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EFFECT OF GYPSUM, ORGANIC MATTER, AND DRYING ON INFILTRATION OF A SODIUM
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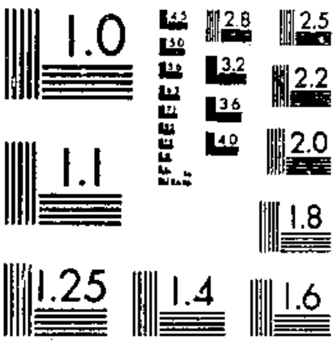

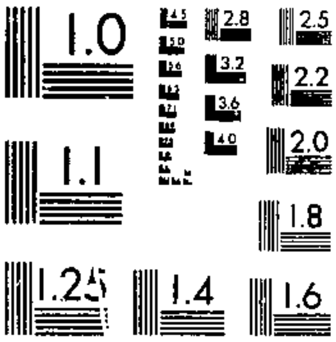

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Effect of Gypsum, Organic Matter, and Drying on Infiltration of a Sodium Water Into a Fine Sandy Loam [1,2]

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CONTENTS

DIFFICULTY in obtaining adequate penetration of irrigation water in fine sandy loams has been encountered in certain instances in the lower Coachella Valley of southern California, especially when the furrow method of irrigation is used. The irrigation water, obtained from deep wells, has a low total salt content but a high ratio of sodium to other cations. The soils, especially the subsoils, often have a high percentage of exchangeable sodium, which has been considered responsible for their low permeability. In order to develop methods for improving water penetration under such conditions it was necessary to obtain additional information concerning the nature of the soil salinity and its relation to water movement in the soil. Since the presence of gypsum and organic

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[2] This work was performed partly under an allotment from the Special Research Fund authorized by Title 1 of the Bankhead-Jones Act of June 29, 1935. The field experiments were conducted at the Torres-Martinez Indian Reservation, managed by the Office of Indian Affairs, U. S. Department of the Interior.

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matter in the soil has been known to result in improved water movement, it was planned to study the effects of applications of gypsum and chopped alfalfa upon infiltration rate, depth of water penetration, permeability, base exchange status, and related chemical and physical properties. To insure continuous depletion of soil moisture by root extraction the experimental plots were established in a planting of bearing date palms. As a part of the investigation also, it was decided to study the drying effect of root action on the soil. The field and laboratory results as reported in detail in this bulletin are here summarized.

SUMMARY

A 2-year experiment was conducted in a bearing date palm garden with the view of improving water infiltration and penetration. The highly stratified fine sandy loam was relatively impervious for a soil of its texture and had a comparatively high water-holding capacity. The irrigation water was of low total salt content but had a high proportion of sodium.

Soil treatments designed to improve the moisture-transmission characteristics comprised (1) the application of powdered gypsum, (2) the addition of chopped alfalfa, and (3) the drying of the root zone to the wilting range by root action. Field measurements were made of infiltration rates at each irrigation during the fruiting season and soil-moisture tension readings were obtained on permanently installed tensiometers. Laboratory measurements were made on soil samples to obtain the composition of soluble salts, the exchangeable base status, the pH values, the organic-matter content, flocculation observations, dispersion ratios, and permeability values.

During each irrigation the infiltration rate decreased continuously. The gypsum and alfalfa treatments approximately doubled the infiltration rate. The depth of penetration was not sufficient, however, until the quantity of water applied was increased considerably beyond that previously used. When the soil was allowed to dry to the wilting percentage by withholding irrigation water, subsequent infiltration rates exceeded even those effected by the gypsum and alfalfa treatments. The relative effect of drying decreased with successive irrigations, but was still apparent at the end of the season.

The calcareous surface soil contains very little soluble salts and soluble and exchangeable sodium. Conversely, the calcareous subsoil in the root zone generally contains appreciable quantities of soluble salts and soluble and exchangeable sodium. Permeability measurements indicate the subsoil, although of coarser texture, to be less permeable than the surface soil. This is attributed to the greater accumulation of sodium. Gypsum increased the permeability of the surface soil, presumably by flocculating the clay. Similar physical effects of the organic-matter treatment were not observed in the laboratory.

Any procedure for improving the infiltration and penetration of water under this and similar situations involves its use in suf-

ficient quantity to leach the sodium salts below the root zone. Drying the soil to the wilting range appears to be an economical and effective method of improving the structure of this soil temporarily, provided care is exercised to prevent injury to the plants, which might result from a prolonged moisture deficit.

FIELD STUDIES

Materials and Methods

EXPERIMENTAL AREA

The field experiments were conducted in a date palm planting at the Torres-Martinez Indian Reservation, about 10 miles southeast of Indio, Calif. This area lies about 3 miles east of the western rim of the Coachella Valley and about 8 miles northeast of Salton Sea. The average annual rainfall of about 3 inches rarely wets the soil to a depth of more than a few inches. Air temperatures in summer are high, with average daily maxima of about 102°, 107°, and 106° F. in June, July, and August, respectively.

SOILS AND PLANTS

The soils are of recent origin and are irregularly stratified, with no uniformity in thickness, texture, or order of strata (*15*).[8] They are derived from unconsolidated outwash material from the nearby mountains that has been redistributed by water and wind. These soils are highly micaceous and contain many small fresh-water shells. Having been formed under arid conditions, they are deficient in organic matter, light gray in color, and rich in soluble mineral materials, and may have an alkali crust in the raw condition.

The soil at the Martinez station experimental area is classified as Indio very fine sandy loam. The underlying materials range in texture from medium and fine sands to clay, with sand predominating in the lower part of the 6-foot profile. The soil is calcareous throughout and has a relatively high water-holding capacity for soil of its texture. Consequently, heavy applications of water are required to obtain adequate penetration. Pillsbury (*25*) has attributed this "high effective field capacity" of Coachella Valley soils to the complex stratification.

The natural vegetation consists mostly of different species of Compositae, Chenopodiaceae, and mesquite. The 15-year-old date palms, of Deglet Noor variety, which had received about 4 inches of water every 10 days during the growing seasons, were moderately vigorous, yet the fruit had shriveled as badly during ripening as fruit on palms receiving obviously insufficient water.

WATER SUPPLY

The irrigation water is obtained from deep wells. It is similar in composition to others in this area (*11*)[9] and has a total salt

[8] Italic numbers in parentheses refer to Literature Cited, p. 35.

