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SOIL SALINITY IN RELATION TO IRRIGATION

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SUMMARY

Investigations of the trend of salinity were conducted in typical farming areas of four southern California counties, over a ten-year period. The data show that the salinity of most of the soil areas examined is not increasing as a direct result of salts contained in the irrigation water. The salts thus added are being displaced downward wherever sufficient water is applied and where drainage conditions permit deep penetration.

The results suggest that most of the land in Imperial Valley with ground-water levels not less than 5 feet below the surface can be utilized, provided the amount of water applied is in considerable excess of crop requirements, and provided also that the ground water does not rise still nearer the surface. That the ground water can be kept down to this depth by artificial drains has already been established at several places in the Valley. The key to the success of Imperial Valley agriculture, therefore, is drainage. But the extent to which drainage can be increased in the Imperial Valley is limited, perhaps solely, by the rate of evaporation of the Salton Sea.

In the locations investigated in Orange, Riverside, and Ventura counties, the threat of salinity is essentially nonexistent. But in applying these results, one important consideration is the permeability of the soil to a depth well below the root zone. Unless the irrigation water or the rains actually penetrate entirely through the root zone, soluble salts will inevitably accumulate in that zone. Another consideration is the character of the salts in the irrigation water. If sodium exceeds 40 to 50 per cent of the total bases and if the soil is free from gypsum, excessive base exchange will take place, with the formation of more or less sodium clay. This will decrease permeability and may lead to salinity increases in the root zone. Under such circumstances, applications of gypsum to the soil or to the irrigation water will be beneficial.

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W. P. KELLEY,[2] B. M. LAURANCE,[3] and H. D. CHAPMAN[4]

INTRODUCTION

It is well known that irrigation commonly brings about increases in the soluble salts of the soil. In many places this increase has become excessive. Several hundred thousand acres of irrigated land in California alone have been severely injured by salts which accumulated after irrigation was begun, and similar effects have been produced in many other states. Few indeed of the irrigated areas in the United States have entirely escaped injury of this kind, and corresponding results have been reported from other countries. Recently it was estimated[5] that within the last eighteen years cultivation has been discontinued on 800,000 acres of irrigated land in the Punjab Province of India, and the rate of land deterioration is said to be increasing. The valleys of the Euphrates and Tigris in southwestern Asia, once highly productive under the ancient system of irrigation, were largely abandoned centuries ago and have remained practically unutilized down to the present time. Such facts have led authorities to question the permanence of irrigated soil. The idea has been advanced that irrigated agriculture is necessarily short-lived.

There are two different sources from which soluble salts may be derived and be caused to accumulate in irrigated soils—namely, (1) the irrigation water itself, and (2) the subsoil or the deep underground where salts were present before irrigation was begun. The ground water in dry climates usually contains considerable dissolved salts. Seepage from canals and irrigation laterals and the application of excessive amounts of irrigation water may cause the water level to rise, sometimes almost to the surface of the soil. As the ground water rises, the soluble salts native to the substrata dissolve, and this increases the concentration of the ground water. When the ground water

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comes sufficiently near the surface, evaporation and transpiration take place, leaving the salts in the soil. This is the result wherever the water evaporates or is transpired, whether on the surface or at some depth below the surface. By this process the salt content of the soil may become extremely high.

The salt accumulations referred to in the first paragraph have arisen chiefly from *pre-existing deposits in the substratum rather than from the irrigation water*. However, salts contained in the irrigation water may contribute to the salt content of both the soil and the ground water. But in some localities, at least, the tendency from the use of saline irrigation water will be for the concentration of the ground water to be reduced rather than increased. Whether the salts dissolved in irrigation water will accumulate in the soil in injurious amounts depends on one or more of the following:

1. The concentration and composition of irrigation water.
2. The amount of water applied per irrigation.
3. The method of soil and irrigation management employed by the farmer.
4. The rainfall.
5. Soil permeability and profile characteristics.
6. Depth to water table.

If the rainfall is light and the irrigation water fails to penetrate below the depth of crop roots, salts added as constituents of the irrigation water will certainly accumulate in the soil. In such cases, the concentration will inevitably become injurious in the course of time. The rate of accumulation will depend on the concentration and amount of the irrigation water applied. On the other hand, if the irrigation water penetrates to a depth below the root zone, soluble salts will be displaced downward and this will tend to limit the accumulation in the root zone. In this case, the accumulation of an injurious concentration in the soil will depend largely on the concentration of the irrigation water.

The concentration of any solution is always increased by withdrawing water from it. This means that when plant roots absorb water from the soil, the concentration of the remaining solution increases. In other words, the concentration of the soil solution gradually increases as plants absorb water from the soil. It is important to understand that *it is the salinity of the soil solution rather than that of the irrigation water that affects crops.*

Excepting brief periods immediately after each application of saline irrigation water, the soil solution is always more concentrated than the irrigation water. Whether or not the concentration will become injurious in a given case depends on the amount of leaching that takes place, and this in turn depends on: (1) the depth of penetration of the water, and (2) the rainfall. Where the rainfall is heavy enough to leach salts out of the root zone, the maximum accumulation of soluble salts resulting from the use of saline water may be produced in the course of a single season's irrigation. On the other hand, where the rainfall is extremely light, as in the Imperial Valley (table 1), the concentration of the soil solution will ultimately become injurious as a direct result of applying saline water, *unless enough irrigation water is applied to penetrate entirely through the root zone.*

Early in his work on arid and semiarid soils, Hilgard recognized the importance of the salts contained in irrigation water. Accordingly, he analyzed irrigation waters on a considerable scale and reported the results to interested farmers. His successors in California and other states have enlarged and extended this work until now practically every important supply of irrigation water in the United States has been analyzed.

Scofield (1940)[6] has laid special emphasis on the relation between the input and outgo of salts—that is, the relation between the amounts of salts added as constituents of the irrigation water and the amounts removed in the drainage. To this relation the term "salt balance" has been applied.

Soluble salts existing in the deep underground, or even in the subsoil just below the depth of root penetration, produce no effect on the growth of crops

TABLE 1

INCHES OF RAINFALL AT POINTS NEAR SAMPLING PLOTS

Year	Imperial Valley*	Riverside*	Orange County				Ventura County	
			Yorba Linda†	Anaheim†	La Habra†	Tustin†	Santa Paula*	Oxnard*
1935	5.3	....	....	....	....	....	....	....
1936	1.6	16.3	....	....	10.1	8.2	14.8	....
1937	1.5	13.9	29.5	16.1	24.7	23.3	24.5	20.7
1938	3.8	15.5	23.9	18.1	24.2	18.4	24.2	19.7
1939	8.5	10.9	14.9	17.1	12.0	15.0	13.2	11.4
1940	5.1	10.2	19.5	13.2	19.2	17.3	14.3	14.4
1941	6.6	21.2	39.7	37.2	30.7	32.0	37.8	36.0
1942	2.5	4.7	13.3	13.1	12.4	14.5	13.1	13.5
1943	4.5	21.4	21.7	18.0	19.9	17.3	17.2	18.5
1944	3.6	12.3	18.0	16.2	14.0	20.5	....	23.8
1945	2.8	11.6	15.9	15.3	11.2	18.2	9.4	8.7
Average	4.2	14.0	21.8	18.3	17.8	18.5	18.7	18.5

* Jan. 1 to Dec. 31.
† Sept. 1 to Aug. 31.

so long as they remain below the reach of plant roots. In many areas on which crops are grown successfully, the deep subsoil contains high concentrations of soluble salts. In some places thick beds of almost pure salt occur in the substratum. The salts in the drainage from such areas are very likely to be derived, in considerable part, from these deposits.

Scofield (1933) found that the yearly chloride content of the combined drainage of the Imperial Valley of California substantially exceeds the total amount of chloride added annually in the irrigation water to the whole Valley. As he pointed out, chloride, native either to the soils, the subsoils, or both, is almost certainly contributing to the salt content of the drainage water currently being discharged into the Salton Sea, the only drainage outlet for the Valley. At the same time, chloride has accumulated in injurious amounts in certain places in the Valley, and this accumulation is still going on. Here it is obvious that the "salt balance" concept has little or no pertinence to agriculture, and this will continue to be true for many years. Probably a similar condition exists in many other irrigated areas.

What is important is not the relation between input of salts in irrigation water and outgo of salts in drainage water *but what is happening to the soil*

[6] See "Literature Cited" for citations, referred to in the text by author and date.

TABLE 2

LOCATION OF SAMPLING PLOTS, SOIL AND WATER-TABLE CHARACTERISTICS, CROPPING SYSTEM, AND SOURCE AND QUALITY OF IRRIGATION WATER USED

Plot no.	Nearest city	County	Crops grown	Soil type	Depth to ground water, feet	Irrigation water characteristics										
						Source	Composition, m.c./l*							Total solids, p.p.m.	Sodium, per cent†
							HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na		
1	El Centro	Imperial	Field	Holtville silty clay	3.5–7.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
2	Holtville	Imperial	Field	Meloland fine sandy loam	>11.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
3	Holtville	Imperial	Field and truck	Imperial silty clay	3.5–9.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
4	Calexico	Imperial	Grapefruit	Imperial silty clay	6.5–11.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
5	Calexico	Imperial	Field and truck	Holtville silty clay loam	5.0–15.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
6	El Centro	Imperial	Grapefruit	Holtville silty clay	3.0–12.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
7	Holtville	Imperial	Field	Imperial silty clay	2.5–10.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
8	Brawley	Imperial	Field and truck	Imperial clay	>11.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
9	Calipatria	Imperial	Field	Holtville clay loam	2.5–8.0	Colo. R. + drainage	3.7	7.9	9.7	0.02	6.2	4.8	10.4	1,397	48
10	Westmorland	Imperial	Field and truck	Meloland loam	1.5–6.0	Colo. River	2.8	2.7	7.2	0.02	5.2	2.6	5.0	865	39
11	Tustin	Orange	Oranges	Yolo clay loam	>30.0	Well	4.0	5.2	2.8	0.20	6.1	2.5	3.3	808	28
12	La Habra	Orange	Lemons	Yolo silty clay	>30.0	Well	3.0	6.3	15.2	1.80	13.4	9.0	3.8	1,717	15
20	Anaheim	Orange	Oranges	Hanford sand	>25.0	Well	3.5	0.4	0.8	0.34	2.4	0.9	1.4	381	30
21	Orange	Orange	Oranges	Dublin clay	>20.0	Wells	4.3	2.6	2.3	0.05	4.2	2.0	3.0	647	33
22	Yorba Linda	Orange	Oranges	Ramona loam	>30.0	Wells	4.6	2.4	4.7	0.20	5.7	2.1	4.2	841	35
16	Oxnard	Ventura	Lemons	Yolo loam	3.0–6.0	Well	4.1	1.2	7.8	....	6.1	3.2	3.7	918	28
17	Oxnard	Ventura	Lemons	Yolo silt loam	3.0–6.0	Well	4.1	1.2	7.8	....	6.1	3.2	3.7	918	28
18	Oxnard	Ventura	Lemons	Yolo sandy loam	4.0–7.0	Well	4.7	1.5	7.2	....	6.0	2.0	2.6	857	25
19	Oxnard	Ventura	Lemons	Yolo sandy loam	4.0–7.0	Well	4.2	1.5	7.2	....	6.0	2.0	2.6	857	25
13	Ventura	Ventura	Walnuts	Yolo clay loam	>20.0	Well	5.6	1.7	8.3	....	7.0	3.5	5.0	1,095	32
14	Ventura	Ventura	Lemons	Yolo clay loam	>20.0	Well	5.4	2.9	13.9	....	11.3	5.5	6.0	1,535	26
15	Santa Paula	Ventura	Oranges	Yolo silt loam	>16.0	Well	6.0	2.2	12.9	....	9.4	4.3	7.5	1,481	35
23	Riverside	Riverside	Oranges	Ramona sandy loam	>30.0	Gage Canal	3.0	0.6	1.0	0.10	2.4	0.7	1.4	352	31

* Milliequivalents per liter.
† Per cent of total bases.

