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drainage of salty soils

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EXPERIENCES IN THE RECLAMATION OF SALINE AND ALKALI SOILS AND IRRIGATION WATER QUALITIES IN TURKEY

by

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1. Extent of salinity and waterlogging problems

According to the preliminary soils map of Turkey completed in 1954, hydromorphic saline alluvial (halomorphic) soils cover 650 200 ha, and solonchak soils cover 69 700 ha. These figures referred to land that had become basically nonarable due to salinity. It was also recognized that 25 percent of the young alluvial soils (totalling 820 400 ha), 681 200 ha of the hydromorphic alluvial soils and 89 800 ha of beach, sand dunes and marsh complexes exhibited salinity and drainage problems.

This added up to 719 900 ha of land basically nonarable due to salinity, plus 1 591 400 ha with some degree of salinity and waterlogging problems.

These data given in relation to the 1954 survey should be considered with caution. In countries like Turkey where irrigation development has accelerated greatly since 1954 larger areas are apt to be salt infested or waterlogged; but there have also been higher investments for land reclamation and drainage since then, which in turn has reduced the problem areas.

The recent soil survey of TOPRAKSU indicates that in the 53 states out of 67 for which the data have already been evaluated 1 724 423 ha have drainage problems and 801 371 ha have some degree of salinity, alkalinity or both.

This is shown in further detail in table 1.

2. Causes of salinity in Turkey

A survey of all available data on saline and/or waterlogged soils indicates that the cause of salinity in Turkey is related to

- climate
- drainage
- farming practices
- soil characteristics.

current info?

When considering the effects of these factors on the present state of salinity in Turkey it is difficult to differentiate between the importance of each.

Apart from the north-eastern Black Sea coast of Turkey, the country can be considered to be in the arid and semi-arid zone.

The southern Mediterranean and western Aegean coasts receive a winter and spring distribution of rainfall of an average of 630 mm/year. The inland plateau with the same kind of distribution receives an average annual precipitation in the range of 220 to 460 mm. The summer and early autumn are dry and hot.

As in most arid and semi-arid regions the natural drainage channels are not adequate. On the coastal plains the average elevation is in the range of 2 to 20 m above sea level. The inland plateaux do not have adequate drainage outlets.

Table 1

Salinity, alkalinity and drainage problem areas in 53 states of Turkey
(ref. TOPRAKSU General Directorate)

Land Use Classification	Salinity and alkalinity (ha)						Waterlogging (ha)			
	slightly saline	saline	alkali	slightly saline-alkali	saline-alkali	Total	inadequate drainage	poor drainage	waterlogged	Total
I-IV	448 446	129 146	2 911	91 193	58 604	730 301	1 270 546	450 701	3 176	1.724 423
V	59 347	7 883		3 514	326	71 070				
Total	507 793	137 029	2 911	94 707	58 930	801 371				

During the last century, with the increase in population and the mechanization of agriculture, the tendency towards irrigation has caused drastic changes in land use in Turkey particularly during the last quarter of a century. The forest land was depleted fastest, resulting in more runoff from the highlands to the lowlands. The rangelands, high- and low-lying, were ploughed and opened up for agricultural use. This also increased the amount of runoff from higher areas. The lowlying natural pastures whose water and salt balance had always been maintained with difficulty lost this balance under farming and, due to the arid and semi-arid zone climate, the salts moved to the upper zone of the profile. The establishment of irrigation systems without providing adequate drainage on the lowlying alluvial coastal plains also led to waterlogging problems.

The coastal alluvial and central plateau plain soils are basically rich in soluble salts. The coastal plains are hydromorphic alluvial soils, while on the central plateau ancient Lacustrine deposits cover fairly large areas.

3. Types of saline soils in Turkey

The nationwide preliminary soil survey prepared in 1954 distinguishes two groups of saline soils, the distinction between the two being based on practical reclamation potential rather than on scientific significance. Both groups may have saline, alkali and saline-alkali classes.

3.1 Hydromorphic saline alluvial (halomorphic) soils

These include the alluvial soils with inadequate drainage and with excess salts. They occur in all parts of Turkey in stream valleys, deltas and basins in association with other alluvial soils. The main causes of salt accumulation are irrigation without adequate drainage and seepage from irrigation canals.

3.2 Solonchak soils

The principal areas of these soils are fairly large tracts of old lake basins and in valleys where groundwater rises to or near the surface temporarily or for long periods.

4. Land and water resources

The present land use situation is summarized in table 2.

Table 2

Present land use in Turkey (ref. 2)

Type of use	Area (1 000 ha)		
Cropped land	14 170		
Fallow land	7 030		
Cultivated land		21 200	
Vegetable, orchard, vineyard, olive		2 339	
Agricultural land			23 539
Pasture, range			30 839
Forest			10 584
Unproductive			13 096
Total			78 058

The total area of plains in the 26 major watersheds of Turkey is 16.7 million ha, out of which 12.5 million ha are believed to be irrigable from the point of view of soil character. The annual surface runoff potential of the 26 watersheds is estimated to be 167×10^9 m^3. About 155×10^9 m^3 of this can be controlled. The total amount of water that can be withdrawn annually from underground reservoirs is estimated to be 4×10^9 m^3.

With these sources the annual total water potential of Turkey is approximately 171×10^9 m^3, of which 80×10^9 m^3 are accepted as usable water.

Because of the geographical and seasonal distribution of precipitation approximately 90 percent of the agricultural lands do not receive adequate rainfall during the vegetation periods of crops.

The potential volume of water supply given above would seem to be adequate for 12.5 million ha, but in many cases the individual water supplies do not have irrigable land around them, or else the irrigable lands are not close to potential water supplies. Considering these water supply/land position relationships, it is believed that about 8.5 million ha of the agricultural lands can in practice be irrigated.

Reconnaissance soil surveys conducted in the watersheds indicate that about 6 million ha could economically be provided with irrigation, and so far only 1.6 million ha are so supplied.

5. Irrigation water quality

Apart from maybe the main lakes (Van, Tuz, Burdur) and some tributaries of the Kizilirmak river, the quality of the major rivers in Turkey from the point of view of irrigation seems to be fairly safe.

The Central TOPRAKSU Research Institute initiated a water quality survey of the major rivers, tributaries and lakes of Turkey in 1970. The cooperation of the Electrical survey administration was obtained to take monthly water samples from their 260 flow and level recording stations in the principal watersheds. It is hoped that these data will be evaluated in 1973. In table 3 some of these data, along with data from other organizations, are listed to give an idea of irrigation water qualities. The rivers, tributaries and lakes presented in this table are the major ones in each watershed mentioned, and only watersheds having water of a quality that can be used for irrigation are included.

The author has also collected random water laboratory analyses of 1 397 samples from the TOPRAKSU regional laboratories. These samples consisted of 651 streams, 221 springs, 41 lakes and reservoirs, 287 deep wells and 197 from present surface irrigation systems. An evaluation of these data in accordance with the USDA Salinity Laboratory salinity and sodium classification is given in table 4.

Other classifications drawn up for the B. Menderes, Kizilirmak and Sakarya river watersheds are given in table 5.

6. Research on reclamation

The damage caused by salinity was first recognized in areas where irrigation systems were established.

The first modern irrigation system was constructed during 1908 in the Konya-Çumra plain to irrigate 53 360 ha. Another large system was on the right bank of the Seyhan in 1944 to irrigate 17 000 ha in the Adana-Tarsus plain. Both these locations as well as other irrigation project sites on the Aegean coast and in Central Anatolia had drainage problems following irrigation that led to salinity. The problems arising led to the establishment of irrigation research stations to deal with the local problems of irrigated farming.

The Soil and Fertilizer Research Institute in Ankara (1954), the Irrigation Research Institutes at Mersin-Tarsus (1948), Konya-Çumra (1949), Ismir-Menemen (1949) and Eskişehir (1952) and the Central TOPRAKSU Research Institute in Ankara (1962) started irrigation and salinity reclamation experiments in their regions. The first and last mentioned carry out salinity experiments also in other parts of Turkey.