[9] HUBERTY, M. R., PILLSBURY, A. F., and SOKOLOFF, V. P. HYDROLOGIC STUDIES IN COACHELLA VALLEY, CALIFORNIA. Calif. Univ. Col. Agr. 49 pp., illus. [Processed.]

concentration of 2.44 milliequivalents (m. e.) per liter (189 p. p. m.), of which the sodium comprises 82 percent of the cations and bicarbonate 64 percent of the anions. Tentative standards classify waters having a sodium percentage of more than 75 as injurious to unsatisfactory (*16*). The principal objections to these waters are the possibilities of reduced permeability and of detrimental accumulations of exchangeable sodium in the soil (*7*).

PLOTS

The palms are planted on a 30-foot spacing each way, and each plot comprises two palms and their irrigation basins. Eighteen basins in 2 rows were selected for study, allowing for 3 treatments with 3 replications in each of 2 rows. The treated basins were adjacent north-south and separated by guard plots east-west. The plan, including the treatments, is shown in figure 1. In 1942 additional infiltration data were obtained in plot 2.

All plots were disked and leveled during the last week of April 1941. Single palm basins, approximately 30 by 30 feet, were enclosed by small levees. Powdered gypsum and chopped

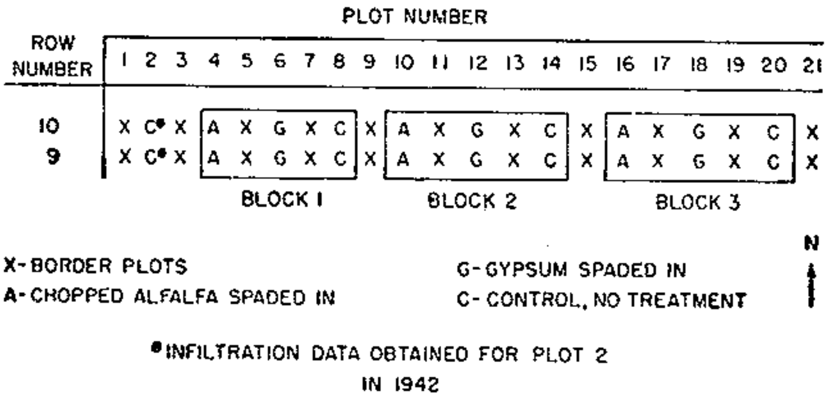

FIGURE 1.—Arrangement of experimental plots, Torres-Martinez Indian Reservation, near Indio, Calif., 1941-42.

alfalfa were applied at the rate of 5 tons each per acre and spaded in by hand. The control plots were similarly spaded. The same treatments were repeated prior to irrigation No. 4 on June 6, except that the alfalfa was more finely ground.

No record was kept of the cultural operations or irrigations during the winter of 1941-42. All plots were cultivated March 23, 1942, and chopped alfalfa was applied to plots 4, 10, and 16 at the rate of 5 tons per acre, and spaded in. No gypsum application was made in 1942.

Sufficient ammonium sulfate was applied to the soil each year to maintain an adequate nitrogen supply for the palms.

IRRIGATION

The irrigation water was delivered to the plots through a 4-inch portable pipe line, and the water applied to each plot measured with a totalizing water meter. For the first three irrigations in 1941, 300 cubic feet of water was applied to each basin, although the basins varied somewhat in area. Subsequently the outside levees were moved so that the area of each plot was 850 ±10 square feet. In 1942 the actual area within each plot was measured and the volumes necessary for a 6-inch depth were applied each time.

Eleven applications of water, totaling 54 inches in depth, were made during the period May 1 to September 12, 1941, and 12, totaling 78 inches, between April 1 and September 1, 1942. During the period of study it became evident that the original applications of 4 inches did not penetrate to an adequate depth. It was also noticed that the infiltration rates improved when the soil was allowed to dry more thoroughly between irrigations. Beginning with the seventh in 1941, the irrigation applications were increased to 6 inches, and beginning with the second irrigation in

TABLE 1.—*Irrigation schedule, 1941 and 1942*

1941				1942			
Irrigation No.	Date	Interval	Depth of water	Irrigation No.	Date	Interval	Depth of water
		Days	*In.*			*Days*	*In.*
1 [1]	May 1	..	[2] 4	([3])	Apr. 6	..	[4] 6
2	May 12	11	[2] 4		Apr. 20	14	[4] 6
3	May 22	10	[2] 4		May 6	16	[4] 6
4 [1]	June 6	15	4		May 19	13	[4] 6
5	June 16	10	4	1	June 3–4	15	6
6	June 26	10	4	2a	June 23–24	20	6
7	July 8	12	[5] 6	2b	June 26–27	3	6
8	July 29	21	6	3a	July 14–15	18	6
([6])	Aug. 10	12	1.75	3b	July 17–18	3	6
9 [7]	Aug. 14	4	6	4a	Aug. 3–4	17	6
10	Aug. 28	14	6	4b	Aug. 7–8	4	6
11 [7]	Sept. 11	14	6	5a	Aug. 24–25	17	6
				5b	Aug. 27–28	3	6

[1] Alfalfa and gypsum applied to treated plots at rate of 5 tons per acre preceding irrigation; all plots cultivated.
[2] 300 cu. ft. applied. Areas of basins varied somewhat.
[3] Alfalfa applied to plots 4, 10, and 16 preceding this irrigation. All plots cultivated.
[4] Water applied to treated and control plots was measured with stakes set in basins; border plots not irrigated.
[5] Six-inch application to treated and control plots, 4-inch to border plots for this and subsequent irrigations.
[6] Rain.
[7] Grass hoed on all plots before irrigation.

1942, double 6-inch applications were made, the second 3 or 4 days after the first.

To determine the effect of thorough soil drying, the border plots were not irrigated between March 23 and June 1, 1942, whereas the treated and control plots were irrigated four times during this interval.

The irrigation dates, intervals between applications, and depths applied in 1941 and 1942 are given in table 1. During the latter part of the 1942 season, the south basin of plot 19 (row 9) received, in addition to the regular irrigations applied to the other plots, an extra application on July 29, and beginning on August 19 it was irrigated at 3- or 4-day intervals until September 25, a total of 12 irrigations in 37 days. Furr and Aldrich *(8)* have reported on the oxygen and carbon dioxide changes in the soil atmosphere resulting from this excessive irrigation.