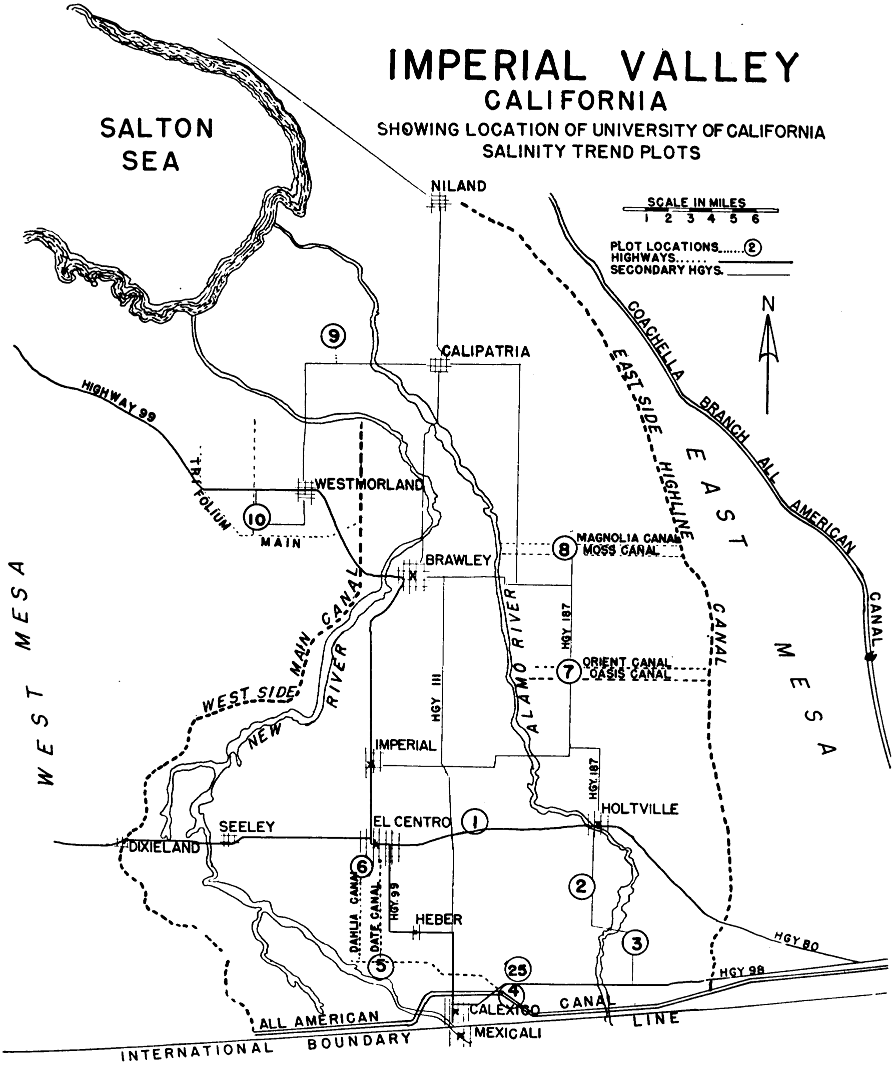

Fig. 1. Map showing location of salinity-trend plots, Imperial Valley.

itself. Is the salt content of the soil or subsoil within the reach of plant roots increasing or decreasing? If increasing, then the agriculture of that area is definitely threatened. If not, successful agriculture is not necessarily endangered. It was with this specific question in mind that the investigation reported in this paper was begun.

SOILS

This problem has been investigated in the Imperial Valley and in Riverside, Orange, and Ventura counties of California. Soil samples taken to the depth of 6 feet from definite locations in each of these regions have been analyzed annually for a period of ten years. A list of the sampling plots show-

TABLE 3

AVERAGE SOIL TEXTURE AND MOISTURE EQUIVALENT BY FOOT DEPTHS DOWN TO 6 FEET*

Horizon, inches	Plot 1, Holtville silty clay		Plot 2, Meloland fine sandy loam		Plot 3, Imperial silty clay	
	Texture	Moisture equiv.	Texture	Moisture equiv.	Texture	Moisture equiv.
0–12	Silty clay	P†	Fine sandy loam	17	Silty clay	29
12–24	Silty clay	20	Fine sandy loam	17	Silty clay	28
24–36	Silty clay	18	Silt loam	25	Silty clay	30
36–48	Silty clay	21	Silt loam	..	Silt loam	24
48–60	Silty clay loam	23	Silt loam	21	Silty clay	28
60–72	Silty clay loam	27	Very fine sandy loam	17	Very fine sandy loam	24

Horizon, inches	Plot 4, Imperial silty clay		Plot 5, Holtville silty clay loam		Plot 6, Holtville silty clay	
	Texture	Moisture equiv.	Texture	Moisture equiv.	Texture	Moisture equiv.
0–12	Silty clay	23	Silty clay loam	P	Silty clay	33
12–24	Silty clay	33	Silt loam	P	Silty clay	34
24–36	Silty clay	33	Silty clay	32	Silty clay	29
36–48	Silt loam	42	Silty clay	31	Silty clay	35
48–60	Silt loam	23	Silt loam	32	Silty clay	26
60–72	Silty clay	33	Silt loam	..	Silty clay	34

Horizon, inches	Plot 7, Imperial silty clay		Plot 8, Imperial clay		Plot 9, Holtville clay loam	
	Texture	Moisture equiv.	Texture	Moisture equiv.	Texture	Moisture equiv.
0–12	Silty clay	34	Clay	31	Clay loam	P
12–24	Silty clay	29	Silty clay	28	Fine sandy loam	P
24–36	Silty clay	34	Clay	34	Very fine sandy loam	P
36–48	Silt loam	29	Clay	P	Fine sandy loam	29
48–60	Silt loam	P	Clay	32	Silt loam	28
60–72	Silty clay	36	Clay	35	Silt loam	25

Horizon, inches	Plot 10, Meloland loam		Plot 11, Yolo clay loam		Plot 12, Yolo silty clay	
	Texture	Moisture equiv.	Texture	Moisture equiv.	Texture	Moisture equiv.
0–12	Loam	17	Clay loam	24	Silty clay loam	27
12–24	Loam	16	Silt loam	23	Silty clay loam	29
24–36	Loamy fine sand	11	Silt loam	22	Silty clay loam	27
36–48	Loam	11	Clay loam	26	Silty clay loam	26
48–60	Silty clay loam	19	Clay loam	31	Silty clay loam	26
60–72	Silty clay loam	25	Clay	34	Clay loam	24

* The texture determinations were made on the 1946 samples, whereas the moisture-equivalent determinations were made on a former set. This probably accounts for some of the discrepancies.
† P = puddled.

TABLE 3—*Concluded*

Horizon, inches	Plot 20, Hanford sand		Plot 21, Dublin clay		Plot 22, Ramona loam	
	Texture	Moisture equiv.	Texture	Moisture equiv.	Texture	Moisture equiv.
0–12	Sand	10	Clay	37	Loam	18
12–24	Sand	10	Clay	38	Clay loam	20
24–36	Sand	9	Clay	37	Clay loam	22
36–48	Loam	23	Clay	37	Silt loam	25
48–60	Silt loam	26	Clay	38	Clay loam	27
60–72	Silt loam	24	Clay	37	Clay loam	30

Horizon, inches	Plot 16, Yolo loam		Plot 24, Ramona sandy loam		Plot 18, Yolo sandy loam	
	Texture	Moisture equiv.	Texture	Moisture equiv.	Texture	Moisture equiv.
0–12	Loam	17	Sandy loam	14	Sandy loam	13
12–24	Fine sandy loam	13	Sandy loam	16	Loam	14
24–36	Fine sandy loam	14	Loam	17	Silt loam	16
36–48	Loam	16	Loam	17	Silt loam	17
48–60	Silt loam	17	Loam	17	Silt loam	15
60–72	Loam	17	Loam	18	Silt loam	15

Horizon, inches	Plot 19, Yolo sandy loam		Plot 13, Yolo clay loam		Plot 14, Yolo clay loam	
	Texture	Moisture equiv.	Texture	Moisture equiv.	Texture	Moisture equiv.
0–12	Sandy loam	13	Clay loam	29	Clay loam	28
12–24	Sand	14	Clay	31	Clay loam	27
24–36	Sandy loam	16	Silty clay	28	Clay loam	23
36–48	Silt loam	17	Clay loam	27	Clay loam	21
48–60	Loam	15	Silt loam	26	Silt loam	18
60–72	Sandy loam	15	Silt loam	25	Clay loam	19

Horizon, inches	Plot 15, Yolo silt loam	
	Texture	Moisture equiv.
0–12	Silt loam	24
12–24	Silt loam	27
24–36	Clay loam	29
36–48	Clay loam	27
48–60	Clay loam	27
60–72	Silt loam	28

ing location, soil type, water-table depth, and the source and quality of irrigation water used is presented in table 2. The distribution and location of the sampling points in Imperial Valley are shown in figure 1. Rainfall records in the various areas for the 10-year period are shown in table 1. Moisture-equivalent determinations and the textural characteristics of the soils of all locations are recorded in table 3.

The soils of the Imperial Valley belong chiefly to the Imperial, Holtville, and Meloland series. Each of these was represented in the Imperial Valley

TABLE 4

STRATIFICATION LOG OF PLOT 1

Soil: Holtville Silty Clay

Depth, inches	Texture	Notes
0–10	Sandy clay loam..........	
10–15	Sandy loam..............	
15–28	Loamy sand..............	
28–36	Loam....................	
36–74	Silty clay................	Laminations of sand, silt, and clay throughout
74–83	Silty clay................	Compact
83–101	Silty clay................	Grades into clay
101–109	Silty clay to clay..........	Very compact
109–120...	Silty clay................	Compact
120–121	Sand.....................	
121–139	Silty loam...............	
139–154	Silty clay loam to clay....	Grades into clay, some laminations of very fine sand
154–173	Clay.....................	Very compact
173–176	Silt loam.................	
176–187	Silty clay................	Very fine sand and silt stringer
187–190	Silty clay................	
190–192	Silty clay................	