Table 3

1970

Chemical composition of some main rivers, tributaries and freshwater lakes in 20 watersheds of Turkey (O. Beyce, unpublished)

Watershed	Annual yield of watershed (m^3 10^6)	River or tributary	Sampling location and date of sampling		EC x 10^6	pH	Soluble cations (me/l)				Soluble anions (me/l)					Class
							Ca+Mg	Na	K	Total	Cl	SO_4	CO_3	HCO_3	Total	
I Meriç	72.5	Ergene	EIEI 105	X/70	645	7.6	4.88	2.33	0.15	7.36	2.20	0.66	0.00	4.50	7.36	C2S1
		Tunca	EIEI 104	IX/70	509	8.6	4.28	1.52	0.07	5.87	1.20	0.00	1.40	1.40	5.87	C2S1
		Meriç	EIEI 103	IX/70	352	8.4	4.36	0.90	0.07	4.36	0.60	0.96	1.60	1.20	4.36	C2S1
III Susurluk	185.9	Susurluk	EIEI 316	IV/71	463	8.5	3.21	0.66	0.06	3.93	0.80	0.32	1.20	1.61	3.93	C2S1
V Gediz	126.0	Gediz	EIEI 518	VI/71	500	8.4	4.00	0.94	0.00	4.94	0.50	1.02	0.00	3.42	4.94	C2S1
VI K. Menderes	151.2	K. Menderes	EIEI 601	IV/71	475	7.4	4.64	0.08	0.00	4.72	1.50	0.32	0.00	2.90	4.72	C2S1
VII B. Menderes	126.0	B. Menderes	EIEI 707	IV/71	750	7.6	7.00	0.45	0.00	7.45	1.00	3.15	0.00	3.30	7.45	C2S1
VIII W.Mediter.	327.6	Dalaman	EIEI 812	IV/71	400	7.5	4.00	0.00	0.00	4.00	1.00	0.20	0.00	2.80	4.00	C2S1
IX Antalya	491.4	Aksu	DSI dam	X/61	461	7.5	3.90	0.32	0.25	4.47	0.26	0.61	0.00	3.60	4.47	C2S1
		Egredir Lake	EIEI 915	VII/71	350	8.1	3.36	0.16	0.00	3.52	0.50	0.22	0.00	2.80	3.52	C2S1
XII Sakarya	69.3	Porsuk	EIEI 1212	IV/71	400	8.2	3.70	0.42	0.00	4.12	0.50	1.62	0.00	2.00	4.12	C2S1
		Sakarya	EIEI 1206	IV/71	559	8.5	4.23	2.15	0.09	6.47	1.00	3.27	0.80	1.40	6.47	C2S1
XIII W. Black Sea	315.0	Soganli	EIEI 1314	IV/71	480	7.7	4.30	0.40	0.00	4.70	0.50	2.00	0.00	2.20	4.70	C2S1
XIV Yesilirmak	126.0	Kelkit	EIEI 1401	X/70	500	8.0	4.00	0.92	0.00	4.92	0.50	1.23	0.00	2.20	4.70	C2S1
		Yesilirmak	EIEI 1402	X/70	500	8.2	4.20	0.64	0.00	4.94	0.50	1.24	0.00	3.20	4.94	C2S1
XV Kizilirmak	72.5	Delice	TS Kula	VIII/62	12000	7.4	21.40	100	0.00	121.40	92.50	24.66	0.00	4.24	121.40	C4S4
		Kizilirmak	TS Hirfanli	VII/63	1210	7.7	8.38	3.62	0.00	12.00	9.00	0.19	0.00	3.81	12.00	C3S1
XVI Konya	72.5	Beyşehir Lake	EIEI 1604 A	VI/71	250	8.5	2.30	0.20	0.00	2.50	0.50	0.08	0.00	1.92	2.50	C1S1
XVII E.Mediter.	409.5	Göksu	EIEI 1714	V/71	478	7.8	3.20	1.58	0.00	4.78	0.60	1.88	0.00	2.30	4.78	C2S1
		Tarsus	DSI dam	VII/59	320	-	3.32	0.43	0.25	4.00	0.32	0.68	0.00	3.00	4.00	C2S1
XVIII Seyhan	289.8	Göksu	EIEI 1801	VIII/70	400	7.1	4.02	0.20	0.00	4.22	0.50	1.96	0.00	1.76	4.22	C2S1
		Zamanti	EIEI 1812	IX/70	400	7.8	3.20	0.94	0.00	4.14	1.50	0.14	0.00	2.50	4.14	C2S1
		Seyhan	DSI dam	VII/59	310	7.5	2.36	0.43	0.14	2.93	0.50	0.08	0.00	2.38	2.96	C2S1
XIX Asi	189.0	Asi	DSI	X/57	700	7.8	4.75	1.52	0.12	6.39	1.00	3.37	0.00	2.02	6.39	C2S1
XX Ceyhan	330.8	Aksu	DSI	/66	560	8.4	5.70	0.21	0.04	5.95	0.22	1.53	0.68	3.52	5.95	C2S1
		Göksun	DSI 4	X/62	370	7.5	3.70	0.21	0.25	4.16	0.08	0.55	0.00	3.28	3.91	C2S1
		Ceyhan	DSI	VI/59	385	8.1	3.30	0.43	0.14	3.87	0.00	0.26	0.42	3.12	3.80	C2S1
XXI Euphrates	220.5	Karasu	DSI dam	IX/59	400	7.6	3.50	1.41	0.25	5.16	1.25	0.00	0.00	3.91	5.16	C2S1
		Murat	DSI	III/65	770	8.2	4.00	3.50	0.21	7.71	3.14	0.31	0.36	3.90	7.71	C3S1
		Euphrates	DSI	IV/61	475	7.3	3.80	0.85	0.06	4.71	0.60	0.91	0.00	3.20	4.71	C2S1
XXIII Çoruh	245.7	Oltu	DSI 10	VIII/62	1350	8.2	6.60	6.40	0.25	13.25	4.15	4.05	0.40	4.65	13.25	C3S1
		Çoruh	DSI 14	V/65	260	8.1	2.40	0.53	0.03	2.96	0.21	0.67	0.28	1.80	2.96	C2S1
XXIV Aras	207.9	Kars	TS	IX/70	340	7.3	2.70	1.00	0.00	3.70	0.30	0.00	0.00	3.40	3.70	C2S1
		Aras	TS dam	IV/65	520	7.0	2.68	2.25	0.00	5.20	2.40	1.60	0.00	1.20	5.20	C2S1
XXVI Tigris	337.0	Tigris	EIEI 2606	IX/70	450	7.1	4.03	0.53	0.00	4.56	0.50	2.08	0.00	1.98	4.56	C2S1

EIEI - Electrical Survey Administration flow stations; DSI - State hydraulic works flow stations; TS - TOPRAKSU laboratory files

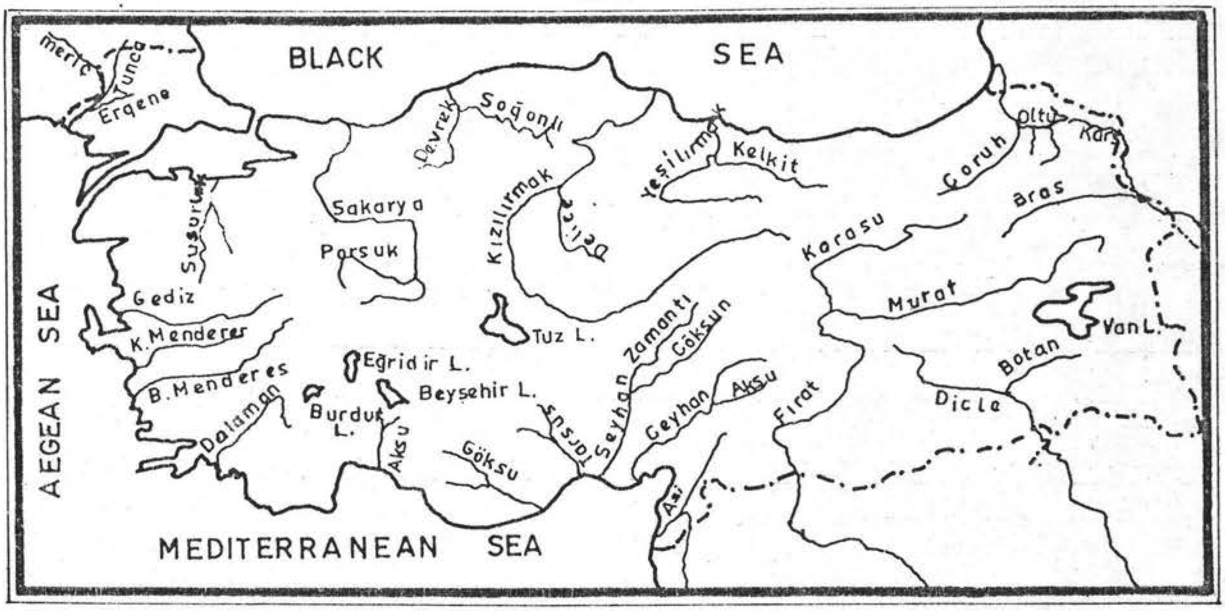


Fig. 1 Main rivers and their tributaries in Turkey

Table 4

A preliminary evaluation of the irrigation waters in Turkey with respect to their qualities (O. Beyce, ref. 2, 4)

Salinity (C), alkalinity (S) Class	Number of samples in class	% of number of samples in class to total number of samples
C_1 S_1	174	12.45
C_2 S_1	685	49.03
C_2 S_2	2	0.14
C_3 S_1	370	26.49
C_3 S_2	25	1.78
C_3 S_3	8	0.57
C_3 S_4	4	0.24
C_4 S_1	55	3.93
C_4 S_2	26	1.83
C_4 S_3	12	0.82
C_4 S_4	38	2.72
Total	1 397	100.00