INFILTRATION RATE [10]

The infiltration rates in the treated and control plots were measured with special water-stage recorders developed and constructed for this purpose. These recorders automatically plot the depth of water as a function of time. The slope at any time is therefore proportional to the infiltration rate at that time. They were used only in the treated and control basins of row 10.

During 1942 additional infiltration data were obtained in the plots of row 9 and in the border plots of row 10 by reading the depth of water on graduated stakes set in basins. These data are incomplete, as the measurements were made only during that part of the day when an observer was at the plots. Virtually no data were obtained for the basins irrigated late in the afternoon, because night readings were not taken and sometimes basins were empty the following morning. The infiltration rates and permeability values have been discussed briefly by Reitemeier and Christiansen *(30)*.

MOISTURE TENSION

Soil-moisture data were obtained by means of tensiometers *(32, 33)*. In 1941 a set of these instruments was installed in each of the treated and control plots in row 10. Each set consisted of five tensiometers with cups at depths of 0.5, 1.5, 2.5, 3.5, and 4.5 feet below the ground surface. They were set in a north-south line, 5 inches apart, midway between the palm and the border between rows 9 and 10. A study was also made of the horizontal distribution of moisture tensions over a plot with tensiometer cups placed at a depth of 1½ feet.

In order to separate the relative effects on soil-moisture content of evaporation from the ground surface and transpiration from the palms, a column of soil in each of two border plots (7 and 11) was isolated from palm roots by digging a narrow 5-foot-deep trench around it and then back-filling the trench. Changes in moisture content of this isolated soil could be caused only by drainage by gravity and losses by evaporation, and possibly by some loss due to horizontal movement of moisture toward the drier soil surrounding the isolated column. Eight tensiometers were placed

[10] The term "infiltration rate" is used in the same sense as the term "infiltration capacity" was used by Horton *(12)*.

in each column, two cups each at depths of 6, 12, 18, and 30 inches.

In 1942, four tensiometers with cups at depths of 1, 2, 3, and 4 feet were installed in each of the treated and control plots in row 10.

Results

INFILTRATION RATE

The individual infiltration rates for the first, second, third, and final or fifth inch of water for the 1941 and 1942 irrigations are listed in tables 2 and 3, respectively. The mean rates for each plot for the three treatments (control, alfalfa, gypsum) for 1941 are given in table 4 and for 1942 in table 5.

Because of soil differences within the experimental area, the infiltration rates were appreciably higher at the west end than in the center and east sections of the row of plots. On the basis of analysis of variance (*35*) the mean infiltration rates of the second inch of water for block 1 were significantly greater (odds of 99:1) than for blocks 2 and 3. For both 1941 and 1942 the mean rates for the gypsum and alfalfa treatments were approximately double those for the control treatments. There is no significant difference between the mean rates for the alfalfa and gypsum treatments, but both are significantly greater (odds of 99:1) than the control. Huberty and Pillsbury (*13*) found that gypsum and various forms of organic matter, including alfalfa meal, improved infiltration into a San Joaquin Valley soil.

Significant differences between irrigations are positively correlated with the interval between irrigations (the larger interval indicating a greater drying of the surface soil) and with cultivation immediately preceding the irrigation (e.g., irrigations 1 and 4 of 1941).

The 1942 infiltration rates for the border basins of row 10 are listed in table 6. In all cases these rates are higher than for the adjacent basins, especially for the first irrigation, when the soil moisture in the border plots probably was in the wilting range. A comparison of the mean rates for the control plots, treated plots (gypsum and alfalfa), and border plots not irrigated between March 23 and June 1, 1942, is given in table 7. For irrigation No. 1, the second inch rates for the border plots average 3.4 times those for the treated plots and 7.2 times those for the control plots. For both irrigations 2b and 4a the corresponding ratios are 1.7 and 2.8. No. 2b was the second half of a 12-inch irrigation and was applied 3 days after the first half, when the soil was still very wet.

The thorough drying of the border plots in spring had a greater effect on infiltration than the alfalfa and gypsum treatments, and the effect was noticeable throughout the season, although the differences were less for later irrigations. From a practical standpoint, the occasional drying of the soil to the wilting range is a more economical and effective method of improving infiltration than the application of amendments to the soil.

The beneficial effect of prolonged drying on infiltration has

TABLE 2.—*Infiltration rates for various soil treatments in 1941*

Irrigation No.	Depth of water	Infiltration rate (inches per hour) for treatment and plot No. —								
		Alfalfa			Gypsum			Control		
		4	10	16	6	12	18	8	14	20
	Inch									
1[1]	1st	0.72	0.51	0.31	0.87	0.50	0.78	0.45	0.29	0.75
	2d	.41	.27	.14	.50	.22	.50	.18	.17	.31
	3d	.42	.23	.13	.43	.17	.35	.12	.14	.20
	Final	.44	—	—	.43	—	.32	—	—	—
2	1st	.57	.30	.26	.66	.37	.55	.23	.25	.36
	2d	.23	.12	.11	.35	.17	.26	.11	.10	.13
	3d	.17	.10	.09	.28	.14	.22	.08	.08	.12
	Final	.18	—	.10	.26	.14	.20	.09	—	—
3	1st	.45	.29	.26	.66	.37	.53	.28	.23	.26
	2d	.21	.12	.10	.32	.15	.23	.12	.10	.12
	3d	.17	.09	.08	.25	.13	.19	.08	.07	.08
	Final	.15	—	—	.24	—	—	.07	.07	—
4[1]	1st	2.33	1.91	.55	1.05	.66	.93	.32	.78	.90
	2d	.78	.50	.17	.49	.19	.40	.17	.18	.34
	3d	.57	.33	.16	.39	[2].13	.30	.12	.12	.25
	Final	.54	—	—	.42	—	.27	.12	—	—
5	1st	1.00	.85	.40	.72	.49	.62	.26	.28	.41
	2d	.50	.37	.13	.40	.21	.30	.11	.11	.18
	3d	.43	.31	.11	.30	.14	.23	.08	.08	.12
	Final	.38	—	.14	.34	—	.19	.08	.08	.12
6	1st	.95	.70	.30	.70	.45	.30	.19	.22	.35
	2d	.46	.27	.13	.38	.20	.25	.10	.09	.15
	3d	.40	.23	.10	.31	.14	.21	.07	.06	.10
	Final	.43	—	.15	.33	—	—	.07	.05	.10
7	1st	1.23	.68	.50	.81	.38	.91	.30	.36	.58
	2d	.54	.29	.19	.55	.27	.46	.13	.15	.27
	3d	.48	.21	.12	.40	.20	.34	.09	.10	.22
	Final	.34	.16	.10	.34	.18	.27	.09	.08	.13
8	1st	1.17	.72	.57	1.10	.92	1.00	.37	.47	.70
	2d	.62	.31	.21	.60	.44	.55	.19	.20	.34
	3d	.44	.20	.15	.53	.18	.34	.14	.14	.25
	Final	.37	.17	.12	.57	.21	.33	.14	.13	.21
9	1st	1.18	.57	.34	.87	.44	.73	.21	.21	.30
	2d	.58	.22	.15	.50	.26	.39	.12	.11	.14
	3d	.43	.18	.11	.39	.18	.31	.09	.09	.12
	Final	.38	.15	.10	.33	.18	.24	.10	.08	.11
10	1st	1.05	.57	.38	.82	.64	.84	[2].23	.25	.34
	2d	.54	.23	.15	.48	.29	.38	.10	.12	.16
	3d	.39	.16	.12	.34	.20	.27	.10	.08	.11
	Final	.32	.15	.10	.31	.17	.23	.10	.08	.11
11	1st	1.50	1.10	.34	.96	.62	.62	.27	.23	.28
	2d	.58	.55	.14	.53	.28	.33	.13	.10	.13
	3d	.40	.19	.10	.38	.17	.24	.10	.08	.09
	Final	.34	.13	.10	.35	.16	.19	.10	.08	.09