TABLE 5

STRATIFICATION LOG OF PLOT 2

Soil: Meloland Fine Sandy Loam

Depth, inches	Texture	Notes
0–7	Sandy loam..............	
7–18	Loamy sand..............	
18–42	Silty clay................	Dense, lentils increasing in number beyond 36 in.
42–65	Very fine silty sand.......	
65–85	Medium sand............	
85–96	Silty clay loam...........	Laminations of very thin sand layers
96–101	Loamy sand..............	
101–106	Sand and silty clay........	Alternating layers
106–107	Silty clay................	
107–108	Loamy sand..............	
108–119	Silty clay................	Compact, some lentils
119–121	Loamy sand..............	
121–126	Clay.....................	Very compact, reddish
126–129	Silty clay................	
129–137	Silty loam...............	Compact
137–150	Clay.....................	Compact, reddish
150–158	Loamy sand..............	
158–160	Clay.....................	Compact, reddish
160–172	Silty clay................	
172–192	Clay.....................	Compact, a few lentils of silty sand

sampling areas. The soils actually sampled were fine clay, silty clay, clay loam, or fine sandy loam. Throughout the Imperial Valley the subsoil to great depth is highly stratified. Cores from several sampling places, taken to the depth of 16 feet in some instances by the Soil Conservation Service, showed numerous thin layers of very fine sand or clay sandwiched between layers of coarser material. The downward movement of water is almost certainly retarded by these layers. However, as will be shown later, the soil at every sampling place in the Imperial Valley is far from being impervious to water. Detailed logs of soil-profile characteristics in four of the Imperial Valley sampling locations are shown in tables 4, 5, 6, and 7.

Means and party (1903), Means and Holmes (1901, 1902) and Hilgard, Shaw, and Snow (1902) showed that before irrigation was begun the alluvium of the Imperial Valley down to 20 or more feet contained substantial amounts of soluble salts. Means and Holmes emphasized the fact that the ground water found at depths of 30 to 50 feet was strongly saline.

TABLE 6

STRATIFICATION LOG OF PLOT 5

Soil: Holtville Silty Clay Loam

Depth, inches	Texture	Notes
0–13	Silty clay	
13–24	Silty clay	Compact, sand lenticules
24–35	Silty clay	
35–47	Silty clay	
47–59	Silty clay	Laminations of silt
59–65	Silty clay	Laminations of silt
65–74	Clay and silt	Numerous laminations of silt
74–88	Sandy clay	Streaks of medium fine sand, shells
88–101	Sandy clay	Laminations of fine sand at 92 in.
101–108	Clay and sand	Stringers of medium sand, shells

TABLE 7

STRATIFICATION LOG OF PLOT 6

Soil: Holtville Silty Clay

Depth, inches	Texture	Notes
0–7	Silty clay	
7–18	Silty clay	Compact, iron stains, some sand lenses
18–25	Silty clay	Sand lenticules, iron stains
25–42	Clay and sand	Large stringer of sand in clay stratum
42–47	Sandy loam	Mixed with silty clay
47–50	Loamy sand	Mixed with some red clay
50–78	Silty clay	Compact, iron stains
78–108	Loamy sand	Iron stains
108–113	Silty clay	Red clay lenses interspersed
113–174	Silty clay	Compact
174–180	Sandy loam	Some laminations of very fine sand
180–190	Sandy clay	Compact

In Riverside, Orange, and Ventura counties the sampling places were located on soils of the Ramona, Hanford, Dublin, and Yolo series. Ground water was a problem only in the Oxnard (Ventura County) locations.

IRRIGATION WATERS

The irrigation water applied in the Imperial Valley was drawn from the Colorado River, and that used on the experimental areas in Orange and Ventura counties from wells. All of these are moderately saline, as shown in table 2. The water used in Riverside County was taken from the Gage Canal and was the least saline of any used in this investigation. It will be noted that some of the well waters contain more total salts than the uncontaminated Colorado River supply as used in the Imperial Valley. The proportions of the different salts varied considerably in the different supplies. With the exception of one well in Orange County (plot 12), the sodium content ranged from 25 to 48 per cent of the total bases.

EXPERIMENTAL PROCEDURE

Methods of Sampling. Soil samples were drawn annually from established sampling plots at ten locations in the Imperial Valley, five in Orange County, seven in Ventura County, and one in Riverside County (see table 2). At each location 10 separate samples of each foot to a depth of 6 feet were taken with a 2-inch soil auger. The exact sampling places were accurately marked, and each subsequent year the samples were taken not more than 12 inches away from the original sampling places. After becoming air-dry in the laboratory, the samples were passed through a 1-mm sieve. Composite samples were made up for each foot in depth of a given sampling place by thoroughly mixing equal amounts of all the 10 samples from that location. These were analyzed for water-soluble salts.

In all cases, the established sampling plots were located on cropped land; some were in citrus orchards, others in fields where crop rotation was practiced. In no case was the irrigation or management of the sampling area different from that of the rest of the field. *The purpose was to determine, under the normal irrigation and cropping practices common to each location, the trend of salinity in the root zone.*

Ground Water. Measurements on the depth to ground water are shown in table 2 and also in tables 9 to 31. Samples of the ground water were taken for analysis several times at certain places. These results will be published in a separate paper dealing specifically with the ground water. Suffice it to say here that the ground water was far from uniform in composition and concentration in different parts of the Imperial Valley. However, there appears to be but little correlation between ground-water composition and salt content of the overlying soil. In Riverside and Orange counties and, excepting the Oxnard area, in Ventura County, the ground water in the sampling locations was too deep throughout the period of this investigation to have any influence on the overlying soil.

Methods of Analysis. Analyses were made on water extracts obtained by shaking 200 grams of soil with 1 liter of distilled water for 30 minutes in a reciprocal shaker. The suspensions were then filtered through clay filters and the filtrates were analyzed for carbonate, bicarbonate, chloride, sulfate, calcium, magnesium, and sodium.

We recognize that analysis of water extracts of the soil does not give a true measure of certain constituents (or possibly of any) as they exist in the soil solution. But in the first place, the soil solution is itself far from constant in a given place, since its concentration varies inversely with the moisture content of the soil, and this variation may be both quantitative and qualitative; the leaching effect of irrigation water and of rains also produces changes in the soil solution. Furthermore, the results obtained by analyzing water extracts are certainly comparable as between different sampling dates. The analyses unquestionably show the essential nature of the trends in salinity, and it is the trends rather than the exact composition of the soil solution that are being investigated.

Variability within a Given Sampling Location. In order to evaluate the significance of year-to-year changes in salt content, sampling error was determined in three of the Imperial Valley locations. In the locations chosen, 10 composite samples were taken in exactly the same manner as that employed

TABLE 8

VARIABILITY OF CHLORIDE AND SULFATE IN TEN REPLICATE SAMPLES FROM SAMPLING PLOTS IN IMPERIAL VALLEY

Sample number	Average concentration of constituent to depth of 6 feet, me/kg*					
	Plot 2		Plot 6		Plot 7	
	Chloride	Sulfate	Chloride	Sulfate	Chloride	Sulfate
1	6.7	44.7	26.6	44.5	24.2	66.8
2	6.5	44.4	26.9	45.0	25.4	62.8
3	6.9	43.5	27.3	44.6	25.4	72.1
4	5.9	43.1	30.0	50.2	26.2	76.3
5	7.1	43.3	27.2	43.0	24.6	72.0
6	6.7	47.1	28.1	57.4	25.6	72.1
7	6.0	44.1	28.8	47.0	26.3	70.2
8	6.3	44.2	30.6	49.5	25.2	72.2
9	7.3	49.1	27.6	47.6	22.9	74.6
10	6.9	50.8	28.9	51.7	25.9	68.5
Mean	6.6	45.4	28.2	48.1	25.7	70.8
Standard deviation	0.5	2.7	1.4	4.3	1.0	3.9

* Milliequivalents per kilogram of soil.

in the annual sampling—that is, each sample represented a composite of 10 cores. In taking these samples, points were established 6 feet away from each of the regular 10 established sampling points. Two circles, one 12 inches and the other 24 inches in radius, were described around each of these 10 points. Ten separate cores were then taken in foot sections down to 6 feet in depth at regularly spaced intervals on the circumference of these circles. In each of the 10 different sampling points, all ten of the samples from the first foot in depth were then composited, those from the second foot similarly, and so on. Chloride and sulfate only were determined in these samples. The results are shown in table 8. The data indicate that the sampling error in the Imperial Valley was not excessive. It is reasonably certain that the samples drawn annually give a fairly reliable indication of the true salt content of the plots.

EXPERIMENTAL RESULTS

The data for the 23 sampling plots are presented in tables 9 to 31. In order to set forth both the trend of salinity, and the character of the salts present for each plot, the average amount of each salt constituent (that is, bicarbonate, chloride, sulfate, calcium, magnesium, and sodium), to a depth of 6 feet, expressed as milliequivalents per million, is shown for each year of sampling. In other columns are given the sodium content as a per cent of total bases; the depth to water table at the time of sampling; the crop growing at this time; and a record of crop condition or yield. Figure 2 (p. 659) shows the vertical distribution of chlorine for three plots in the Imperial Valley at the beginning and the end of the experiment.

Before considering the data, it is important to point out that the soil samples were drawn without regard to the time of the immediately preceding irrigation. Some samples were taken only a few days after an irrigation, others several days later, and still others three or four weeks later. Therefore, where the ground water was high, variations in the effects of the ground water must have been reflected in the salt content of the soil. If sampled within a few days after the preceding irrigation, capillary rise of salts from the rather highly saline ground water as it occurs in the Imperial Valley was probably least pronounced, whereas just preceding an irrigation it was most marked. Hence, some variations found at a given plot, particularly with the ground water 5 to 8 feet from the surface, were probably due to this cause.

Also, the leaching action of the irrigation water was probably far from constant in the different plots, and possibly even on a given plot, owing to variations in the method of water application and in the amount applied. Where alfalfa and flax were grown, the flooding system was used, whereas with cultivated crops, such as citrus trees and truck crops, the furrow method was generally employed. But the amount of water applied by a given farmer was not always the same for each irrigation or for each year. Generally speaking, the amount of water applied in a single irrigation was greatest with the truck crops and least with alfalfa. For these reasons it is not surprising that the vertical distribution of salts at a given place varied from time to time. However, the average amounts of the several constituents found in the soil to a depth of 6 feet probably afford a sound basis for judgment regarding the trends in salinity.

Imperial Valley. The soil at certain sampling places contained crystals of gypsum, at others practically none. Since the solubility of gypsum is affected by other soluble salts, it is difficult to interpret the calcium and sulfate data. However, in view of the parallelism between sulfate and sodium, particularly in certain places, all the data are reported. It may be pointed out that the ratio of sodium to calcium ranged from approximately 1½ to 3. The ratio of calcium to magnesium ranged from 1½ to 2. As shown in the tables, the sodium percentage ranged from about 40 to 70 per cent of the total bases, and was usually in excess of 50 per cent. Salt solutions of the composition and concentration existing in the soils of the Imperial Valley will not effect more than a limited amount of base exchange in the soil. The clay was probably not more than 20 to 25 per cent sodium-saturated at any of the sampling places; and as the soil is leached with Colorado River water, the percentage of sodium saturation will tend to decrease. Furthermore, as long as the soil solution remains high in total salts of the kinds found in the Imperial Valley, the soil colloids will be largely flocculated and reasonably permeable to water. Furthermore, the soils of the Imperial Valley do not become excessively dispersed upon leaching. Therefore, for practical purposes, base exchange can be disregarded in the Imperial Valley. The emphasis certain workers (Eaton and Sokoloff, 1935) have placed on relatively small percentages of replace-

TABLE 9

SALINITY TREND IN PLOT 1 (IMPERIAL VALLEY)

Soil: Holtville silty clay

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Nov., 1935	4.9	6.2	23.4	8.1	5.4	20.0	60	4.0	Milo	Good crop
Feb., 1937	5.8	5.9	23.0	11.0	6.6	19.0	52	3.2	Alfalfa	Pasture
Feb., 1938	5.5	6.4	26.9	10.4	6.5	20.8	55	4.5	Alfalfa	Pasture
Feb., 1939	4.0	11.8	33.5	14.1	7.8	27.4	56	4.0	Alfalfa	4 tons
Feb., 1940	5.5	12.1	34.3	13.3	18.2	20.1	39	4.2	Alfalfa Flax	No record
Feb., 1941	5.2	11.7	43.9	21.4	11.7	27.3	45	3.8	Flax	35 bu.
Apr., 1942	4.2	14.2	33.9	13.1	10.9	28.7	54	3.7	Flax	26.5 bu.
Feb., 1943	4.5	11.2	32.6	13.6	7.4	27.0	56	3.7	Flax	44.1 bu.
Mar., 1944	5.0	12.1	39.7	16.6	9.6	29.2	53	3.5	Alfalfa	4.36 tons
Feb., 1945	3.9	23.4	57.0	23.7	16.4	44.0	52	4.3	Alfalfa	Pasture
Average....	4.9	11.5	34.8	14.5	10.0	26.3	52	3.9		

* Milliequivalents per kilogram of soil.
† At time of sampling.