Table 5

Classification of irrigation waters in B. Menderes, Kizilirmak and Sakarya river watersheds

Watershed	B. Menderes (1)		Kizilirmak (2)	Sakarya (3)
Type of source	surface	underground	surface	surface
No. of samples	549	46	52	21
Class	%	%	%	%
C_1 S_1	0.36			
C_2 S_1	46.91	45.65	21.15	61.90
C_2 S_4			1.92	
C_3 S_1	47.09	47.84	50.00	38.09
C_3 S_2			25.00	
C_4 S_1	5.64	2.17	1.92	
C_4 S_2		4.34		

(1) TOPRAKSU Menemen Research Institute; (2) and (3) reference 4, samples cover only the main river and its tributaries for the month of May

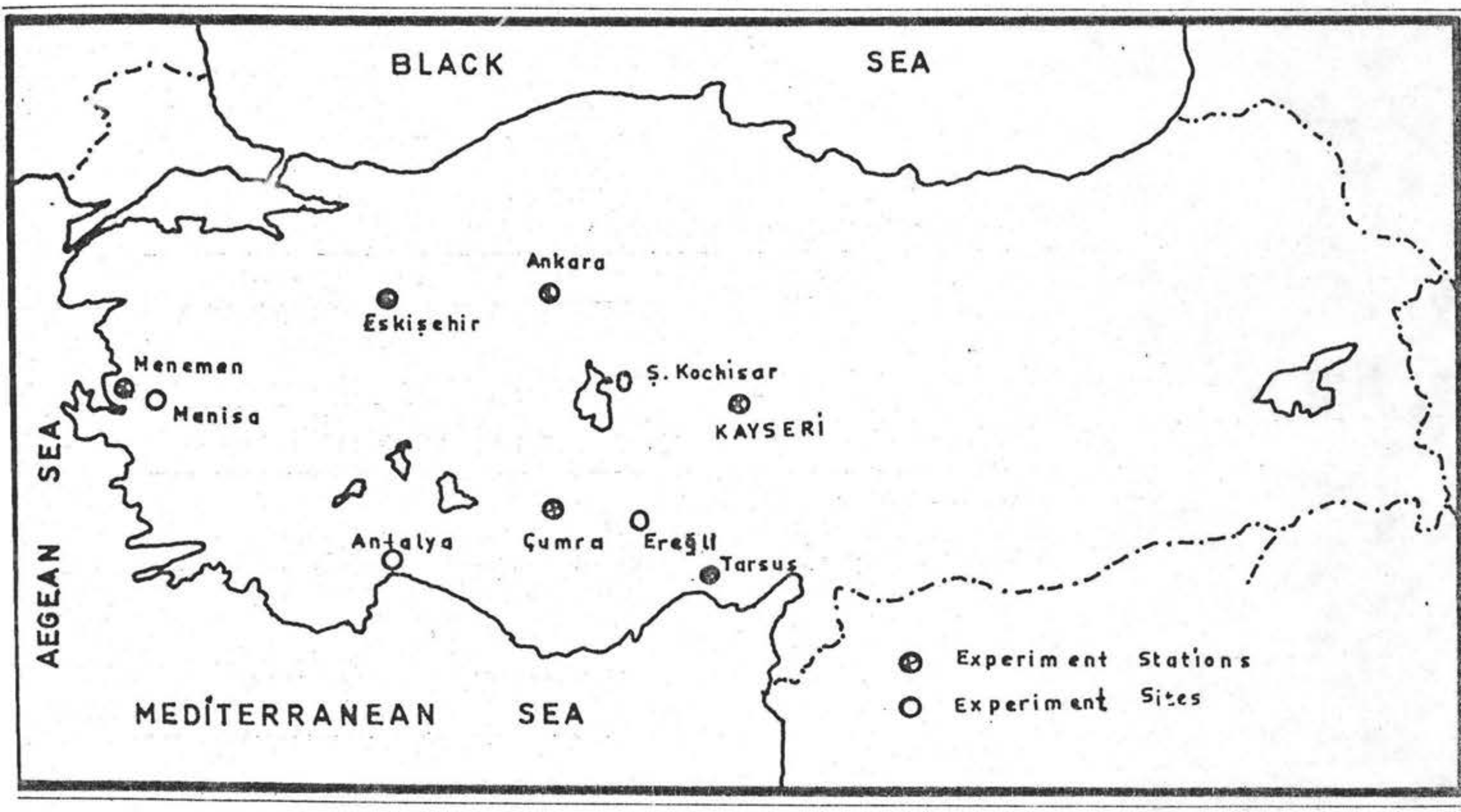


Fig. 2 Experimental stations and experimental sites where salinity reclamation studies are being made

The first field experiments were started by the Tarsus Irrigation Research Institute in Alifaki where, in 1952, a substation was established on these heavy saline soils covering approximately 4 000 ha of saline soil. The initial field experiments consisted of opening drainage canals about 1.5 m deep at intervals of 120 m. The first results in 1953 indicated that rice could be grown on these soils and that with deep drainage the soluble salts could be leached. Data obtained from this area showing the effect of leaching together with rice crop and winter rains are given in table 6.

Table 6

Leaching of soluble salts from a drained field under rice crop and winter rains at Mersin-Tarsus (Alifaki) (ref. 1, 2)

Treatments and dates of sampling	Total soluble salts (%) 0-30 cm	30-60 cm	60-90 cm	90-120 cm
Original soil (12.4.57)	0.36	0.44	0.50	0.55
After first rice crop (11.11.57)	0.26	0.32	0.46	0.51
Winter rains (503 mm) (12.5.58)	0.08	0.16	0.30	0.22
After 2nd rice crop (5.11.58)	0.13	0.19	0.25	0.25
Winter rains (444 mm) (20.3.59)	0.06	0.09	0.12	0.12
After 1st cotton crop (5.10.59)1/	0.10	0.22	0.41	0.40

1/ note resalination under cotton crop

Table 7

Effect of leaching and gypsum applications on soil salinity and alkalinity at Mersin-Tarsus (B. Oztan, ref. 1)

Treatment	Dates of sampling	$EC_e \times 10^3$ Depth of sampling (cm)				ESP Depth of sampling (cm)			
		0 – 30	30–60	60–90	90–120	0 – 30	30–60	60–90	90–120
Leaching (no gypsum)	1	23.97	36.66	35.02	-	23.23	28.27	43.17	-
	2	2.61	18.66	29.32	23.89	24.21	24.81	28.49	28.59
	3	4.46	26.04	27.11	25.34	13.14	14.44	25.65	24.77
Gypsum (460 kg/dec)	1	26.18	32.45	38.85	-	24.85	32.87	34.85	-
	2	2.49	16.59	16.99	17.47	20.29	32.79	31.68	27.54
	3	5.32	16.36	15.22	13.29	5.98	21.79	25.40	29.44

Dates of sampling: 1 – before leaching (20.1.59)
2 – after 333 mm rainfall and 615 mm leaching (6.11.59)
3 – after 490 mm rainfall and alfalfa irrigation (17.10.60)

Table 8

Effect of leaching and gypsum applications on soil salinity and alkalinity at Izmir-Menemen (B. Oztan, ref. 1)

Treatment	Dates of sampling	$EC_e \times 10^3$ Depth of sampling (cm)			ESP Depth of sampling (cm)			Alfalfa hay yield (kg/dec)
		0 – 30	30–60	60–90	0 – 30	30–60	60–90	
Leaching	1	71.84	74.23	83.52	59.42	73.34	55.70	
	2							
	3	1.03	1.21	1.18	7.19	19.52	28.26	
	4	2.06	4.56	3.45	11.04	23.18	30.67	418.2
	5	2.94	3.21	4.02	33.37	45.49	44.11	
	6	1.86	2.29	3.86	16.50	-	36.53	791.5
Leaching with gypsum (1500 kg/dec)	1				60.15	28.80	55.70	
	2	2.19	2.82	2.82	27.98	45.03	51.49	
	3	1.09	1.62	1.35	15.52	33.31	42.21	
	4	2.78	3.15	1.87	18.75	15.86	28.82	827.8
	5	4.75	8.43	8.83	14.74	30.79	30.47	
	6	4.48	9.71	10.51	16.41	17.29	14.07	1 125.1

Dates of sampling: 1 – before leaching (2.5.58)
2 – after leaching with 1000 mm of water (2.12.58)
3 – after 453 mm rainfall (12.4.59)
4 – after seeding alfalfa (12.5.59) and 548 mm irrig. water (24.10.59)
5 – after winter rainfall (spring 1960)
6 – after alfalfa irrigations (8.11.60)

Mr. B. Oztan of the Ankara Soil and Fertilizer Institute started a series of reclamation experiments employing chemical amendments in various locations in Turkey. The experimental plots were all provided with drainage canals around them.