[1] Gypsum and chopped alfalfa added to respective plots at rates of 5 tons per acre, and all plots spaded prior to first and fourth irrigations.
[2] Estimated from partial record.

been generally recognized, but few data have been published showing relative effects. Taylor (*36*) suggested the alternate middle method of irrigation for special conditions. Gardner (*9*) found that the change from the disperse to the granular state occurs only at low moisture content, and Haynes (*10*) found that the permeability of a black alkali soil is improved by alternate wetting and drying. Other authors have commented on improvements due to soil drying but have presented no data.

TABLE 3.—*Infiltration rates for various soil treatments in 1942*

Irrigation No.	Depth of water	Infiltration rate (inches per hour) for treatment [1] and plot No. —									
		Alfalfa			Gypsum			Control			
		4	10	16	6	12	18	2	8	14	20
	Inch										
1	1st	0.84	0.41	0.52	0.75	0.51	0.34	1.20	0.31	0.27	0.22
	2d	.38	.17	.17	.39	.24	.15	.53	.16	.12	.09
	3d	.27	.11	.10	.29	.15	.09	.36	.10	.08	.07
	5th	.22	.10	.09	.20	.13	.07	.24	.09	.06	.06
2a	1st	1.10	.50	.66	.87	.58	.46	1.10	.45	.40	.31
	2d	.46	.21	.24	.46	.30	.24	.53	.22	.17	.15
	3d	.37	.14	.16	.37	.22	.16	[2].38	.16	.12	.09
	5th	.30	.17	.13	[2].25	.16	.14	[2].25	.12	.10	.07
2b	1st	.34	.17	[2].16	.33	.19	.16	.35	.14	.14	.12
	2d	.26	.14	[2].11	.25	.15	.09	.26	.14	.09	.07
	3d	.26	.12	[2].10	.21	.13	.09	.23	.13	.08	.06
	5th	.23	.12	[2].09	.16	.11	.08	.18	.11	.07	.06
3a	1st	1.05	.77	.61	.81	.52	.44	.84	.34	.33	.30
	2d	.48	.34	.22	.36	.23	.18	.42	.17	.12	.13
	3d	.34	.20	.13	.27	.17	.13	.33	.12	.09	.09
	5th	.29	.16	.13	.21	.15	.12	.24	.11	.08	.08
3b	1st	.42	.17	.17	.34	.17	.15	.32	.15	.11	.11
	2d	.29	.14	.12	.25	.12	.10	.25	.12	.08	[2].08
	3d	.27	.13	.11	.19	.11	.09	.22	.10	.08	[2].07
	5th	.24	.13	[2].11	.16	.10	[2].08	.19	.09	.07	[2].07
4a	1st	1.00	([3])	.66	.62	.45	.46	1.00	.37	.29	.28
	2d	.48	([3])	.20	.34	.23	.20	.49	.18	.11	.13
	3d	.37	([3])	.13	.27	.16	.13	.30	.13	.09	.08
	5th	.26	([3])	.12	.19	.15	.12	.25	.13	.08	.07

[1] See footnote 1, table 2, for 1941 treatments.
[2] Estimated from partial record.
[3] Apparently leak in levee, record faulty.

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TABLE 4.—*Mean infiltration rates for various soil treatments in 1941*

Treatment and plot	Infiltration rate			
	First inch	Second inch	Third inch	Final inch [1]
	Inches per hour	*Inches per hour*	*Inches per hour*	*Inches per hour*
Alfalfa:				
No. 4	1.10 ± 0.153	0.60 ± 0.050	0.39 ± 0.036	0.35 ± 0.011
No. 10	.75 ± .136	.30 ± .041	.20 ± .022	.15 ± .007
No. 16	.38 ± .033	.15 ± .010	.12 ± .007	.10 ± .004
Mean	.74 ± .086	.31 ± .033	.24 ± .025	.20 ± .029
Gypsum:				
No. 6	.84 ± .045	.46 ± .027	.36 ± .024	.38 ± .047
No. 12	.53 ± .050	.24 ± .024	.16 ± .008	.18 ± .018
No. 18	.71 ± .063	.37 ± .032	.27 ± .018	.25 ± .023
Mean	.69 ± .037	.36 ± .022	.27 ± .018	.27 ± .028
Control:				
No. 8	.28 ± .023	.13 ± .009	.10 ± .007	.11 ± .009
No. 14	.32 ± .051	.13 ± .012	.09 ± .008	.09 ± .010
No. 20	.47 ± .066	.21 ± .027	.15 ± .020	.13 ± .021
Mean	.36 ± .032	.16 ± .012	.11 ± .009	.11 ± .009

[1] Mean for last 5 irrigations only.