TABLE 10

SALINITY TREND IN PLOT 2 (IMPERIAL VALLEY)

Soil: Meloland fine sandy loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Dec., 1935	5.0	12.7	35.9	14.4	7.5	28.8	57	>11	Alfalfa	Pasture
Feb., 1937	6.0	13.7	38.1	15.6	11.8	33.3	55	>11	Alfalfa	Pasture
Feb., 1938	5.3	11.8	41.7	17.5	9.7	31.2	53	>11	Alfalfa	Pasture
Feb., 1939	5.2	11.7	46.9	21.6	10.4	32.1	50	>11	Alfalfa	Pasture
Feb., 1940	7.8	6.2	28.2	16.3	6.7	19.5	46	>11	Barley	Good crop
Feb., 1941	5.7	5.1	33.0	17.9	9.0	16.3	38	>11	Flax	31 bu.
Mar., 1942	4.2	4.2	24.8	12.5	6.6	14.0	42	>11	Flax	39 bu.
Feb., 1943	4.5	5.0	32.8	14.5	7.3	19.9	48	>11	Flax	42 bu.
Mar., 1944	4.4	9.8	36.8	14.2	16.4	20.3	40	>11	Flax	41 bu.
Feb., 1945	4.3	6.3	37.1	14.1	9.2	24.6	51	>11	Barley	Good crop
Average....	5.2	8.6	35.5	15.9	9.5	24.0	49	>11		

* Milliequivalents per kilogram of soil.
† At time of sampling.

able sodium in saline soils containing high amounts of gypsum or other soluble calcium salts, we believe to be inapplicable to the Imperial Valley. The practical problem in the Imperial Valley is drainage, and not base exchange.

As shown in tables 10, 11, 13, and 16, the soils in plots 2, 3, 5, and 8, are distinctly not increasing in salinity; rather, the content of chloride in these plots either remained low or else decreased in the latter part of the period of this study. Soluble sodium also decreased in plots 2 and 8 and remained fairly constant in plots 3 and 5.

On the other hand, the salinity of the soil in plots 1, 4, and 6 (see tables

TABLE 11

SALINITY TREND IN PLOT 3 (IMPERIAL VALLEY)

Soil: Imperial silty clay

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Dec., 1935	4.9	5.1	15.2	6.8	5.3	12.2	50	9.0	Lettuce	239 crates
Feb., 1937	5.6	4.4	16.3	8.0	7.9	12.4	44	9.0	Wheat	45 bu.
Feb., 1938	5.5	4.1	17.6	7.5	3.9	15.1	57	5.9	Lettuce	300 crates
Feb., 1939	5.4	6.7	30.4	12.5	7.8	22.0	52	7.6	Beets	20.4 tons
Feb., 1940	4.9	3.7	23.5	10.1	7.2	16.2	48	6.4	Beets	17.3 tons
Feb., 1941	5.5	4.5	19.5	8.7	7.5	13.0	45	7.5	Lettuce	245 crates
Mar., 1942	5.1	3.2	19.9	9.9	5.2	12.3	45	7.8	Beets	14.2 tons
Feb., 1943	5.3	2.4	16.0	8.0	5.4	11.3	46	7.5	Carrots	
Mar., 1944	5.1	3.9	19.3	7.3	5.6	15.3	54	5.6	Cantaloupe	
Feb., 1945	5.2	3.1	20.4	9.5	5.7	12.9	46	4.5	Carrots	Excellent crop
Average....	5.2	4.1	19.8	8.8	6.1	14.3	49	7.1		

* Milliequivalents per kilogram of soil.
† At time of sampling.

TABLE 12

SALINITY TREND IN PLOT 4 (IMPERIAL VALLEY)

Soil: Imperial silty clay

Date sampled	Average salt content to depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes/acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Dec., 1935	5.0	7.8	16.3	7.8	4.0	17.7	60	8.8	Grapefruit	528
Feb., 1937	7.9	11.3	19.8	13.8	4.2	20.4	53	10.3	Grapefruit	673
Feb., 1938	4.2	13.1	22.8	12.8	5.1	21.3	54	7.6	Grapefruit	667
Feb., 1939	4.9	6.6	22.3	9.1	3.8	19.9	61	10.0	Grapefruit	667
Feb., 1940	5.3	5.6	21.9	8.9	5.3	18.4	56	8.2	Grapefruit	533
Feb., 1941	5.2	8.3	24.2	12.4	9.5	16.3	43	8.0	Grapefruit	289
Mar., 1942	5.0	8.7	21.7	10.8	5.8	18.8	53	7.3	Grapefruit	289
Feb., 1943	5.9	10.7	33.8	15.1	9.3	26.6	52	7.9	Grapefruit	289
Mar., 1944	6.5	15.0	36.6	16.7	8.8	30.7	55	9.3	Grapefruit	444
Feb., 1945	4.7	11.8	45.8	17.6	10.6	31.7	53	6.5	Grapefruit	366
Average....	5.5	9.9	26.5	12.5	6.6	22.2	54	8.4		474

* Milliequivalents per kilogram of soil.
† At time of sampling.

9, 12, and 14) increased significantly during this period. This was most marked during the first 6 years of the sampling period in plot 6; and it was during this period that the ground water rose most rapidly. After 1941 the depth to ground water fluctuated between 4 and 5 feet throughout the greater part of the remaining sampling period; and during this latter time the salt content of the soil in this plot did not change greatly.

The water table in plot 4 remained substantially lower than in plot 6 throughout the sampling period; and the increase in salts was substantially less. Moreover, the basin system of irrigation was used part of the time in plot 4, whereas the ordinary furrow system was used in plot 6.

TABLE 13

SALINITY TREND IN PLOT 5 (IMPERIAL VALLEY)

Soil: Holtville silty clay loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Nov. 1935	5.6	7.9	21.2	8.0	3.0	22.1	67	>15.0	Alfalfa	Pasture
Feb., 1937	6.3	8.2	20.8	7.3	3.8	21.8	66	>15.0	Alfalfa	Pasture
Feb., 1938	4.9	8.5	27.9	9.7	4.9	24.5	63	6.0	Lettuce	Excellent crop
Feb., 1939	5.5	2.5	18.8	6.6	1.3	19.4	71	6.0	Lettuce	Excellent crop
Feb., 1940	5.1	3.4	17.5	4.7	3.8	17.5	67	> 6.0	Cabbage	Excellent crop
Feb., 1941	6.2	2.7	24.3	7.2	5.7	18.3	59	> 6.0	Beets	24.9 tons
Mar., 1942	5.9	3.4	17.4	6.1	3.5	17.4	64	> 6.0	Beets	24 tons
Feb., 1943	5.1	3.1	19.7	7.4	6.1	16.4	55	> 6.0	Flax	47.6 bu.
Mar., 1944	5.8	3.8	22.4	6.6	2.2	23.2	73	>11.0	Flax	44 bu.
Feb., 1945	5.6	5.0	23.8	7.8	5.2	20.9	62	>11.0	Alfalfa	Excellent crop
Average....	5.6	4.8	21.1	7.1	3.9	20.1	65			

* Milliequivalents per kilogram of soil.
† At time of sampling.

TABLE 14

SALINITY TREND IN PLOT 6 (IMPERIAL VALLEY)

Soil: Holtville silty clay

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes/acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Dec., 1935	6.1	8.5	17.7	7.4	2.1	21.7	70	nd‡	Grapefruit	520
Feb., 1937	6.2	8.8	23.2	10.5	5.8	22.6	58	12.2	Grapefruit	592
Feb., 1938	4.9	11.6	24.5	10.6	5.3	24.2	60	9.9	Grapefruit	652
Feb., 1939	4.3	11.8	30.1	12.7	5.6	27.3	60	7.0	Grapefruit	640
Feb., 1940	5.5	18.8	26.8	12.6	14.4	24.1	47	8.3	Grapefruit	664
Feb., 1941	4.6	23.3	41.2	22.6	12.2	36.7	51	7.0	Grapefruit	620
Mar., 1942	4.8	29.6	43.3	19.9	13.9	43.7	56	5.5	Grapefruit	589
Feb., 1943	4.6	30.6	46.8	21.6	14.5	45.8	56	4.8	Grapefruit	591
Mar., 1944	4.7	23.0	58.4	26.3	13.6	46.2	54	3.1	Grapefruit	520
Feb., 1945	4.8	25.7	70.7	34.3	17.1	49.7	49	6.0	Grapefruit	560
Average....	5.0	19.2	38.3	17.8	10.4	34.2	55	7.1		595

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Not determined.

Plot 1 was irrigated rather lightly because the owner feared that heavy irrigation would further elevate the water table, which was already high at the beginning of the experiment. It fluctuated between about 4 and 5.5 feet throughout the greater part of the experimental period. In view of the rough parallelism between sodium and sulfate shown in tables 9 and 12, it seems probable that sodium sulfate, preëxisting in the ground water, was largely responsible for the increases in plots 1 and 4; this is not so evident in plot 6.

Sodium chloride was also a factor in plots 1 and 6, but not in plot 4. It is interesting to note that soluble magnesium increased manyfold in plot 6, tripled in plot 1, and more than doubled in plot 4. It can safely be said, then, that

TABLE 15

SALINITY TREND IN PLOT 7 (IMPERIAL VALLEY)

Soil: Imperial silty clay (stratified phase)

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Nov., 1935	4.3	41.1	71.5	27.1	16.0	73.9	63	8.2	Milo	Stubble
Feb., 1937	5.6	22.2	63.2	20.6	15.1	58.1	62	6.2	Milo	......
Feb., 1938	6.0	36.9	72.2	25.4	16.0	71.5	63	6.2	Wheat	Fair crop
Feb., 1939	4.3	19.7	74.4	30.2	9.5	59.7	60	6.0	Wheat	Fair crop
Feb., 1940	7.1	15.4	54.2	23.7	8.1	45.9	59	4.2	Wheat	Fair crop
Feb., 1941	4.7	31.0	74.7	31.1	20.4	57.3	53	5.0	Flax	Light yield
Mar., 1942	4.2	30.1	69.4	24.1	17.2	62.8	60	5.3	No crop	......
Feb., 1943	4.7	18.6	64.8	26.4	15.4	45.9	52	2.6	Flax	23 bu.
Mar., 1944	4.0	55.6	90.1	34.9	22.1	92.6	62	8.3	Alfalfa	Pasture
Feb., 1945	4.9	60.4	82.6	37.1	21.5	87.9	60	4.7	Barley	Fair crop
Feb., 1946	4.4	19.2	74.6	25.2	17.3	56.4	57	5.3	Beets	17.8 tons
Average....	4.9	31.8	72.0	27.8	16.2	64.3	59	5.6		

* Milliequivalents per kilogram of soil.
† At time of sampling.