The results of the leaching trial at Tarsus are summarized in table 7. The effect of 460 kg/dec of gypsum was significant in the removal of exchangeable Na and the leaching of soluble salts after the second year, but these still remained at unsafe levels especially below the first 30 cm. Mr. Oztan attributes this to the impossibility of draining the drainage ditches for certain periods of time due to outlet problems.

Table 9

Effect of leaching and various rates of gypsum application before and after 400 mm water application at Eskişehir-Kizildiken (B. Öztan, ref. 1)

Treatment	Dates of sampling	$EC_e \times 10^3$ Depth of sampling (cm) 0 – 30	30–60	60–90	90–120	ESP Depth of sampling (cm) 0 – 30	30–60	60–90	90–120
Leaching (no gypsum)	1	38.50	46.20	41.74	37.37	75.56	45.10	51.83	69.82
	2	10.98	20.07	29.22	29.02	39.04	29.59	40.49	60.48
Gypsum (350 kg/dec)	1	12.23	19.08	26.40	30.90	30.50	27.82	20.25	58.12
	2	4.25	4.86	7.34	11.75	6.05	9.64	14.35	29.10
Gypsum (400 kg/dec)	1	26.60	49.80	52.00	43.38	34.42	31.34	28.90	16.48
	2	9.11	6.72	10.69	21.95	15.58	24.30	7.31	3.47
Gypsum (450 kg/dec)	1	38.50	46.20	41.74	37.37	46.10	46.10	51.83	69.82
	2	10.73	20.92	38.84	40.75	35.65	36.65	24.52	30.35
Gypsum (500 kg/dec)	1	4.92	8.58	10.73	14.61	26.34	26.34	25.02	46.06
	2	4.70	7.27	11.03	29.20	35.30	35.30	46.11	25.59

Dates of sampling: 1 – before leaching
2 – after 400 mm leaching water application

Table 10

Leaching of soluble salts in the first 30 cm of soil at Konya-Eregli (A. Güven, unpublished, 1970)

Depth of leaching water D_{lw} (cm)	$\frac{D_{lw}}{D_s}$	Total soluble salts (%)	Percent of initial salt remaining in the soil $\frac{C}{Co}$ 100
0	0	0.45	100.00
10	0.33	0.26	57.77
20	0.66	0.22	48.88
30	1.00	0.21	46.66
40	1.33	0.22	48.88
50	1.66	0.22	48.88

Another experiment in the same series was conducted at Menemen on lighter but highly saline and sodic soils during 1958–60. The plots represented 3 000 ha of the type of soil of this area. After providing drainage canals the leaching was started in the spring of 1958 and in the spring of 1959 the plots were seeded with alfalfa.

Due to the lightness of the soil texture the leaching of soluble salts was satisfactory both with and without gypsum. The removal of exchangeable Na was similar in the first 30 cm in both treatments, but below that depth it was incomparably in favour of gypsum treatment (table 8).

At Eskişehir-Kizildiken, again on heavy textured highly saline and sodic soils, leaching without gypsum and with various rates of gypsum application gave the results shown in table 9. These results seem very encouraging at 350 and 400 kg/dec gypsum application, but the ineffectiveness of higher rates in the removal of exchangeable Na is rather difficult to explain.

At a drainage project site at Konya-Eregli, Mr. A. Güven of the TOPRAKSU VI region conducted a simple leaching experiment on the leaching of salts. Table 10 indicates the removal of soluble salts from the first 30 cm of the profile. This profile down to 120 cm had the following salt content before leaching:

depth of soil (cm)	total soluble salts (%)
0 – 30	0.45
30 – 60	0.25
60 – 90	0.23
90 – 120	0.15

In 1968 the Central TOPRAKSU Research Institute started a series of saline and sodic soil reclamation experiments at the project sites of the TOPRAKSU General Directorate.

During the summer of 1968 an experiment was conducted at Kayseri-Karasaz; on the deep peat soils with salinity and boron problems found there, various leaching methods were compared (continuous ponding, intermittent ponding and intermittent sprinkling). The soil was sampled after each 10 cm of water application down to 1 m profile depth. The percentage of initial salt remaining in the 1 m soil profile ($\frac{C}{Co}$ 100) after each 10 cm application for each treatment is given in table 11. The salt content of the soil was expressed as the electrical conductivity of the saturation extract. The initial average salt content of the soil profile was about 20 mmhos/cm; the final value after 170 cm leaching water application was around 4 mmhos/cm.

Table 11

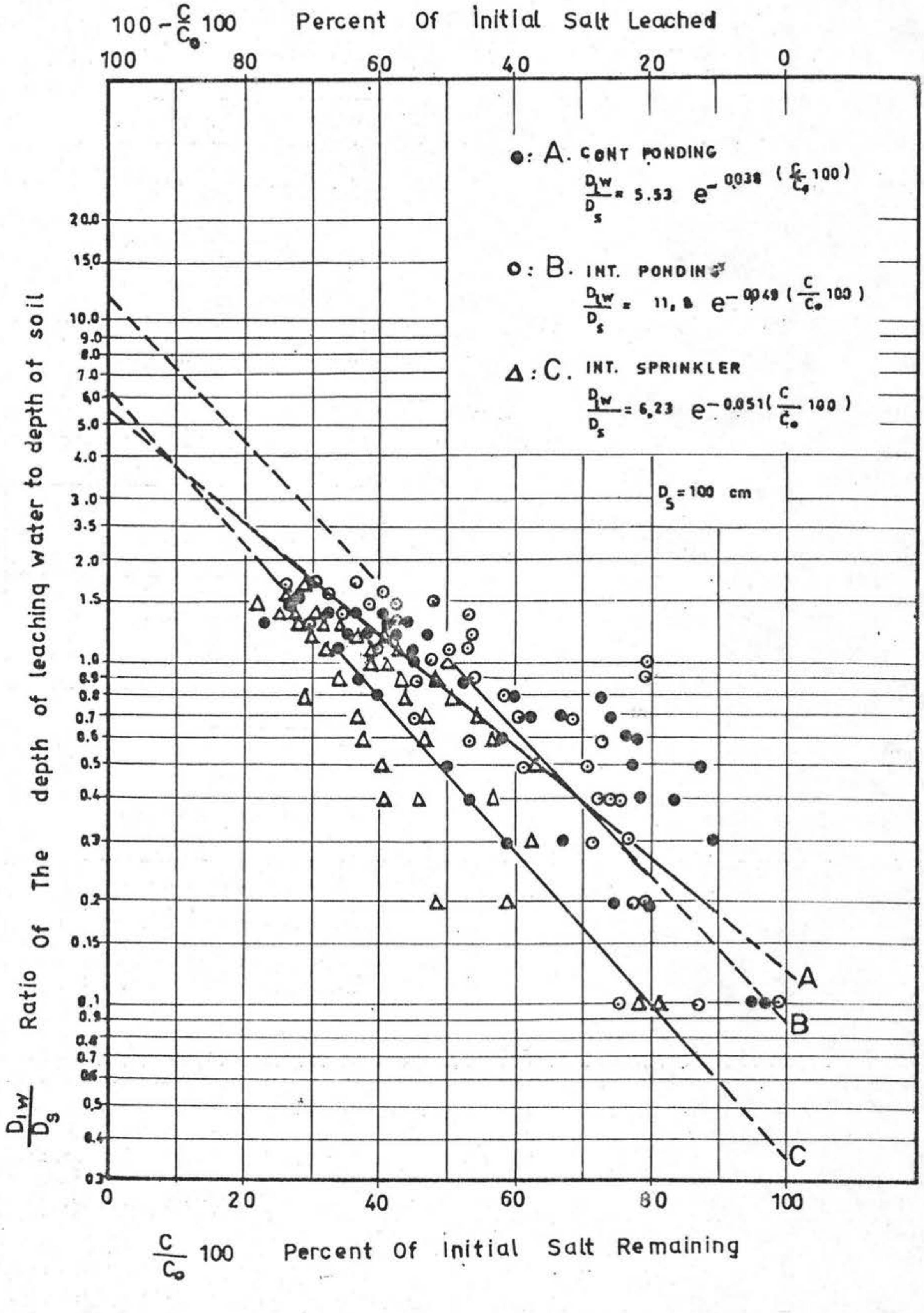
Percentage of initial salt remaining in the 1 m soil profile during leaching with three methods on Kayseri-Karasaz peat soils (O. Beyce et al, ref. 3)

D_{lw} (cm)	$\frac{D_{lw}}{Ds}$	Continuous ponding A $\frac{C}{Co}$ 100	Intermittent ponding B $\frac{C}{Co}$ 100	Intermittent sprinkling C $\frac{C}{Co}$ 100
0	0	100.0	100.0	100.0
10	0.1	92.6	87.1	79.9
20	0.2	76.9	78.2	58.6
30	0.3	71.6	74.2	62.4
40	0.4	71.6	73.8	47.3
50	0.5	71.7	66.1	47.1
60	0.6	70.7	63.1	47.1
70	0.7	67.3	58.4	46.1
80	0.8	57.8	58.5	41.4
90	0.9	45.3	59.5	41.9
100	1.0	46.4	57.8	43.4
110	1.1	43.8	48.2	38.2
120	1.2	40.4	46.4	36.2
130	1.3	36.3	44.0	31.3
140	1.4	36.7	44.3	23.8
150	1.5	33.6	43.1	24.8
160	1.6	28.7	37.1	26.5
170	1.7	26.4	31.6	29.6

The leaching equations obtained for the three methods of leaching water application are given in table 12.