TABLE 5.—*Mean infiltration rates for various soil treatments in 1942* [1]

Treatment and plot	Infiltration rate			
	First inch	Second inch	Third inch	Final inch
	Inches per hour	*Inches per hour*	*Inches per hour*	*Inches per hour*
Alfalfa:				
No. 4	1.00 ± 0.056	0.45 ± 0.024	0.34 ± 0.024	0.27 ± 0.018
No. 10 [2]	.56 ± .108	.24 ± .051	.15 ± .026	.14 ± .022
No. 16	.61 ± .033	.21 ± .015	.13 ± .012	.12 ± .010
Mean	.74 ± .071	.30 ± .038	.20 ± .037	.17 ± .019
Gypsum:				
No. 6	.76 ± .053	.39 ± .026	.30 ± .024	.21 ± .013
No. 12	.51 ± .027	.25 ± .017	.17 ± .016	.15 ± .006
No. 18	.42 ± .029	.19 ± .019	.13 ± .013	.11 ± .015
Mean	.57 ± .047	.28 ± .027	.20 ± .024	.16 ± .014
Control:				
No. 8	.37 ± .030	.18 ± .015	.13 ± .013	.11 ± .009
No. 14	.32 ± .029	.13 ± .013	.10 ± .009	.08 ± .008
No. 20	.28 ± .020	.12 ± .013	.08 ± .005	.07 ± .004
Mean	.31 ± .019	.14 ± .010	.10 ± .007	.09 ± .007

[1] For irrigations 1, 2a, 3a, and 4a only.
[2] Data for irrigation 4a missing because of leak in levee.

TABLE 6.—*Infiltration rates for border plots in 1942* [1]

Plot No.	Infiltration rate (inches per hour) for irrigation —								
	No. 1			No. 2b			No. 4a		
	1st inch	2d inch	3d inch	1st inch	2d inch	3d inch	1st inch	2d inch	3d inch
3	2.00	1.00	0.73	0.85	0.58	0.29	0.77	0.67	0.56
5	2.50	1.54	1.13	.49	.44	.38	....	....	....
7	1.25	.61	.48	.32	.27	.23	.53	.53	.29
9	....	...	....	.32	.22	.17	.77	.32	.16
11	....	....	....	.39	.27	.24	...	...	....
13	1.31	.83	....	.35	.18	.16	.56	.31	.08
15	1.43	.59	...	.28	.19	.16	.38	.13	....
17	1.00	.56	.23	.22	.14	.13	1.10	.38	.24
19	2.00	1.14	.63	.43	.24	.19	.71	.43	....
21	2.22	.65	.54	.38	.27	.21	.63	.42	....

[1] Approximate rates determined from stakes set in basins.

TABLE 7.—*Mean infiltration rates for treated, control, and border plots in 1942*

Irrigation No.	Inches of water	Infiltration rate for —		
		Treated plots	Control plots	Border plots
		Inches per hour	*Inches per hour*	*Inches per hour*
1	1st	0.56 ± 0.079	0.27 ± 0.026	1.71 ± 0.166
	2d	.25 ± .044	.12 ± .017	.86 ± .122
	3d	.17 ± .036	.08 ± .008	.62 ± .123
2b	1st	.22 ± .035	.13 ± .007	.40 ± .065
	2d	.17 ± .029	.10 ± .021	.28 ± .042
	3d	.15 ± .028	.09 ± .021	.22 ± .023
4a	1st	[1] .53 ± .100	.31 ± .090	.93 ± .111
	2d	[1] .24 ± .063	.14 ± .021	.40 ± .056
	3d	.18 ± .047	.10 ± .015	.27 ± .082

[1] Data for plot 10 missing.

SOIL-MOISTURE DATA

TENSIOMETER RECORDS

The tensiometer readings afforded a continuous record of the soil moisture and an indication of the depth of penetration of water following each irrigation. The tensiometer scales were set to register the negative hydraulic head of water with respect to the ground surface. Differences in reading of tensiometers, therefore, provide an indication of the direction of vertical movement of soil moisture, i.e., either up or down (*33*). The tensiometer data for plots 8, 12, and 16 for 1941 and 1942 are shown in figures 2, 3, and 4. The negative hydraulic head is plotted downward to a logarithmic scale. The resulting curves have approximately the same shape as if the soil-moisture percentage had been plotted to an ordinary scale against time. The tensiometers cover only part of the available moisture range, as their operation becomes unsatisfactory when the tension approaches 850 cm. of water.

Experience with tensiometers in Coachella Valley soils indicates that the tensiometer range covers more than half the total available soil-moisture range. Although the three plots illustrated include one for each treatment, they should not be considered as typical for these treatments. For example, there is little similarity in the characteristics of the curves shown in figure 2 for plot 8 with those for the other control plots 14 and 20. The moisture tension at the different depths is affected by root distribution, which in turn depends upon stratification and salt content.

For plot 8, figure 2 shows that for the first three irrigations of 1941 the soil at the 6-inch depth was not very dry (the tensiometer mercury column was still on scale) when the water was applied. The water penetrated past the 30-inch depth, but did not reach 54 inches. The fourth, fifth, sixth, and seventh irrigations did not penetrate to 30 inches, and apparently barely reached the 18-inch level, as the tension at this depth was reduced to only about 300 cm. of water. The soil at 30- and 42-inch depths dried continuously during this period. The tensiometers at 18-, 30-, and 42-inch depths all reached their limit of 850 cm. of water tension about the same time, during the latter part of July. The eighth irrigation reduced the tension at the 18-inch depth to less than 200 cm., but did not affect the tension at 30 inches. The ninth irrigation (August 14) penetrated to the 30-inch depth, and the eleventh (September 11) apparently reached 42 inches. The soil at the 54-inch depth was fairly dry and was not affected by any of the irrigations during the season. The slight irregularities on the curve for this depth result from refilling the tensiometer with water.

In 1942 the situation was quite different. There was some available moisture present at all depths on June 1, but the first irrigation of 6 inches apparently did not affect the tensiometer at the 24-inch depth. The second half of the second irrigation (2b) and all subsequent irrigations of 12 inches, however, penetrated through the 48-inch depth. There appears to have been moisture extraction at all depths in this plot.