TABLE 16

SALINITY TREND IN PLOT 8 (IMPERIAL VALLEY)

Soil: Imperial clay

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Nov., 1935	4.0	37.1	84.8	42.8	19.1	59.7	49	>16	Alfalfa	Pasture
Feb., 1937	5.0	39.6	90.8	41.4	23.0	71.6	53	>16	Alfalfa	Pasture
Feb., 1938	4.2	38.6	92.3	42.1	21.5	69.7	52	>16	Alfalfa	Pasture
Feb., 1939	3.8	31.8	93.2	45.8	14.2	69.4	54	>16	Alfalfa	Pasture
Feb., 1940	5.7	36.6	101.7	56.0	22.8	66.4	46	>16	Alfalfa	Pasture
Feb., 1941	5.3	31.4	92.7	48.4	25.8	54.3	42	>16	Barley	Excellent crop
Mar., 1942	4.6	10.2	100.2	43.4	23.0	49.0	42	9	Lettuce	200 crates
Feb., 1943	5.1	6.9	94.6	40.5	20.2	47.4	44	>11	Cantaloupes	192 crates
Feb., 1944	4.9	6.9	110.0	44.3	27.1	50.6	41	>11	Lettuce	208 crates
Feb., 1945	5.0	5.4	99.0	37.1	22.5	49.5	45	>11	Flax	47 bu.
Average....	4.8	24.4	96.0	44.2	22.0	58.8	47			

* Milliequivalents per kilogram of soil.
† At time of sampling.

salinity is becoming a very definite threat in plots 1 and 6, and to some extent in plot 4.

The soil in plot 7 (table 15) remained relatively highly saline throughout the period of this investigation. With the exception of 1944 and 1945, however, the trend was toward reduced salinity. The marked increase in salinity found in 1944 and 1945 was occasioned by the fact that in the late fall of 1943 surface soil from a near-by unirrigated lot, where excessive salts had accumulated, was spread over this plot to a depth of about 1 foot for the purpose of changing the direction of surface slope. Undoubtedly this largely accounts for the increases found in 1944 and 1945. However, a heavy flooding

TABLE 17

SALINITY TREND IN PLOT 9 (IMPERIAL VALLEY)

Soil: Holtville clay loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Nov., 1935	3.2	49.6	56.6	31.0	16.9	61.1	56	nd‡	Barley	900 lbs.
Feb., 1937	8.3	47.0	71.6	35.8	17.5	71.8	57	3.5	Milo stubble	1,000 lbs.
Feb., 1938	5.9	46.3	75.9	33.8	19.3	76.1	59	3.5	Cotton	1½ bales
Feb., 1939	3.4	46.0	65.6	30.0	14.0	66.9	60	3.0	Cotton	½ bale
Feb., 1940	5.3	36.9	68.2	31.2	17.5	59.3	55	3.0	Wheat	Crop lost (rust)
Mar., 1941	5.1	41.8	74.5	38.6	21.3	60.7	50	6.0	Wheat	Crop lost (rust)
Mar., 1942	4.2	65.3	82.8	44.4	23.4	84.4	55	8.0	Wheat	Seed did not germinate
Feb., 1943	4.5	72.2	104.4	47.6	32.2	102.6	56	7.5	Flax	Failure
Mar., 1944	4.8	59.9	83.8	37.6	23.8	86.9	59	3.0	{Sesbania Barley	Good stand Fair crop
Feb., 1945	5.4	39.8	91.4	38.5	24.3	73.7	54	4.4	Flax	14 bu.
Average....	5.0	50.5	77.5	36.8	21.0	74.3	56	4.7		

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Not determined.

TABLE 18

SALINITY TREND IN PLOT 10 (IMPERIAL VALLEY)

Soil: Meloland loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Nov., 1935	4.6	11.9	25.6	7.7	5.8	28.2	68	2.7	Alfalfa	Pasture
Feb., 1937	5.6	9.9	26.3	8.3	6.3	26.7	65	4.0	Alfalfa	Pasture
Feb., 1938	5.0	17.8	38.5	11.1	7.5	42.3	69	4.5	Cantaloupes	No record
Feb., 1939	3.5	7.7	32.0	12.2	5.9	26.3	59	3.5	Cantaloupes	No record
Feb., 1940	4.7	18.3	33.5	11.6	9.4	34.7	62	4.0	Flax	28.5 bu.
Feb., 1941	4.6	21.8	40.5	13.8	9.8	43.7	65	4.0	Alfalfa	Pasture
Mar., 1942	4.2	19.7	43.6	16.1	12.6	39.1	58	4.3	Alfalfa	Pasture
Feb., 1943	3.7	11.6	41.8	16.4	11.5	29.0	51	2.8	Alfalfa	Pasture
Mar., 1944	4.5	17.6	47.9	16.1	12.5	39.8	58	2.9	Watermelons	Good crop
Feb., 1945	3.8	17.2	37.0	13.1	8.2	35.7	63	1.9	Cabbage	Poor crop
Average....	4.4	15.3	36.7	12.6	8.9	34.6	62	3.5		

* Milliequivalents per kilogram of soil.
† At time of sampling.

in the winter of 1945–46 leached out much of the salt, so that when sampled in February, 1946, the salt content was even less than in 1935. Thus it was found, as in the experiments reported by Thomas (1936), that soluble salts can be effectively leached out of the Imperial Valley soil. This can be most readily accomplished when the soil is well drained, as is now true of plot 7, which was tile-drained in 1943.

The soil in plot 9 (table 17) represents a special case in that the irrigation water was considerably more saline than that applied to the other sampling locations in the Imperial Valley, and the soil was highly saline at the outset.

TABLE 19

SALINITY TREND IN PLOT 23 (RIVERSIDE COUNTY)

Soil: Ramona sandy loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*						Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	Ca	Mg	Na				
Sept., 1935	3.0	1.7	2.1	1.8	0.9	4.1	60	>30	Oranges	305
Dec., 1936	3.2	1.9	2.1	2.4	1.3	4.5	55	>30	Oranges	202
Dec., 1937	3.5	2.3	3.0	2.3	2.2	4.2	48	>30	Oranges	250
Dec., 1938	3.0	2.0	4.1	2.9	2.6	4.0	42	>30	Oranges	188
Dec., 1939	3.7	3.1	4.2	4.0	1.2	5.7	52	>30	Oranges	234
Dec., 1940	3.3	2.4	3.5	2.1	2.5	4.8	51	>30	Oranges	366
Dec., 1941	4.0	2.0	2.2	2.8	2.5	3.6	40	>30	Oranges	628
Dec., 1942	4.0	3.7	3.6	2.8	2.7	5.5	50	>30	Oranges	483
Dec., 1943	3.3	3.3	3.2	2.7	1.5	5.6	57	>30	Oranges	107‡
Jan., 1944	3.7	3.6	3.5	2.5	1.7	6.6	61	>30	Oranges	295
Average....	3.5	2.6	3.2	2.6	1.9	4.9	52	>30		306

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Low yield the result of a spring frost.

TABLE 20

SALINITY TREND IN PLOT 11 (ORANGE COUNTY, TUSTIN AREA)

Soil: Yolo clay loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
Apr., 1936	5.2	3.9	3.3	0.2	5.0	3.5	4.1	33	>30	Oranges	363
Apr., 1937	4.8	2.0	4.2	nd‡	4.3	3.4	4.5	37	>30	Oranges	333
Apr., 1938	5.2	1.7	2.2	nd	3.6	2.0	4.2	43	>30	Oranges	385
Apr., 1939	4.1	3.3	4.4	1.3	5.6	2.3	5.1	39	>30	Oranges	355
Apr., 1940	4.8	1.3	2.0	0.8	4.3	1.2	3.7	40	>30	Oranges	284
Apr., 1941	5.2	1.2	2.3	1.0	4.1	1.6	4.4	44	>30	Oranges	321
Apr., 1942	5.1	2.7	4.0	0.9	4.9	3.3	5.2	39	>30	Oranges	466
Apr., 1943	4.7	2.2	3.5	0.2	3.4	2.3	4.4	44	>30	Oranges	532
Apr., 1944	5.1	2.3	3.0	0.8	2.6	3.3	5.0	46	>30	Oranges	197
Apr., 1945	4.5	2.5	6.2	0.6	4.9	3.0	5.6	41	>30	Oranges	...
Average....	4.9	2.3	3.5	0.7	4.3	2.6	4.6	40	>30		360

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Not determined.

The fluctuations in salinity found were probably caused mainly by the capillary rise of salts from the very saline ground water at this location.

In view of the high water table, the data for plot 10 (table 18) are particularly interesting. While fluctuating from year to year, the content of the several constituents remained fairly constant throughout the ten-year period of this investigation. The soil was no more saline in 1945 than in 1938.

Riverside, Orange, and Ventura Counties. The experiments in these counties were made on soils which, with the exception of those in the Oxnard area, contained but little soluble salts at the outset (see tables 19 to 31). Only two

TABLE 21

SALINITY TREND IN PLOT 12 (ORANGE COUNTY, LA HABRA AREA)

Soil: Yolo silty clay

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
Apr., 1936	5.6	1.5	3.3	0.5	5.2	1.4	4.3	39	>30	Lemons	161
Apr., 1937	4.9	0.9	2.8	0.4	4.7	1.8	2.7	29	>30	Lemons	122
Apr., 1938	5.1	1.3	1.4	nd‡	4.2	1.2	2.4	31	>30	Lemons	131
Apr., 1939	3.9	0.9	4.9	0.7	6.4	2.1	2.0	19	>30	Lemons	354
Apr., 1940	5.1	1.1	2.6	1.3	6.3	1.6	2.7	25	>30	Lemons	413
Apr., 1941	5.2	1.1	3.4	0.9	7.1	2.0	1.1	11	>30	Lemons	712
Apr., 1942	4.8	2.4	6.8	1.9	9.2	3.9	2.9	18	>30	Lemons	533
Apr., 1943	4.3	3.5	11.3	0.3	12.4	4.1	2.7	14	>30	Lemons	688
Apr., 1944	4.9	3.0	9.3	0.6	9.1	5.1	2.9	17	>30	Lemons	522
Apr., 1945	4.5	3.3	11.0	0.5	12.1	3.5	3.5	18	>30	Lemons	580
Average....	4.8	1.9	5.7	0.8	7.7	2.7	2.7	21	>30		422

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Not determined.