The average boron content of the 1 m soil profile was about 8 ppm before leaching. After the application of 150 cm of leaching water it was lowered to 4 ppm. The percentage of initial boron remaining in the soil is given in table 13.

The leaching equations obtained for boron are given in table 14.



$$\frac{D_{lw}}{D_s} = 5.53\ e^{-0.038\left(\frac{C}{C_0}100\right)}$$

$$\frac{D_{lw}}{D_s} = 11.8\ e^{-0.049\left(\frac{C}{C_0}100\right)}$$

$$\frac{D_{lw}}{D_s} = 6.23\ e^{-0.051\left(\frac{C}{C_0}100\right)}$$

Fig. 3 Leaching curves and equations for Kayseri-Karasaz peat soils under three leaching methods (Ö. Beyce et al, ref. 3)

Table 12

Leaching equations obtained for three different leaching methods on Kayseri-Karasaz peat soils (O. Beyce et al, ref. 3)

Method of leaching	Salt leaching equations
Continuous ponding	$\frac{D_{lw}}{D_s} = 5.53\ e^{-0.038\ \frac{C}{Co} 100}$
Intermittent ponding	$\frac{D_{lw}}{D_s} = 11.8\ e^{-0.049\ \frac{C}{Co} 100}$
Intermittent sprinkling	$\frac{D_{lw}}{D_s} = 6.23\ e^{-0.051\ \frac{C}{Co} 100}$

Table 13

Percentage of initial boron remaining in the 1 m soil profile during leaching with three methods on Kayseri-Karasaz peat soils (O. Beyce et al, ref. 3)

D_{lw} (cm)	$\frac{D_{lw}}{D_s}$	Continuous ponding $\frac{C}{Co}$ 100	Intermittent ponding $\frac{C}{Co}$ 100	Intermittent sprinkling $\frac{C}{Co}$ 100
0	0	100.0	100.0	100.0
50	0.5	77.[illegible]	95.7	81.3
100	1.0	69.5	87.1	78.5
150	1.5	65.5	77.3	51.3

Table 14

Leaching equations for boron under three different leaching methods on Kayseri-Karasaz peat soils (O. Beyce et al, ref. 3)

Methods of leaching	Boron leaching equations
Continuous ponding	$\frac{D_{lw}}{D_s} = 3.77 - 0.039\ \frac{C}{Co}\ 100$
Intermittent ponding	$\frac{D_{lw}}{D_s} = 6.46 - 0.064\ \frac{C}{Co}\ 100$
Intermittent sprinkling	$\frac{D_{lw}}{D_s} = 3.76 - 0.039\ \frac{C}{Co}\ 100$

Sample calculations of the amount of leaching water required to lower the $EC_e \times 10^3$ of the 1 m profile from 18.3 mmhos/cm to 8 mmhos/cm, that is to bring it to 43 percent of the initial salt content, gave 109 cm under ponding and 69.9 cm under intermittent sprinkling. To cause a 57 percent reduction in boron or to bring it to 43 percent of the initial boron content, the depth of leaching water required was 209 cm under continuous ponding, 371 cm for intermittent ponding, and 208 cm for intermittent sprinkling.

During 1970, at the Antalya-Köprüçay irrigation and drainage project area covering 836 ha of heavy saline and alkali soils, a reclamation experiment was carried out. The leaching water was applied in 10 cm quantities with 24-hour intervals between the disappearance of water from the soil surface and the next application.

The lowering of ESP due to the removal of exchangeable Na in the 1 m soil profile after 40 cm of applications is given in table 15. The removal of 11.6 me/100 gr of exchangeable Na with no gypsum application is equivalent to the natural gypsum found in the profile. The average electrical conductivity of the top 1 m soil profile was around 19 mmhos/cm. The leaching equation obtained for soluble salts was

$$\frac{D_{lw}}{D_s} = 5.09\ e^{-0.047 \frac{C}{Co} 100}$$

A similar field experiment was conducted at Manisa on the Gediz irrigation and drainage project area during 1971. There too the soils were heavy, saline and alkali. The leaching water was applied in 10 cm quantities with 24-hour intervals between the disappearance of the water from the soil surface and the next application.

Table 15

ESP status and exchangeable Na removal from the soil profile under various gypsum application rates and leaching water levels at Antalya-Köprüçay (O. Beyce et al, unpublished)

Treatment	Depth of soil (cm)	ESP				Removed exchangeable Na (me/100 g)		
	D_{lw}:	0 cm	40 cm	80 cm	120 cm	40 cm	80 cm	120 cm
no gypsum	0–20	19.61	11.50	12.35	7.85	2.48	2.29	3.25
	20–40	18.60	14.61	15.17	16.44	1.00	1.42	0.08
	40–60	22.71	15.06	10.05	19.44	1.69	3.49	1.90
	60–80	22.82	28.76	12.51	19.23	+1.13	2.58	2.97
	80–100	21.64	37.10	21.84	15.93	+0.54	1.23	3.40
	Total					3.50	11.01	11.60
	Average	21.07	21.41	14.38	15.77			
gypsum 20 tons/ha 1/	0–20	19.83	6.39	3.95	2.05	4.77	5.56	6.63
	20–40	16.31	13.03	9.48	6.39	1.62	2.56	4.01
	40–60	15.81	14.86	10.68	10.34	1.00	1.45	2.28
	60–80	22.70	15.63	13.23	11.99	2.77	3.34	4.32
	80–100	24.35	16.81	10.07	15.13	1.50	2.93	2.27
	Total					11.66	15.84	19.51
	Average	19.80	13.34	9.48	9.18			
gypsum 40 tons/ha 1/	0–20	26.03	21.92	4.50	0.08	1.08	8.40	[illegible]
	20–40	23.14	16.10	17.37	0.72	1.89	2.54	8.05
	40–60	23.50	41.62	10.52	1.16	+7.37	5.25	8.43
	60–80	27.14	34.14	13.47	7.03	+2.68	5.14	7.77
	80–100	33.21	27.40	13.88	4.78	0.96	6.56	9.67
	Total					+6.12	27.89	43.52
	Average	24.60	28.09	11.95	2.76			

1/ the gypsum used was 80% $CaSO_4.2H_2O$

The lowering of ESP due to the removal of exchangeable Na in the 1 m soil profile after 140 cm and 280 cm of water applications is summarized in table 16.

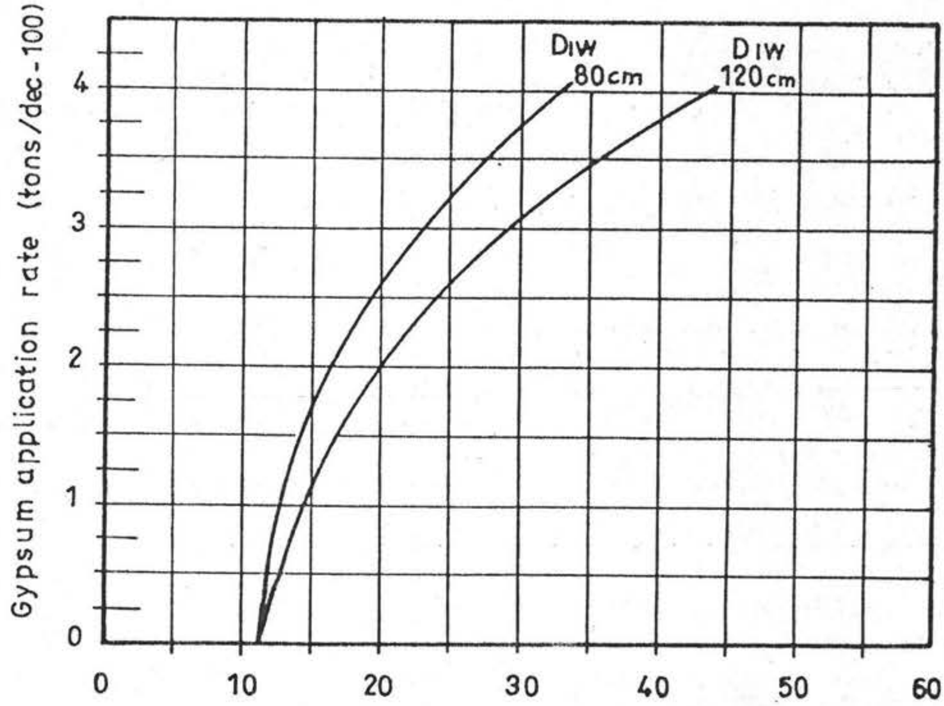


Fig. 4 Gypsum application rate curves for the Antalya-Köprüçay project area - alkali soils (O. Beyce et al, unpublished)

