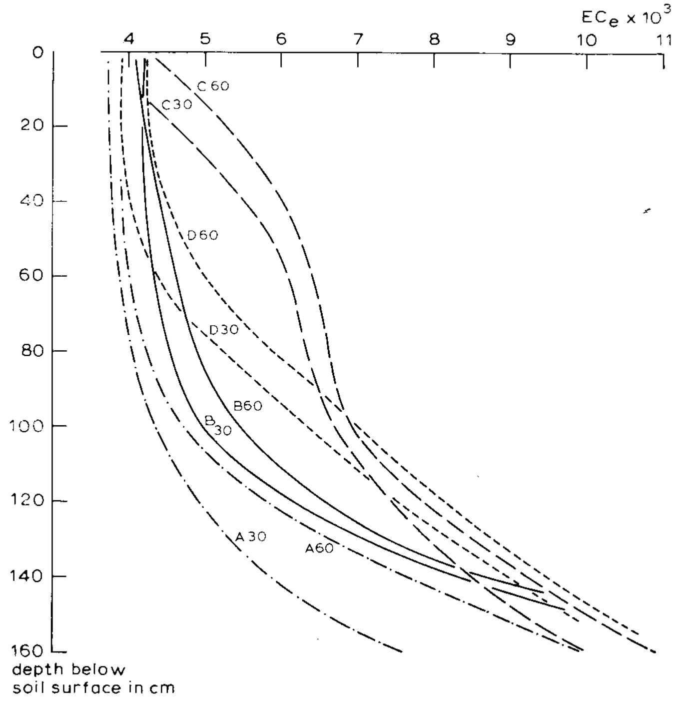

Fig. 7 Mean soil salinity for the sections of the field at Bejaoua at various depths of the soil profile.

5) In section C alfalfa was grown from the beginning to the end of the report period. Every year the soil was irrigated with 1000–1200 mm water. These quantities had an important influence. Especially the layers at 40–80 and 80–120 cm depth showed an increase in salinity. After the alfalfa the soil needs a fallow period and in connection with leaching of the soil, the winter period is to be preferred. In 1963 the EC_e generally did not exceed values of 8 or 9 which can be tolerated. But the growing conditions were less favourable than in sections A and B.

6) Compared with the sections A and B, section D was irrigated fairly intensively. Immediately after the artichokes, corn was planted. Nevertheless the salt situation was favourable if compared with that in section C. The EC_e of the layer at 80–120 cm fluctuated between 7 and 8, whereas the electric conductivity in the other layers was much less. The development of corn was a bit retarded. Also in this section there was a tendency towards improvement of the situation.

7) It is recommended that a crop rotation is taken in which, besides fallow periods, wintercrops and perennials with a rest period in summer, like artichokes, have their place.

Groundwater fluctuations through irrigation and drainage

The fluctuations of the groundwater level were studied in a number of observation wells placed along the length of the experiment field, in the middle of the sections in lines perpendicular on the tile lines. The wells were made from galvanized iron tubes with a length of 3 m and a diameter of 5 cm. The tubes were perforated over a length of 250 cm. The upper 50 cm was not perforated in order to prevent surface run-off from flowing into the tubes.

In general the water table was measured every Monday. After irrigation and heavy rainfall, daily observations were carried out.

The observations are evaluated per plot. In general it can be concluded that the groundwater level was found at drainage depth, except shortly after heavy rain and irrigation gifts; in dry periods the groundwater level was below drain level.

During irrigation the groundwater level rises to the soil surface, filling up the fissures. Soon after irrigation the water is absorbed by the swelling soil. The problem arises, how much time is needed before the groundwater level reaches a level at which it does not hamper plant growth by asphyxiation of the roots.

From the different series of data it can be concluded that the periods of temporary groundwater rise due to irrigation are shorter in the sections of 30 m spacing than in those of 60 m.

In Fig. 8 an example is given of the reactions of the groundwater level in tube 57 of the 60 m drained plot of section C (alfalfa), the most intensively irrigated part of the experiment field. In general the groundwater level reached a level lower than 0.50 m below soil surface within one day after irrigation and after 3 or 4 days the phreatic surface sank to a level of 1 m or more below soil surface.

The drain spacing of 60 m was sufficient for drainage, due to the water absorption capacity of the clay soil and the high evapotranspiration in dryer periods.

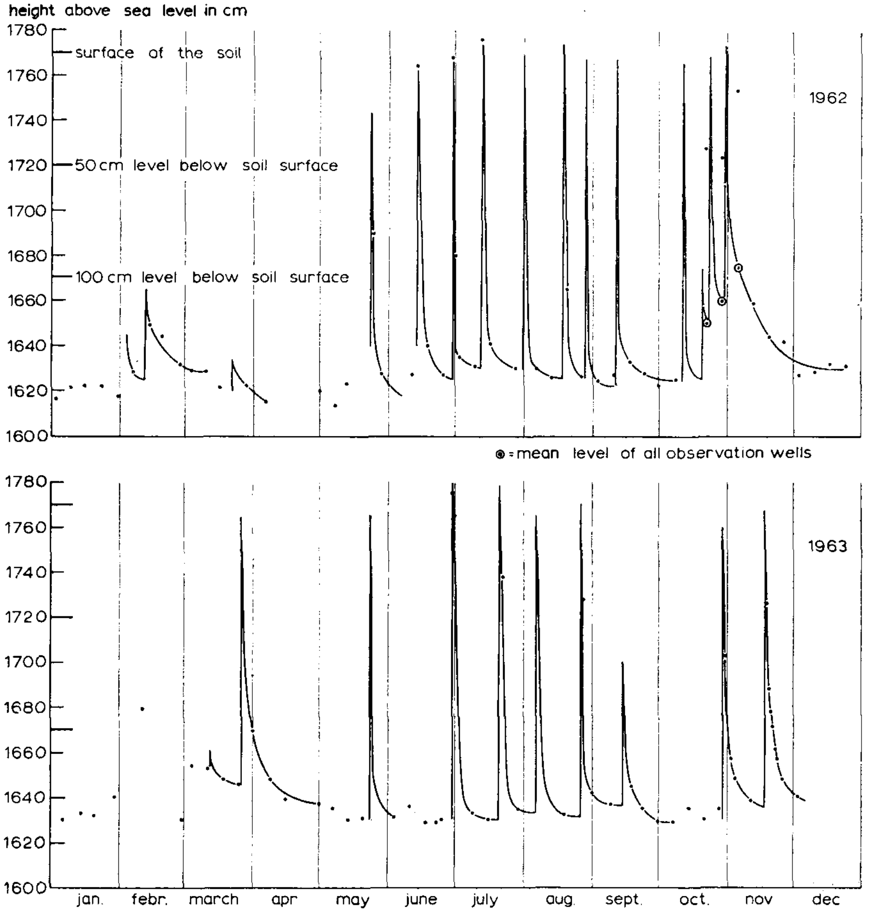

Fig. 8 Fluctuations of the groundwater level in observation well 57 at Bejaoua (60 m plot of section C).

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