The tensiometer data for plot 12 in 1941 (fig. 3) show a different condition. Here on May 1 the moisture content to the 30-inch depth was high, but it was fairly low at 54 inches and probably low at 42 inches. The apparent increase in moisture content at 54 inches on May 10 was caused by an accident with the tensiometer and not by water penetration to that depth. The soil remained relatively wet at the 6- and 18-inch depths during May and June, but there was no penetration beyond 30 inches during this period. The moisture content was fairly low at the 42- and

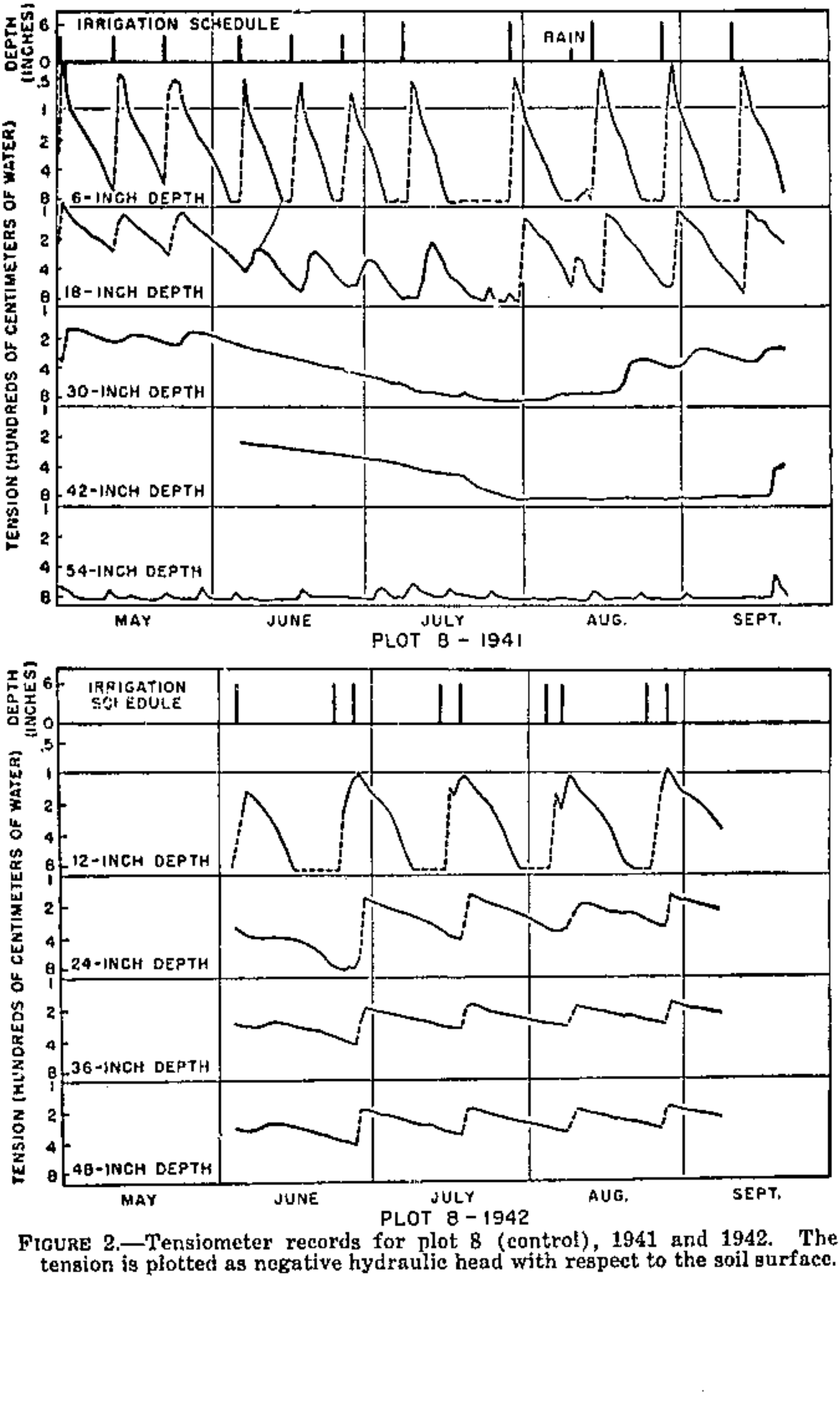

FIGURE 2.—Tensiometer records for plot 8 (control), 1941 and 1942. The tension is plotted as negative hydraulic head with respect to the soil surface.