Table 16

ESP status and exchangeable Na removal from the soil profile under various gypsum application rates and leaching water levels, Manisa-Gediz project (O. Beyce et al, unpublished)

Treatment	Depth of soil (cm) D_{lw}:	ESP 0 cm	ESP 140 cm	ESP 280 cm	Removed exchangeable Na (me/100 g) 140 cm	Removed exchangeable Na (me/100 g) 280 cm
no gypsum	0-20	38.95	28.59	16.69	3.65	5.52
	20-40	40.17	24.57	15.37	6.52	8.65
	40-60	18.57	19.13	16.20	1.22	2.07
	60-80	17.44	16.89	15.26	1.04	2.49
	80-100	22.64	19.77	15.52	1.00	1.38
	Total				13.41	20.11
	Average	27.55	21.79	15.81		
gypsum 10 tons/ha (as before)	0-20	47.30	28.18	12.93	6.31	7.96
	20-40	41.97	25.40	12.81	7.40	9.14
	40-60	21.50	25.95	12.27	1.84	2.95
	60-80	22.96	24.41	12.55	0.03	2.01
	80-100	28.96	23.40	11.70	1.72	2.32
	Total				17.30	24.38
	Average	32.54	25.47	12.45		
gypsum 20 tons/ha (as before)	0-20	41.95	28.52	12.77	6.08	7.32
	20-40	41.09	20.49	12.82	4.50	5.89
	40-60	21.50	25.95	12.27	1.84	2.95
	60-80	22.96	24.41	12.55	0.03	2.01
	80-100	26.47	12.06	11.39	1.34	1.80
	Total				22.11	25.73
	Average	32.40	17.95	12.31		

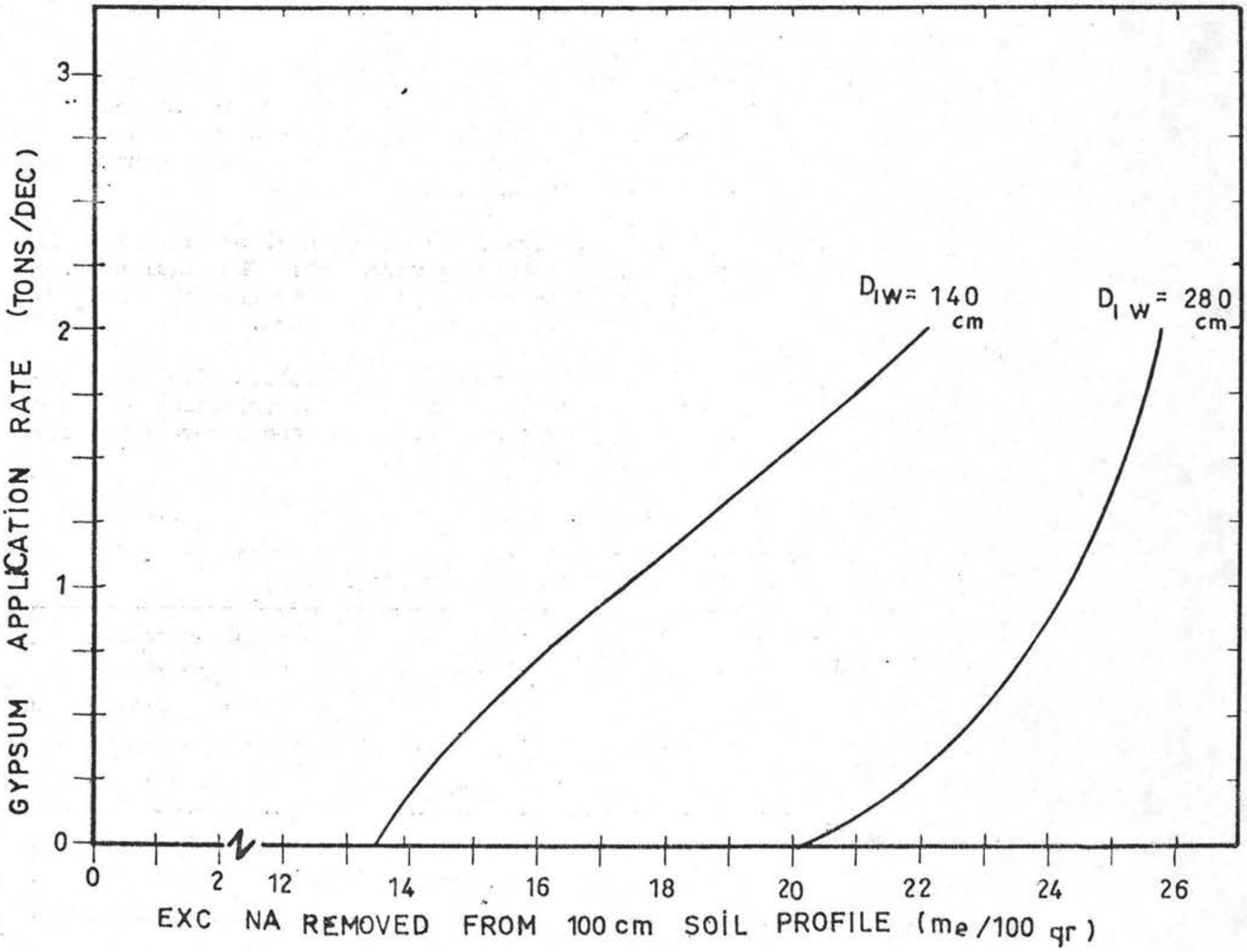


Fig. 5 Gypsum application rate curves for the Manisa-Gediz project area - alkali soils (Ü. Beyce et al, unpublished)

To obtain a gypsum application rate monogram to be used by the drainage engineers on the Antalya-Köprüçay and Manisa-Gediz projects, the $(ESP)_i$ values before leaching and the $(ESP)_f$ values obtained following various rates of gypsum and leaching in all treatments (see tables 15 and 16) can be used in the Gypsum Requirement equation

$$GR = (860 \times 10^{-6}) (A_s \times D_s \times A) \left(\frac{(ESP)_i - (ESP)_f}{100}\right) CEC$$

The GR values obtained, when plotted against the rate of gypsum applied, will give curves similar to those in figs. 4 and 5.

7. Conclusions drawn from experiment results

All the preceding examples of saline and alkali soils are given to show the character and reclamation potentials of these soils; also in a way they support the assumption that the main cause of salinity in Turkey is directly related to inadequate drainage. With the exception of some small local areas where the parent material is very rich in sodium salts, all saline soils in Turkey have drainage or waterlogging problems.

When artificial drainage is provided in these areas and when annual precipitation is around 500 mm, salinity in the upper soil profile diminishes very fast. The figures given in table 17 for three locations in Turkey indicate the leaching of salts from the soil profile under natural conditions when the water table is lowered by drainage.

Wherever possible, if such land can be put under rice crop or pasture after drainage is provided, the removal of salt is appreciable. Table 18 shows the distribution of the salt content between two drainage ditches following two years of rice crop and two years of irrigated pasture.

Table 17

Leaching of soluble salts from drained fields as effected by precipitation in various parts of Turkey (ref. 1, 2)

Location	Mediterranean coast (Tarsus-Alifaki)		Aegean coast (Izmir-Menemen)		Central Anatolia (Ankara-S.Koçhisar)	
Precipitation mm	523 mm		453 mm		300 mm x 6 years	
Date of sampling	Nov. 1960	May 1961	Dec. 1958	April 1959	Autumn 1963	Spring 1969
	$EC_e \times 10^3$		$EC_e \times 10^3$		$EC_e \times 10^3$	
0-30 cm soil depth	16.9	6.4	4.8	2.1	18.0	3.2
30-60 cm " "	20.3	19.1	23.3	13.0	13.0	8.0
60-90 cm " "	23.4	24.3	59.3	37.9	13.7	7.0

Table 18

Distribution of soil salinity in a transverse field cross section - open drains 1.5 m deep and 150 m spaced - after two years leaching with rice followed by two years of irrigated pasture, Mersin-Tarsus-Alifaki (ref. 1)

Depth of soil (cm)	$EC_e \times 10^3$ Distance from the drains (m)						
	20 m	40 m	60 m	75 m	60 m	40 m	20 m
0 - 30	1.7	4.0	11.0	9.0	4.1	2.0	1.7
30 - 60	4.3	8.2	11.5	17.0	8.5	7.2	8.0
60 - 90	4.3	11.0	13.8	21.7	11.0	8.5	8.7
90 - 120	6.2	12.1	14.3	22.0	15.0	10.7	10.0

Mr. M. Saatçilar from the Menemen Regional TOPRAKSU Research Institute conducted a series of leaching experiments on saline land installed with clay pipe, plastic pipe and open ditch drainage in 1971. The drains were spaced at 25 m and were 1.5 m deep. The average electrical conductivities of the saturation extracts for the 0-120 cm soil profile before and after applications of 88, 176 and 264 mm of water with three types of drainage are summarized in table 19. No explanation is given by the authors of why the different types of drainage system affected the leaching of salts in different ways.