TABLE 22

SALINITY TREND IN PLOT 20 (ORANGE COUNTY, ANAHEIM AREA)

Soil: Hanford sand

Date sampled	Average salt content to a depth of 6 feet, me/kg*								Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	CO_3	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
1937	0.4	4.8	1.4	1.4	0.3	1.2	tr‡	6.8	85	>25	Oranges	111
1938	0.7	6.5	1.0	2.0	0.9	2.2	2.1	5.7	57	>25	Oranges	444
1939	1.7	4.6	0.7	1.6	0.3	2.8	0.9	5.1	58	>25	Oranges	199
1940	0.8	6.2	0.7	1.4	0.6	2.3	1.6	5.9	60	>25	Oranges	563
1941	1.3	4.5	0.6	1.2	0.7	3.2	0.6	4.5	54	>25	Oranges	410
1942	0.5	5.0	0.7	1.7	1.2	3.7	1.8	3.3	37	>25	Oranges	611
1943	0.4	4.9	2.1	2.7	1.5	3.0	2.8	5.7	50	>25	Oranges	491
1944	1.3	4.1	1.6	2.2	1.8	3.9	2.3	5.7	48	>25	Oranges	339
1945	0.8	3.9	1.0	3.6	0.5	3.6	1.4	5.2	51	>25	Oranges	500
1946	0.3	3.9	1.3	7.3	0.8	6.6	2.8	5.6	37	>25	Oranges	500
Average	0.8	4.8	1.1	2.5	0.9	3.2	1.7	5.3	52	>25		417

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Trace.

of these plots (all but one are citrus orchards) evidenced a significant increase in total salts. In plots 12 and 15 (tables 21 and 27), the concentration of sulfate tended to increase. If this should continue, sulfate might become a problem in these soils. In plot 15, the concentration of sodium also increased.

The irrigation water used on plot 12 (table 21), a lemon orchard in Orange County, was the most saline used in these investigations. Soil samples drawn in the fall or early winter, before the rainy season, showed each year substantially greater amounts of salts than at or near the close of the rainy season the following spring. The average annual rainfall is somewhat more than 15 inches, practically all of which falls during the winter and early spring months. This is sufficient to effect substantial leaching, particularly of chloride and sodium. Sulfate, however, is not so readily removed by leaching. The average rainfall at plot 11 (Tustin, Orange County) is approximately the same as at plot 12, while in Ventura County it is close to 20 inches a year.

TABLE 23

SALINITY TREND IN PLOT 21 (ORANGE COUNTY, ORANGE AREA)

Soil: Dublin clay

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
Oct., 1937	4.1	1.7	2.7	0.3	1.9	1.1	6.2	67	>20	Oranges	76
Oct., 1938	5.2	2.0	2.9	0.3	2.3	0.9	7.1	69	>20	Oranges	211
Oct., 1939	5.6	1.6	4.9	0.3	4.1	1.0	7.2	59	>20	Oranges	141
Oct., 1940	6.3	1.7	2.7	0.1	2.9	0.2	7.9	72	>20	Oranges	214
Oct., 1941	4.2	1.2	2.2	0.3	1.2	0.7	5.6	75	>20	Oranges	196
Oct., 1942	5.3	1.7	3.4	0.4	2.0	3.3	5.7	52	>20	Oranges	158
Oct., 1943	4.9	1.4	2.5	0.2	4.4	0.3	5.4	53	>20	Oranges	334
Oct., 1944	6.3	2.0	2.9	0.7	2.1	2.8	7.9	63	>20	Oranges	220
Oct., 1945	5.1	2.2	3.3	0.2	2.2	1.2	7.3	68	>20	Oranges	335
Oct., 1946	4.8	2.2	3.0	0.1	2.0	2.5	6.5	59	>20	Oranges	216
Average....	5.2	1.8	3.0	0.3	2.5	1.4	6.7	63	>20		210

* Milliequivalents per kilogram of soil.
† At time of sampling.

TABLE 24

SALINITY TREND IN PLOT 22 (ORANGE COUNTY, YORBA LINDA AREA)

Soil: Ramona loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*								Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	CO_3	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
1937	1.2	5.7	3.2	4.1	0.4	5.0	tr‡	10.5	68	>30	Oranges	158
1938	tr.	7.5	2.4	3.8	0.6	2.9	2.2	9.2	64	>30	Oranges	335
1939	0.4	6.0	2.1	4.2	0.3	3.1	0.8	9.0	70	>30	Oranges	324
1940	tr.	6.3	1.6	3.1	0.4	2.6	0.8	8.0	70	>30	Oranges	385
1941	0.7	5.5	1.1	2.7	0.3	2.2	0.7	7.4	72	>30	Oranges	417
1942	0.8	5.2	2.0	3.4	0.5	2.4	3.0	6.5	55	>30	Oranges	332
1943	0.4	5.8	1.6	3.4	1.0	3.0	1.7	9.7	67	>30	Oranges	342
1944	0.6	6.6	2.2	3.7	0.3	2.3	2.6	9.3	65	>30	Oranges	432
1945	0.7	5.4	3.0	6.3	1.2	4.2	1.4	10.3	65	>30	Oranges	517
1946	0.6	5.2	3.6	6.2	1.0	6.0	1.2	8.9	55	>30	Oranges	300
Average	0.7	5.9	2.3	4.1	0.6	3.4	1.6	8.9	64	>30		354

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Trace.

It should be pointed out that the amount of irrigation water applied at plot 12 in Orange County was considerably less than at the other sampling places. The owner, realizing that his irrigation water is quite saline, applied it sparingly. Consequently, only a limited amount of salts was added to the soil annually. As a matter of fact it is not necessary to irrigate a lemon orchard on this soil more than one or two times a year, except possibly in summers

TABLE 25

SALINITY TREND IN PLOT 13 (VENTURA COUNTY, VENTURA AREA)

Soil: Yolo clay loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, pounds per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
June, 1936	5.9	2.6	2.6	0.2	2.8	2.2	5.7	53	>20	Walnuts	1,300
June, 1937	4.9	1.2	2.4	0.2	3.2	2.0	4.5	46	>20	Walnuts	1,434
June, 1938	8.3	1.4	1.7	...	4.9	1.8	4.7	41	>20	Walnuts	1,967
June, 1939	5.8	1.2	3.6	0.6	5.0	1.1	4.9	45	>20	Walnuts	2,267
June, 1940	10.7	1.4	4.5	...	11.1	1.0	5.0	29	>20	Walnuts	567‡
June, 1941	5.3	0.7	0.5	...	3.1	1.0	2.4	37	>20	Walnuts	2,000
June, 1942	4.2	0.5	1.4	0.6	2.9	1.0	2.8	42	>20	Walnuts	1,760
June, 1943	5.1	0.6	1.7	0.2	3.4	1.5	2.7	36	>20	Walnuts	2,240
June, 1944	5.8	0.8	3.1	0.2	3.2	3.2	3.5	35	>20	Walnuts	2,240
June, 1945	5.4	0.9	3.1	0.3	4.0	2.6	3.1	32	>20	Walnuts	1,700
Average....	6.1	1.1	2.5	0.2	4.4	1.7	3.9	39	>20		1,748

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Small yield due to delayed foliation.

TABLE 26

SALINITY TREND IN PLOT 14 (VENTURA COUNTY, VENTURA AREA)

Soil: Yolo clay loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
June, 1936	5.8	2.8	2.8	0.4	4.1	3.2	4.5	38	>20	Lemons	230
June, 1937	4.9	1.3	1.4	0.3	2.6	1.7	3.5	45	>20	Lemons	464
June, 1938	5.3	1.4	1.5	...	3.9	2.3	2.5	29	>20	Lemons	468
June, 1939	6.1	1.6	2.1	0.2	5.5	1.8	2.8	28	>20	Lemons	524
June, 1940	6.4	1.6	2.8	...	8.1	1.0	2.8	24	>20	Lemons	646
June, 1941	5.0	0.6	0.9	0.3	3.5	1.5	1.8	26	>20	Lemons	980
June, 1942	4.9	0.8	3.7	0.2	4.3	1.6	3.5	37	>20	Lemons	520
June, 1943	4.2	1.0	3.0	0.1	4.1	1.8	2.0	25	>20	Lemons	1,211
June, 1944	5.2	1.3	4.5	0.7	4.5	3.7	3.4	29	>20	Lemons	740
June, 1945	4.4	1.2	4.5	0.5	4.5	2.9	3.3	31	>20	Lemons	810
Average....	5.2	1.4	2.7	0.3	4.5	2.1	3.0	31	>20		659

* Milliequivalents per kilogram of soil.
† At time of sampling.

following low rainfall the previous winter; for the soil has a high water-holding capacity and the rate of evaporation is not excessive in this locality.

The Oxnard Area. The results obtained at the four sampling places in the Oxnard area of Ventura County (plots 16, 17, 18, and 19) are especially interesting. Several years before this investigation was started, strongly saline ground water underlaid these sampling places at a depth of 4 to 5 feet. Through capillary rise and evaporation, the soil had become heavily charged with soluble salts. A few years before the first samples were drawn, this area was tile-drained and then flooded two or more times with irrigation water in order to leach out the accumulated salts.

TABLE 27

SALINITY TREND IN PLOT 15 (VENTURA COUNTY, SANTA PAULA AREA)

Soil: Yolo silt loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
June, 1936	5.4	1.3	2.9	0.5	3.1	1.9	5.0	50	>16	Oranges	278
June, 1937	5.6	1.8	2.1	0.2	2.6	1.6	5.3	56	>16	Oranges	154
June, 1938	6.2	1.3	4.1	nd‡	5.5	1.6	5.5	44	>16	Oranges	383
June, 1939	7.3	1.5	4.7	0.3	5.6	2.8	5.8	41	>16	Oranges	261
June, 1940	8.0	1.9	7.0	nd	8.7	2.1	6.9	39	>16	Oranges	352
June, 1941	4.5	0.7	2.1	0.9	3.0	1.2	3.9	48	>16	Oranges	399
June, 1942	4.8	1.4	8.2	0.7	7.5	2.3	6.6	40	>16	Oranges	503
June, 1943	4.2	1.3	9.8	0.7	6.7	2.4	7.3	45	>16	Oranges	378
June, 1944	4.9	2.0	14.3	1.9	7.0	4.8	11.4	49	>16	Oranges	574
June, 1945	3.9	1.9	12.4	1.3	8.6	3.1	8.0	41	>16	Oranges	452
Average....	5.5	1.5	6.8	0.8	5.8	2.4	6.6	45	>16		373

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Not determined.

TABLE 28

SALINITY TREND IN PLOT 16 (VENTURA COUNTY, OXNARD AREA)

Soil: Yolo loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
June, 1937	3.6	7.8	120.7	0.2	67.0	11.2	54.6	41	3	......	......
June, 1938	3.8	2.0	97.7	nd‡	67.4	14.6	19.2	19	4½	......	......
June, 1939	3.6	1.1	67.6	tr.§	52.4	7.8	11.6	16	>6	Lemons	Not bearing
June, 1940	3.8	1.0	76.4	nd	61.3	10.3	9.8	12	>6	Lemons	Not bearing
June, 1941	3.7	0.8	53.8	0.4	42.3	11.8	4.8	8	>6	Lemons	30
June, 1942	3.0	1.1	77.5	0.5	62.5	12.7	7.0	9	>6	Lemons	59
June, 1943	4.0	0.9	67.9	0.3	53.8	12.7	6.5	9	>6	Lemons	358
June, 1944	3.7	1.4	68.2	0.6	53.5	15.7	5.0	7	>6	Lemons	164
June, 1945	3.3	1.0	64.1	0.5	40.7	23.4	4.3	6	>6	Lemons	273
June, 1946	3.5	1.2	75.5	0.3	59.6	17.8	2.8	3	>6	Lemons	531
Average....	3.6	1.8	76.9	0.3	56.0	13.8	12.6	15.0			

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Not determined.
§ Trace.

As is shown in tables 28 and 29, the content of soluble sodium in plots 16 and 17 decreased markedly within the period of this investigation. This is especially noteworthy in view of the fact that the furrow system of irrigation was used. These soils are no longer to be regarded as saline. They are essentially normal in all important respects. The high sulfate content is due chiefly to native gypsum in the soil, and this is largely innocuous.