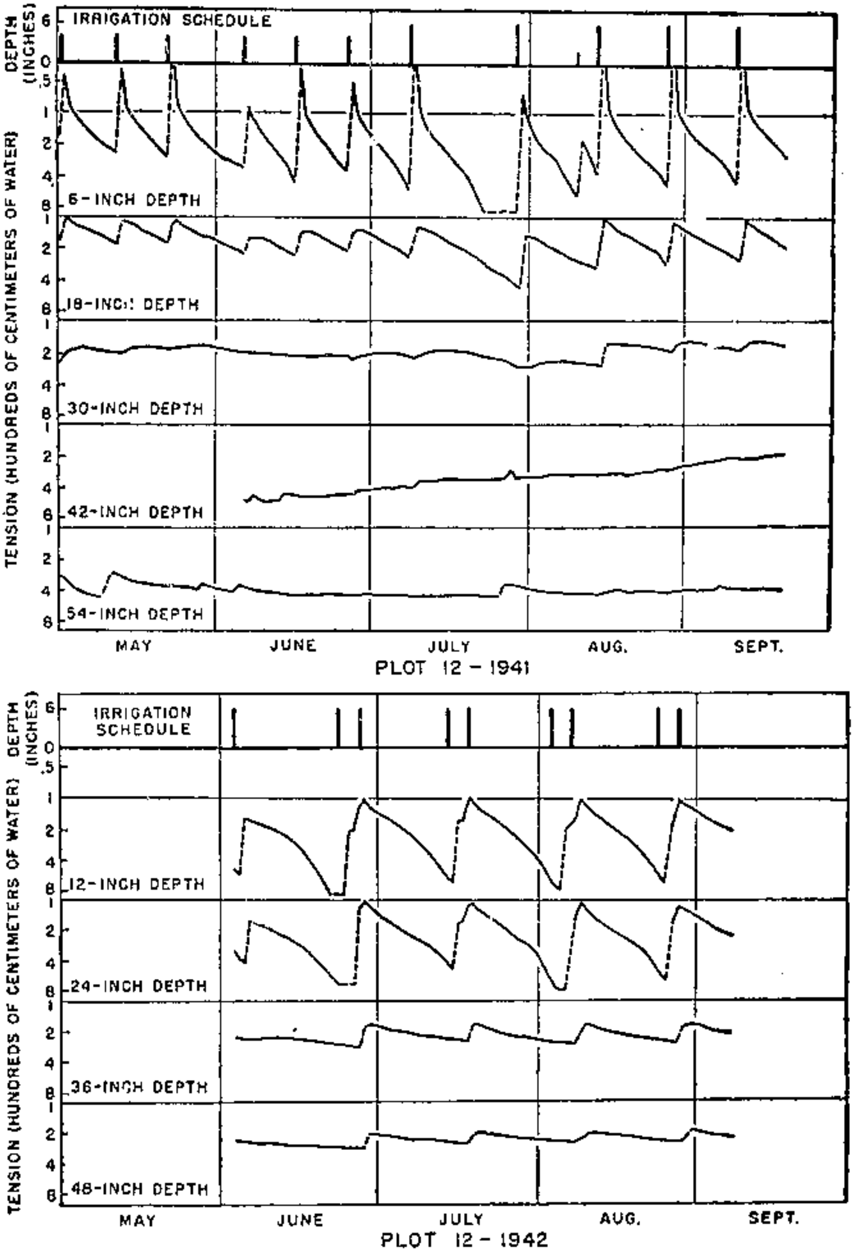

FIGURE 3.—Tensiometer records for plot 12 (gypsum), 1941 and 1942. The tension is plotted as negative hydraulic head with respect to the soil surface.

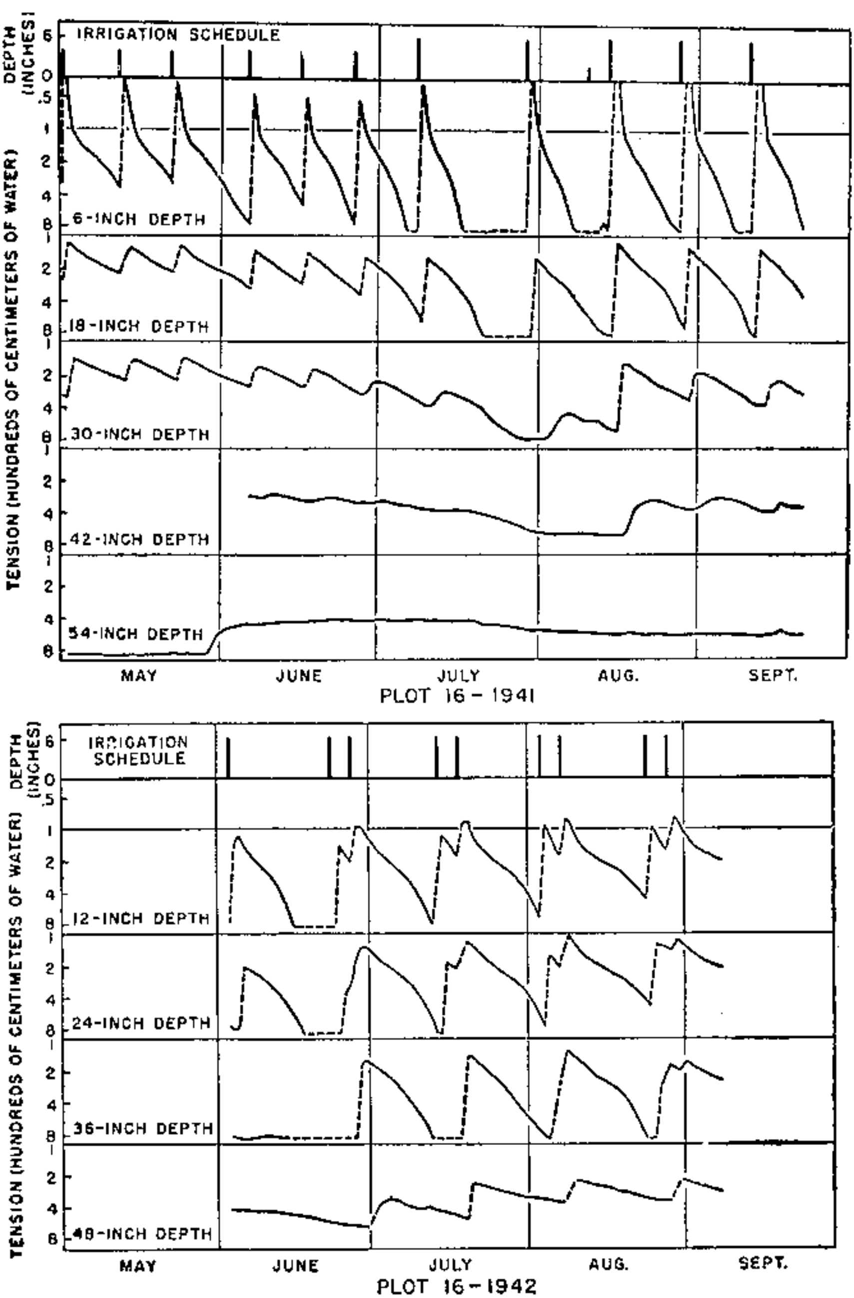

FIGURE 4.—Tensiometer records for plot 16 (alfalfa), 1941 and 1942. The tension is plotted as negative hydraulic head with respect to the soil surface.

54-inch depths, but at 42 inches it increased gradually during the season. Only during the longer interval between July 8 and 29 did the tension at 6 inches exceed 850 cm. of water. The data indicate that there was little if any extraction of water at or below the 30-inch depth during the season. In 1942 the heavier irrigations penetrated beyond 48 inches, but there was little extraction at 36 or 48 inches.

In plot 16 the soil moisture in 1941 was somewhat similar to that in plot 8 (fig. 4). The third irrigation, on May 22, apparently reached the 54-inch level, but subsequent irrigations did not, and there was slight extraction of moisture at this level during the season. The ninth irrigation on August 14 penetrated to the 42-inch depth.

In 1942 the first 6-inch irrigation did not reach 36 inches, but the subsequent 12-inch irrigations all penetrated to 48 inches. There was rapid extraction of moisture down to 36 inches, and some at 48 inches. This was the only plot in which the tension at 36 inches exceeded that at 12 and 24 inches, which indicates intense root activity at 36 inches.