Table 19

Leaching of soluble salts under three types of drainage in the 120 cm soil profile at Menemen-Kakliç (M. Saatçilar et al, unpublished)

Depth of leaching water (cm)	Clay pipe drains		Plastic pipe drains		Open ditch drains	
	$(EC \times 10^3)_i$	$(EC \times 10^3)_f$	$(EC \times 10^3)_i$	$(EC \times 10^3)_f$	$(EC \times 10^3)_i$	$(EC \times 10^3)_f$
79.2			21	3	24	4
88.0	28	11				
123.2	42	3				
140.8			18	3	26	11
158.4	39	3	21	4	37	13

8. Drainage projects on saline and alkali soil reclamation in Turkey

The role of drainage in the reclamation of saline and alkali soils is fully understood and accepted as a result of research and field trials, particularly at the Seyhan irrigation and drainage project.

On the Çukurova plain between 1964 and 1971 a gross project area (stages 1 and 2) of 107 300 ha was provided with field subsurface drainage on 16 076 ha; at the Gediz project on the Gediz plain (Aegean) a gross project area of 96 000 ha was provided with field subsurface drainage on 12 027 ha (table 20). Most of the area covered by field drainage in these two project areas had salinity or alkalinity problems to varying degrees. Only 900 ha of the Gediz project received a gypsum application; in 1971 20 tons/ha of gypsum were applied. Areas that had lost their productivity prior to drainage have been cultivated within a few years of installing drainage.

Apart from these two major project areas, 86 793 ha were provided with field drains (interceptor and surface drainage) from 1954 to 1971 in various parts of the country (table 21).

In the Seyhan and Gediz projects the main drainage canals were constructed by the state hydraulic works (DSI) and the collector and field drainage by TOPRAKSU.

Table 20

Collector and field subsurface drains installed at the Seyhan and Gediz projects between 1964 and 1971 (TOPRAKSU General Directorate)

Year	Seyhan project: Collector drains Area (ha)	Length (km)	Cost (1000 TL)	Seyhan project: Lateral (field) drains Area (ha)	Length (km)	Cost (1000 TL)	Gediz project: Collector drains Area (ha)	Length (km)	Cost (1000 TL)	Gediz project: Lateral (field) drains Area (ha)	Length (km)	Cost (1000 TL) [1]
1964		20					3000	51	2608			
1965		89					300	9	433			
1966		11		1326	69	933	455	8	490			
1967		8		3180	155	2678	3900	56	2838	800	24	726
1968		32		3798	240	4257	3200	47	2563	3200	69	2332
1969		10		4130	253	4312	4855	116	3586	3600	153	3921
1970		13		2220	362	6385	200	-		3167	181	4356
1971		-		1423	379	5708	760	14	771	1260	56	2390
Total		183		16076	1458	24273	16670	301	13319	12027	483	13725

[1] 14.00 Turkish lira = 1 US $

Table 21

Field, interceptor and surface drains installed in various parts of Turkey during 1954-1971 other than the Seyhan and Gediz projects (TOPRAKSU General Directorate)

Year	No. of projects	No. of farmer families	Area (ha)	Cost (1000 TL)
1954-61	13	2 789	2 072	2 923
1962	23	5 386	8 644	5 541
1963	30	4 200	9 960	7 233
1964	27	5 154	8 864	9 947
1965	33	8 381	12 449	12 148
1966	28	3 687	10 517	11 163
1967	29	3 769	8 937	12 364
1968	24	4 136	7 128	12 092
1969	24	4 347	8 988	9 665
1970	13	1 658	5 293	5 034
1971	13	2 076	3 941	4 443
Total	257	45 583	86 793	92 553

8.1 Construction and cost of subsurface drainage at the Seyhan project

The experience and data obtained at this project enabled us to make the given evaluations and cost estimates.

Size of project site: The total area of the development site is 181 300 ha. The Seyhan river divides this alluvial plain into two sections, running from the Taurus mountains in the north to the Mediterranean sea in the south. The part to the east of the Seyhan river (down to the Ceyhan river) is called the Yüregir Plain and the part to the west (down to the Tarsus river, Berdan) is called the Tarsus Plain. The Yüregir Plain covers 109 500 ha and the Tarsus Plain 71 800 ha. The project area is divided into three sections; section 1 covers 55 200 ha, section 2, 52 100 ha, and section 3, 74 000 ha. So far the work done has been on sections 1 and 2.

Topography of the project site: The elevation above sea level ranges from 0 to 60 m. The average slope between 0 and 20 m elevation is 0-1 percent while from 20 to 60 m the elevation is 1 percent or more. The land is rather undulating above 30 m.

Soils: The soils on the project site are alluviums of the Tarsus, Seyhan and Ceyhan rivers. Although these are heavy textured soils they do not have rocks, stones or tree roots to obstruct excavation and heavy machinery can work on them with no difficulty. The area that has waterlogging problems lies generally within the 0 to 1 percent slope range.

Extent of waterlogging: The area of the drainage problem (waterlogging) is 20 000 ha in section 1 and 20 870 in section 2.

Drainage system: Between 1966 and 1971 farm drainage (subsurface, clay pipe) was completed on 23 067 ha; the total length of clay pipe drains is 1 458 km. The main drainage ditches were constructed by the state hydraulic works (DSI), and the closed pipe system laid out by TOPRAKSU is connected to the open ditch system. The farm drainage is a parallel system.

Depth of piped drains: Piped drains are 1.8 m deep - suitable for cotton which is the dominant crop.

Spacing of field drains: The field drain spacings are in the range of 80-100-150-180 m depending on the soil texture and hydraulic conductivity.

Drainage material used: The clay pipe used for field drainage is 15 cm in diameter and 33 cm long. The filter material used is a sand gravel mixture. Where two pipes join, a strip of tar paper 10 cm wide and 2/3 of the outer diameter of the pipe is used.

Drainage machinery and equipment:
- Trencher, bucket wheel type (capable of digging trenches down to 203 cm)
  horsepower: Cleveland J 57-80 HP, made in U.S.A.
  width of trench: 38 to 76 cm (70 cm at Seyhan project)
  equipped with depth and slope control device (mechanical and spirit level)
- Tractors with trailers, trucks and loaders are used to carry the pipes and filter material
- Angle-dozer is used for refilling trenches
- A team of 5 is employed (including trencher operator).

Cost of drainage: Under the Seyhan project site conditions, with a trencher it is possible to lay 50 m of pipe per hour with an average working day of 10 hours. The following cost analysis for 1 linear m of pipe is made for 1971 prices. The values given also include machinery, equipment, labour and contractors' profits (table 22).

Table 22

Cost of 1 linear m of piped drainage at Seyhan project

Item	Per linear metre length		
	Quantity	Cost per unit TL	Total cost TL
Trenching (by trencher)	1 260 m^3	3.94	4.96
Clay pipe	3	2.73	8.19
Placing pipe	1 m	0.50	0.50
Placing filter material	0.175 m^3	6.84	1.20
Transport of filter material	0.280 tons	20.82	5.83
Refilling of trenches (by machine)	0.987 m^3	1.88	1.86
Tar paper	0.12 m^2	2.31	0.28
Junctions and relief wells			2.70
Service roads	1 m	1.26	1.26
Total cost of 1 m of piped drainage			26.78 TL

Abbreviations

A_s	=	bulk density of soil g/cm3
A	=	area, 1000 m^2
C	=	salt content of the soil profile at any given time during leaching
C_o	=	initial salt content of the soil profile
$\frac{C}{C_o}100$	=	percent of initial salt remaining in the soil profile
D_{1w}	=	depth of leaching water applied
D_s	=	depth of soil profile
ESP	=	exchangeable sodium percentage
$EC_e x10^3$	=	electrical conductivity of the soil saturation extract
GR	=	gypsum requirement tons/dec
NaX	=	removed exchangeable sodium, me/100 g
i	=	initial value
f	=	final value