In plots 18 and 19 (tables 30 and 31), the intensity of leaching before the experiment was begun had reduced the content of salts to a comparatively low level. Subsequently ordinary furrow irrigation and natural rainfall have

TABLE 29

SALINITY TREND IN PLOT 17 (VENTURA COUNTY, OXNARD AREA)

Soil: Yolo silty loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
June, 1937	3.3	2.8	120.3	0.3	81.7	18.1	26.9	21.0	2.5	Beans	......
June, 1938	3.3	3.0	136.6	tr.‡	104.7	17.5	16.8	12.1	3.5	Beans	......
June, 1939	3.3	1.3	167.2	tr.	141.2	19.8	9.6	6.0	5§	Beans	......
June, 1940	3.8	1.2	154.3	tr.	134.0	16.9	8.9	6.0	5	Lemons	Young trees
June, 1941	3.5	1.1	111.9	0.3	91.7	19.4	5.7	5.0	>6	Lemons	16
June, 1942	3.0	1.1	110.7	0.4	89.9	18.5	6.5	6.0	>6	Lemons	15
June, 1943	4.1	0.9	110.3	0.3	90.7	18.3	6.1	5.0	>6	Lemons	238
June, 1944	3.1	1.2	105.3	1.5	85.2	20.7	4.9	4.0	>6	Lemons	163
June, 1945	3.1	1.2	103.0	0.3	86.1	16.1	5.5	5.1	>6	Lemons	192
June, 1946	3.9	1.3	77.4	0.5	64.3	13.0	5.4	7.0	>6	Lemons	425
Average....	3.4	1.5	119.7	0.5	96.9	17.8	9.6	8.0			

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Trace.
§ Tile drain installed in 1938.

TABLE 30

SALINITY TREND IN PLOT 18 (VENTURA COUNTY, OXNARD AREA)

Soil: Yolo sandy loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
June, 1937	3.9	1.9	98.2	...	70.1	15.4	15.7	16	4.0	Lemons	485
June, 1938	3.0	2.5	95.0	...	69.4	15.0	15.7	16	4.5	Lemons	514
June, 1939	3.5	1.8	65.1	...	48.9	12.2	9.8	14	4.7	Lemons	485
June, 1940	3.8	1.5	92.5	...	72.5	15.1	10.0	10	7.0	Lemons	279
June, 1941	4.0	0.9	72.5	0.3	58.8	14.1	4.2	5	>5.5	Lemons	1,088
June, 1942	3.7	1.4	93.7	1.0	78.3	15.4	6.7	7	>5.5	Lemons	441
June, 1943	4.2	1.4	46.2	0.4	32.8	9.0	10.4	20	>5.5	Lemons	608
June, 1944	4.3	2.5	65.4	1.3	52.9	15.5	5.0	7	>5.5	Lemons	453
June, 1945	3.5	2.1	85.2	0.3	69.3	13.7	7.4	8	>5.5	Lemons	412
June, 1946	3.5	1.8	87.0	0.4	69.8	18.7	4.2	5	>5.5	Lemons	478
Average....	3.7	1.8	80.1	0.6	62.3	14.4	8.9	10			524

* Milliequivalents per kilogram of soil.
† At time of sampling.

effectively kept the salts down below the root zone. The result has been, as at plots 16 and 17, large yields of fine-quality lemons from these orchards. The growth of the trees has also been good—even though of the crops grown in California, the lemon tree is one of the most sensitive to soluble salts.

It is especially significant that soluble sodium, expressed in per cent of the total soluble bases, has for several years been exceptionally low in the soil of all four of the sampling places in the Oxnard area. The soil has not become excessively dispersed and impermeable to water as a result of leaching out the soluble salts. It is now approximately normal in properties.

On another farm in the Oxnard area where the soil is a heavy clay and contained a high concentration of soluble salts, it was found several years ago that the salts could also be leached out and large yields of alfalfa were obtained later (Kelley, 1937, p. 28).

TABLE 31

SALINITY TREND IN PLOT 19 (VENTURA COUNTY, OXNARD AREA)

Soil: Yolo sandy loam

Date sampled	Average salt content to a depth of 6 feet, me/kg*							Sodium as per cent of total bases	Depth to ground water,† feet	Crop at time of sampling	Crop condition or yield, field boxes per acre
	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na				
June, 1937	3.9	1.6	80.9	nd‡	66.5	12.5	6.1	7	4.0	Lemons	485
June, 1938	3.0	1.8	64.3	0.2	53.4	9.6	6.2	9	4.4	Lemons	514
June, 1939	3.5	1.3	61.5	tr.§	52.3	10.7	3.3	5	4.6	Lemons	485
June, 1940	4.0	1.4	74.3	nd	65.9	9.5	4.3	5	7.0	Lemons	279
June, 1941	4.2	1.2	61.5	1.1	54.1	11.2	2.9	4	>5.5	Lemons	1,088
June, 1942	3.4	1.9	68.2	1.7	59.4	11.6	4.2	6	>5.5	Lemons	441
June, 1943	4.1	1.7	83.8	0.4	68.8	10.2	10.9	12	>5.5	Lemons	608
June, 1944	3.9	1.7	55.7	1.7	46.0	13.6	3.7	6	>5.5	Lemons	453
June, 1945	3.5	3.9	60.0	0.4	50.6	9.8	7.0	10	>5.5	Lemons	412
June, 1946	3.6	1.6	38.5	0.4	32.2	6.3	5.3	12	>5.5	Lemons	nd
Average....	3.7	1.8	64.9	0.8	54.9	10.5	5.4	8			529

* Milliequivalents per kilogram of soil.
† At time of sampling.
‡ Not determined.
§ Trace.

Thus it follows that the saline soil of the Oxnard area can be readily reclaimed by drainage and leaching. When this has been done, ordinary irrigation plus natural rainfall will prevent the rise of soluble salts from the highly saline ground water.

GENERAL DISCUSSION

The foregoing data show quite conclusively that the salinity of neither the Imperial Valley soils nor the group of citrus orchard soils in Orange, Ventura, and Riverside counties, with one or two possible exceptions, is increasing *as a direct result of the salt contained in the irrigation water.* Neither is the soil gaining in salinity from other sources except where the ground-water level is high and even then only at certain places. It appears that the salts added in the irrigation water are being displaced downward wherever sufficient water is applied and where the drainage conditions permit deep penetration of water.

Amounts of Water Applied in Relation to Salt Accumulation. The changes in chlorine concentration on three Imperial Valley plots indicate how the amount of water applied may influence the accumulation of salts, especially their vertical distribution. Figure 2 shows the chlorine concentration in these plots—nos. 3, 6, and 8—for each foot of depth at the beginning and at the end of the experiment.

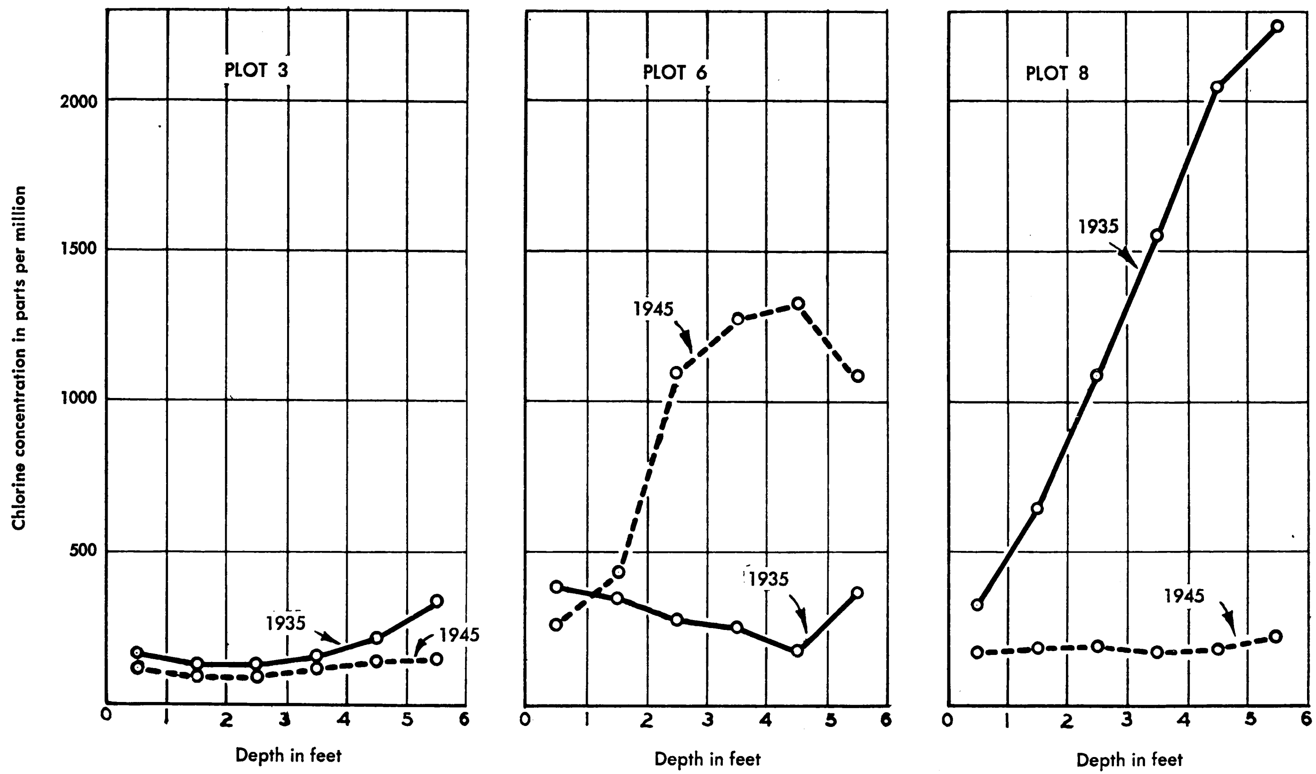

Fig. 2. Vertical distribution of chlorine in three Imperial Valley plots. Truck crops were grown on plot 3, and it was heavily irrigated throughout the experiment. Plot 6 was planted to grapefruit, and it was moderately irrigated. Plot 8 was planted to alfalfa when the experiment began, and it was rather lightly irrigated; the alfalfa was plowed up in 1941 and barley was planted for one year; from 1942 to 1945, truck crops were grown and irrigation was heavy.

On plot 8 there was a marked increase in chlorine with soil depth at the time the experiment was begun, as shown by the 1935 graph for this plot in figure 2. The water table was too deep to be of influence. Alfalfa had been grown for several years, and the amount of water applied had been insufficient to leach the salts. The vertical distribution of salts remained practically unchanged as long as alfalfa was grown. But when the alfalfa was plowed up and the plot planted to truck crops, which are irrigated much more heavily, a rapid reduction in salt content took place. At the close of the first season after lettuce was planted (1942), the chlorine decreased more than 50 per cent throughout the profile; and this diminution continued until the end of the experiment. The final distribution of chlorine is shown in the 1945 graph for plot 8.

The graphs for plot 6 (fig. 2) show quite the opposite of those for plot 8. Here the chlorine content below the depth of 2 feet was about three times as great in 1945 as in 1935. This plot, planted to grapefruit, was irrigated by the furrow method, the amount of water applied being substantially less than that applied to truck crops. The water table was not a problem when the experiment was begun in 1935 and probably had not been previously. But the ground water rose rapidly after 1937 and remained high until the close of the experiment. The combination of high water table and relatively light irrigation was responsible for the marked increase in salts in the subsoil. The amount of water applied was insufficient to prevent the upward movement of salts from the saline ground water.