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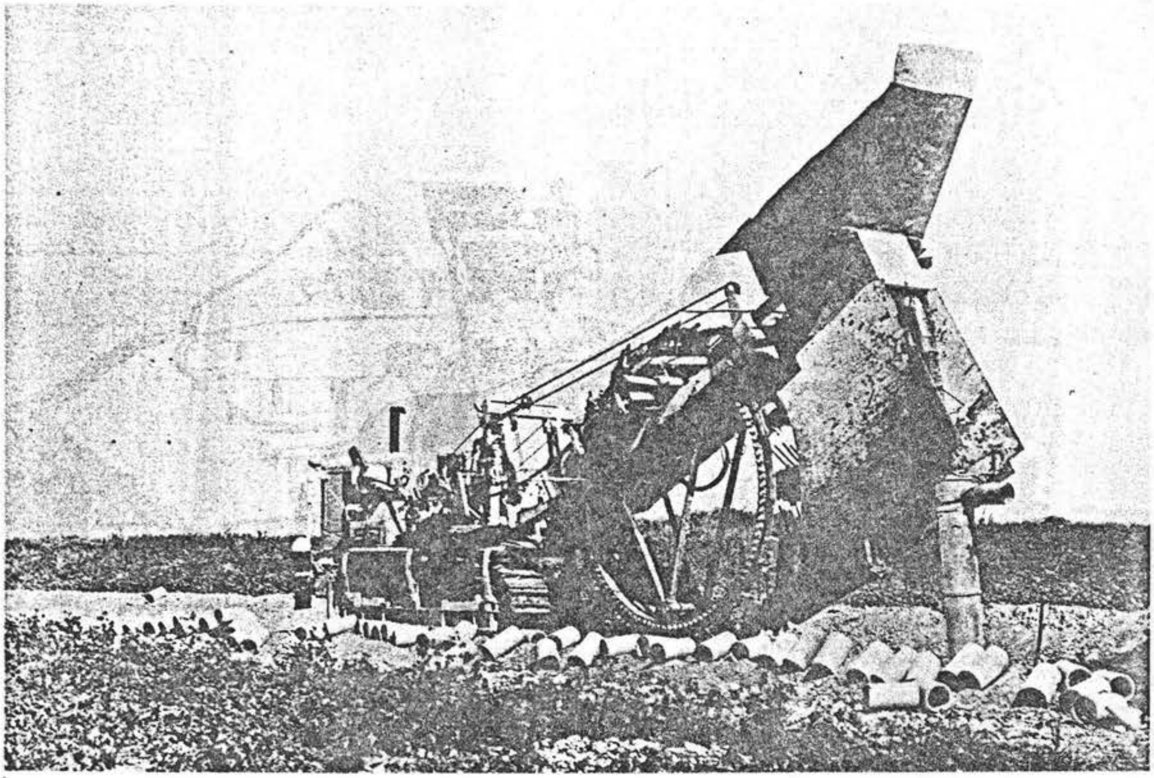

Plate 1 Cleveland J 57-80 HP USA-made Bucket wheel type trencher used on Seyhan Project

Plate 2 Cleveland trencher and crew laying pipes at Seyhan Project

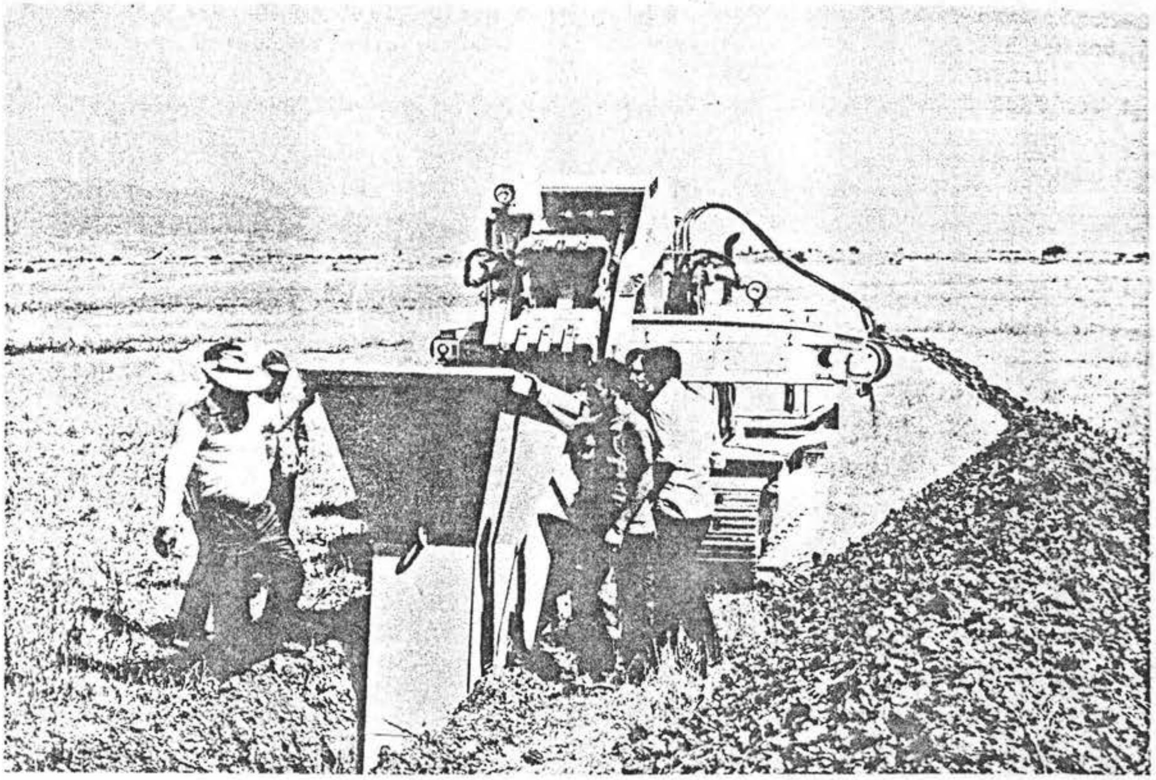

Plate 3 Schaeff trancher made in Fed. Rep. Germany used on Gediz Project

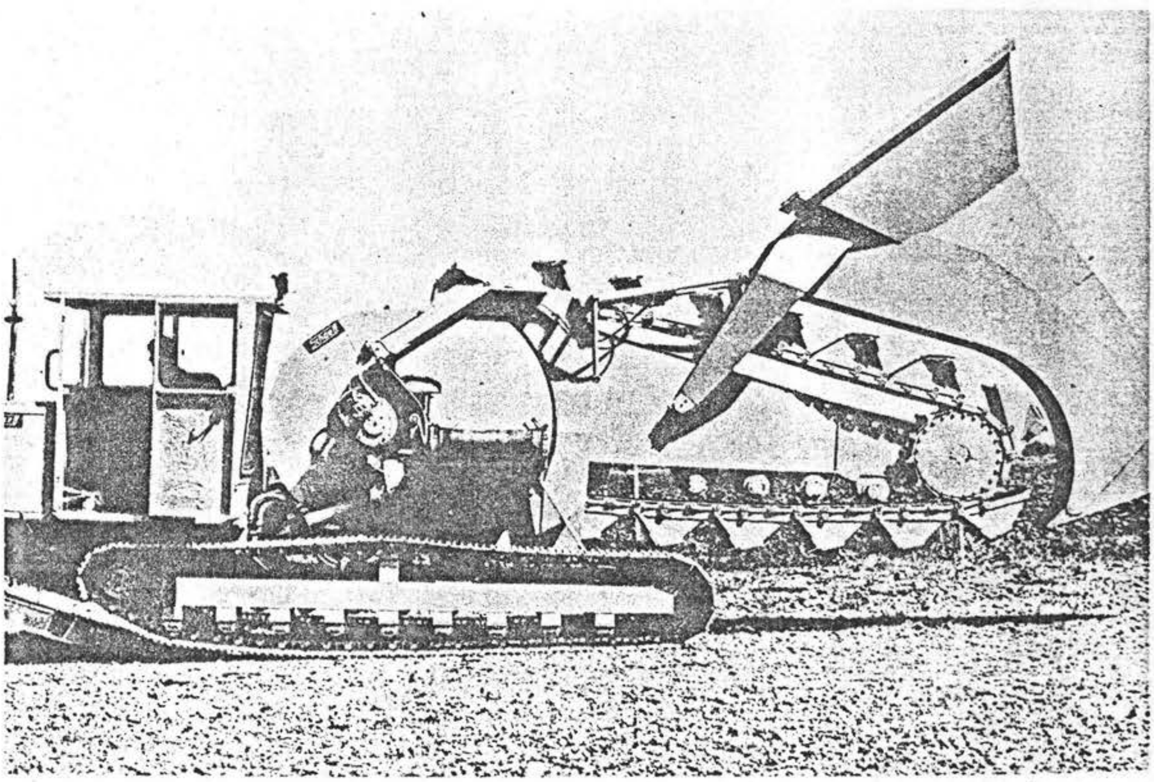

Plate 4 Schaeff trencher and crew laying pipes at Gediz Project