The graphs for plot 3 (fig. 2) show that a water table within 5 to 6 feet of the surface need not result in salt accumulation above the level of the ground water. By irrigating rather heavily, as in truck cropping in general in the Imperial Valley, the direction of water movement is probably downward the greater part of the time. The consequence is that salts do not rise seriously. As shown in the graphs, this soil contained less chlorine throughout the profile in 1945 than in 1935.

Irrigation Practice to Prevent Salt Accumulation. In order to prevent accumulation of the salts added in the irrigation water, it is absolutely necessary to apply more water, if the rainfall is light, than is required by the crops. *In such case, rigid conservation of irrigation water is incompatible with soil conservation. A substantial amount of irrigation water must be wasted by liberal application as a necessary means of preventing increased salinity of the soil.* This, of course, will tend to increase the need for drainage; but unless it is done, serious injury will result sooner or later from the salts originating in the water itself.

Drainage Problem in the Imperial Valley. The results of this investigation clearly indicate that the most important problem confronting the Imperial Valley is not salinity as such, but drainage. Responsible authorities in the Valley should therefore bend every effort to improve the drainage conditions. Unless the Valley soils are drained wherever the ground water is dangerously high or is threatening to become so, injury from salt accumulation is likely to appear soon. On this point our results fully confirm the conclusion drawn by Means and Holmes (1901).

The results of this investigation also suggest that it is possible to utilize successfully much of the land in the Imperial Valley with a ground-water level not less than 5 feet below the surface, *provided irrigation water in excess of crop requirements is applied and provided also that the ground water does not rise still nearer the surface.* This is an important conclusion because of the expense of lowering the water table much below 5 feet in depth. That the water table can be kept down to this depth by artificial drains has already been well established at several places in the Imperial Valley.

After adequate drains have been established, it will be necessary in many places to flood the land thoroughly in order to leach out the salts that have already accumulated in the upper part of the soil. In certain localities it may even be necessary to repeat the flooding from time to time; but if this is done systematically little apprehension need be felt about the salinity problem in the Imperial Valley.

In this connection it should be pointed out that the extent to which drainage can be increased in the Imperial Valley is limited, perhaps solely, by the rate of evaporation of the Salton Sea. This sump is the only readily available drainage outlet for both the Imperial and the Coachella valleys. When adequate drainage has been established in these valleys, the ultimate amount of drainage discharge will probably exceed the evaporation capacity of the present Salton Sea. Should this be found to be the case, then the choice will be as between (1) enlarging the surface area of the Salton Sea, thereby flooding some of the low-lying areas of relatively low value around the present margins of the Sea, or (2) allowing more valuable lands to pass out of cultivation because of excessive salinity.

As is well known, different crops are able to tolerate different amounts of salts. Fruit trees, including grapefruit, are more sensitive than most field crops. It is probably inadvisable to attempt to grow grapefruit on those soils of the Imperial Valley where the ground water level is within 4 or 5 feet of the surface. But truck crops, flax, and other grains and possibly alfalfa can be successfully grown by paying careful attention to the irrigation, and by seeing to it that the drains function properly.

The soil in many places already contains relatively large amounts of soluble salts, and the water table is high in many parts of the Imperial Valley. Therefore, unless drainage is attended to promptly, serious damage is likely to occur quite widely through the accumulation of soluble salts. *The key to the success of Imperial Valley agriculture, therefore, is drainage. This point cannot be overemphasized.*

Soil Permeability in the Imperial Valley. From time to time the claim has been made that the permeability of the soils of the Imperial Valley is so low as to preclude the leaching out of soluble salts. This view is not supported by our experience. It is true that under alfalfa we have often found the soil to be dry below a depth of 4 or 5 feet. This was the case in the first few years of the experiments in plots 2 and 8. However, when these plots were later plowed up and planted to truck crops, water penetration soon exceeded 10 feet in depth and, as shown in the tables, the content of soluble salts markedly declined. We have observed the reverse at plot 5. When truck crops were grown, water penetration was good—being beyond the reach of the auger. Later, when alfalfa was sown, the soil in the fifth and sixth feet became almost air-dry and was not wetted by subsequent irrigations.

There are probably two reasons for the facts mentioned in the preceding paragraph: (1) Under continued irrigation as usually applied to alfalfa, the surface soil of the Imperial Valley tends to become silted to such an extent as to impede water penetration. (2) Owing to the prevailing high temperatures in the Imperial Valley, irrigation water must be applied to alfalfa in light applications, otherwise scalding of the crop will take place. Consequently, where alfalfa is being grown, not enough water is usually applied to wet the soil more than a few feet in depth. Upon plowing at a later time, the surface silting effect is disturbed and then water penetrates readily. This appears to be true of both the so-called soft soils and the hard soils of the Valley.

There is abundant evidence that leaching the soils of the Imperial Valley does not produce extreme impermeability, such as is produced in many saline soils that are low in soluble calcium. This conclusion is supported by the investigations of Gardner (1945).

Sources of Salts in Imperial Valley Soils. As was shown by Means and Holmes (1902) and by Hilgard, Shaw, and Snow (1902), the concentration of salts varied widely in the original soils of different parts of the Imperial Valley. This is well illustrated by the results obtained in plots 2 and 8. Neither of these is known to have experienced a high water table and both have been irrigated for many years with the same kind of irrigation water. Yet the salt content of the soil in plot 8 was found to be more than double that in plot 2.

From the data reported in table 10, it is possible to calculate the approximate chloride concentration of the soil solution that will result from the use of Colorado River water in the Imperial Valley, under good drainage conditions and the application of liberal amounts of water. This soil has a moisture equivalent of about 25 per cent. At approximate field capacity, the soil solution from 1939 to 1945 was about 7.4 times as concentrated as the irrigation water. When the moisture content of the soil approached the wilting point, the soil solution was from 12 to 14 times as concentrated as the Colorado River water.

This means that the concentration of the solution that is displaced downward upon irrigating and which may ultimately reach the water table, will not exceed about twelve times that of the irrigation water. Since, as will be shown in another paper, the chloride concentration of the ground water at several points in the Imperial Valley greatly exceeds this figure, much of the chloride now present in the ground water must have come from natural deposits in the substratum. It follows, then, that current irrigation in the Imperial Valley is tending to dilute the ground water rather than to increase its concentration.

Generally speaking, the relation between the concentration of the irrigation water and that of the soil solution is extremely variable and complex. It is influenced by the rainfall, the porosity of the soil, the amount of water applied as irrigation, the frequence of irrigation, and the moisture content of the soil.

Salinity Problem in Riverside, Orange, and Ventura Counties. The threat of salinity is essentially nonexistent in the citrus orchards sampled in Riverside, Orange, and Ventura counties. Chloride and sodium, applied in the irrigation water, are currently being leached out by the joint action of the rains and the irrigation water. The results at these places are in full agreement with unpublished results obtained by one of us several years ago on some orange groves near Riverside where saline water from wells had been applied for many years. It was found that the salts had penetrated to a depth of more than 40 feet. Since the rainfall was only about 11 inches per annum, the deep penetration of the salts found cannot possibly be the result of the leaching action of the rains; it could only be the result of the deep penetration of the irrigation water itself.

With porous soil and subsoil, an annual precipitation of from 15 to 20 inches will effect substantial leaching. In such case—for example, Orange and Ventura counties—it is probably not necessary to apply moderately saline irrigation water in excess of combined evaporation and transpiration rates. *But as the precipitation decreases, the amount of irrigation water needed increases; and with extremely light rainfall, as in the Imperial Valley, there is no possibility of avoiding ever increasing accumulations of soluble salts, except by applying irrigation in substantial excess of the amounts required by the crops grown.*

Application to Other Irrigated Areas. There is no reasonable ground for doubt that the results obtained in this investigation apply to many other irrigated areas. The total salinity and kinds of salts found in the irrigation water available in many other California localities and also in other western states are not greatly different from one or another of the waters used on these plots. Moreover, the soil and climatic conditions elsewhere are probably not more extreme than those reported herein. But in certain other localities the water used is considerably more saline than any of those discussed in this paper. Where this is so, it may be necessary to apply still greater amounts of water to prevent the accumulation of excessive salinity in the soil. This is especially likely to be true where the rainfall is light and evaporation high. In extreme cases the amount applied in *every* irrigation should considerably exceed that needed merely to wet the soil and subsoil to the full depth of root penetration. Then the salts left in the soil by evaporation and transpiration from one irrigation will largely be leached out by the next.

Factors Affecting Salt Accumulation. There are other important factors to consider in applying the results of these investigations in other localities. One is the permeability of the soil to a depth well below the root zone. Unless the irrigation water or the rain actually penetrates entirely through the root zone, soluble salts will inevitably accumulate in the root zone. Another factor is the character of the salts in the irrigation water. If sodium salts equal or exceed 40 to 50 per cent of the total salts, and if the soil is free from gypsum, excessive amounts of base exchange will take place, with the formation of more or less sodium clay. This will reduce the permeability of the soil, and when leached with less-saline water or by rain water, the soil will tend to become badly deflocculated and devoid of the normal granular structure. Where no kind of water except high-sodium water is available, applications of gypsum should be made at frequent intervals, perhaps annually; or better still, gypsum should be dissolved in the irrigation water before it is applied.

Special emphasis should be placed on the fact that *the more saline the irrigation water, the greater the amount that should be applied per irrigation.*

This conclusion will probably run counter to the natural inclination of the farmer, but it is based on sound reasoning and experimental evidence.

Substantial amounts of soluble salts were leached out by the furrow method of irrigation. This is shown by the results obtained on plot 8 (table 16 and figure 2) in the Imperial Valley after the introduction of truck cropping in 1942. But where water still more saline is used, it may be necessary to employ some form of flooding or the sprinkling method of water application.

The Future of Irrigated Areas. The results of this investigation and information obtained in other investigations (Kelley, 1937; Means and Holmes, 1902) show conclusively that the accumulation of excessive amounts of salts in the soil, together with the associated chemical changes that are frequently produced by soluble salts, are not inevitable concomitants of irrigation. Since one or the other, or both, of these types of effect are important causes of land deterioration under irrigation, the conclusion follows that irrigated soils are not necessarily short-lived. However, in the course of time, variable from place to place, successful crop production is likely to become difficult on any type of irrigated soil, if the ground water is allowed to rise and to remain within capillary reach of the root zone of the crops grown; in fact, unless special precautions are taken, crop growth will become impossible. **Therefore, the permanent maintenance of successful crop production depends absolutely on the maintenance of effective drainage.**

Irrigated soils are also subject to the depletion of essential plant nutrients. Therefore, sooner or later, irrigated soils will require the application of fertilizers. The need for crop rotation and erosion control also apply to irrigated soils. These, however, are not peculiarities of irrigated soils; they apply in some degree to practically all soils whether irrigated or unirrigated.

We can say then, that irrigated agriculture is not necessarily foredoomed. Knowledge is now available which, if properly applied, will preserve irrigated soils against injury from excessive salt accumulation. But in certain localities the application of this knowledge may prove to be difficult and possibly excessively expensive. This, however, appears not to be the case with the greater part of the irrigated soils of California.

Since drainage is of paramount importance, the conditions affecting drainage in a given locality will require special consideration. Drainage, the proper methods of irrigation, and soil management in general are peculiarly local problems in that the specific soil and hydrological conditions and the climate, all have significant influence on the accumulation of salts.

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