The depth of water penetration following an irrigation depends primarily upon three factors: (1) The field capacity, (2) the moisture content of the soil at time of irrigation, and (3) the quantity of water applied. Because of the wide range in texture of the subsoil—clay to coarse sand—and the heterogeneous stratification, the field capacity varies with depth and location.

SOIL-MOISTURE SAMPLING

On June 2, 1942, soil-moisture samples were taken from the three control basins in row 9 (plots 8, 14, and 20) and in three adjacent border basins of row 9 (plots 7, 13, and 19). The average moisture percentage for each foot of soil is given in table 8.

TABLE 8.—*Average soil-moisture percentage of 3 control plots and 3 border plots in row 9 prior to irrigation 1, June 2, 1942* [1]

Depth (feet)	Average soil moisture in —	
	Control plots (8, 14, and 20)	Border plots (7, 13, and 19)
	Percent	*Percent*
0–1	8.70	3.29
1–2	7.39	3.63
2–3	7.66	3.20
3–4	5.23	3.18
4–5	3.43	2.68

[1] Each figure is an average of 6 samples, 2 in each plot.

Samples were also taken in the control plots before and after the second irrigation. The average moisture content for each foot of soil and the increase in moisture (expressed as depth in inches) are given in table 9. Considering the loss of moisture by evaporation and transpiration during the 7-day period, the 10.6 inches

TABLE 9.—*Average soil-moisture percentage of the control plots in row 9 before and after irrigation*[1]

Depth (feet)	Average soil moisture — Before irrigation (June 23, 1942)	Average soil moisture — After irrigation (June 30, 1942)	Increase in moisture — Percent	Increase in moisture — Approximate depth
	Percent	*Percent*		*Inches*
0–1	4.74	28.04	23.30	4.2
1–2	5.44	24.54	19.10	3.4
2–3	5.81	18.76	12.95	2.3
3–4	5.32	8.20	2.88	.5
4–5	2.12	3.13	1.01	.2
Total				10.6

[1] Each figure is an average of 6 samples, 2 in each plot.

accounted for agrees satisfactorily with the 12 inches applied.

Assuming that the moisture percentages in the control plots on June 30 and in the border plots on June 2 can be taken as fair approximations of the field capacity and wilting percentage, respectively, the extremely wide range of available moisture is apparent. The ratios of these moisture percentages are 8.5, 6.7, 5.8, and 2.6 for the first, second, third, and fourth foot, respectively. Tensiometer data indicate that the water did not completely penetrate the fourth foot in plot 20, and barely reached 4 feet in plot 14 following the second irrigation.

The depths of penetration of water for each of the plots, as indicated by tensiometers, are given in table 10 for 1941 and in

TABLE 10.—*Depth of water penetration for various soil treatments, 1941*

Irrigation No.	Interval	Alfalfa 4	Alfalfa 10	Alfalfa 16	Gypsum 6	Gypsum 12	Gypsum 18	Control 8	Control 14	Control 20
	Days	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1		30+	30+	30+	54−	54	30+	30+	54	30+
2	11	54	30	30+	54	30	30+	30	30	30+
3	10	54	30	54−	54	30	30+	[2] 30+	30	30
4	15	30−	18	42	30	18	[3] 42	18	18	18
5	10	30	18	42	30	18	54−	18	18	18
6	10	30	30−	42−	30	42−	54−	18	18	18−
7	12	42	30−	30	42−	42−	54−	18	30−	18
8	21	18	18	30−	30	30	30	18	30−	42
([4])	12	6	6	....	6	6	6	....	6	....
9	4	42−	30	42	42	30	54−	30	30	42−
10	14	42−	42−	42	42	42−	54−	30	30	42−
11	14	30	42−	42	42	42	42	42	30	30

Depth of water penetration[1] for treatment and plot No.

[1] + = Penetration beyond 30 inches, no tensiometer at 42 inches; — = only slight wetting of soil at this depth.

[2] Approximately 6 inches of water applied, owing to break in levee.

[3] Approximately 4.4 inches of water applied instead of 4.

[4] Rain.

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table 11 for 1942. From table 10 it is apparent that less penetration is obtained when an irrigation follows a long interval and the soil is correspondingly drier. For example, irrigation 7 following a 12-day interval penetrated about 1 foot deeper than irrigation 8 following a 21-day interval. The discrepancy in plot 20 is attributed to water running down around the tensiometer, owing to shrinkage of the soil on drying.

TABLE 11.—*Depth of water penetration for various soil treatments, 1942*

Irrigation No.	Interval	Depth of water penetration[1] for treatment and plot No.								
		Alfalfa			Gypsum			Control		
		4	10	16	6	12	18	8	14	20
	Days	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1	15–16	36	36	24	24	24	36	48—	24	24
2a	20									
2b	3–4	48	48	48	48	48	36	48	48—	36
3a	17–18									
3b	3–4	48	48	48	48	48	48—	48	48	48—
4a	17–18									
4b	3–4	48	48	48	48	48	48—	48	48	48—
5a	17–18									
5b	2–4	48	48	48	48	48	48	48	48	48

[1] — = Only slight wetting of soil at this depth

SOIL-MOISTURE TENSIONS IN ISOLATED SOIL COLUMNS

Soil-moisture tensions at all depths in the isolated soil columns in plots 7 and 11 in 1941 remained at a comparatively low level throughout the season. The record for tensiometer set A in plot 7 is shown in figure 5. A comparison of this figure with the records for other plots, especially the adjacent plot 8 (fig. 2), indicates that the rapid increase in tension at the 6-inch level in the other plots is caused primarily by extraction of soil moisture by roots and not by evaporation from the soil surface. The tensiometer readings for both sets in the two plots were very similar throughout the season. The tension (negative hydraulic head referred to ground surface) at the 6-inch level exceeded 250 cm. of water only once during the season, and that was during the 3-week interval between irrigations 7 and 8 on July 8 and 29, respectively. In plot 8, the tensiometer reading exceeded 250 cm. on July 14, 6 days after irrigation, and 800 cm. 3 days later.

Since there was no moisture extraction by plants in these isolated columns, the loss of moisture was due to evaporation from the soil surface, slow downward drainage, and possible lateral movement caused by higher tensions outside the columns. The moisture tension after the initial rapid drainage has taken place should correspond to that at field capacity. About 4 days after irrigation all tensiometers read about 130 cm. of water. At the 6-inch level this increased to 180 cm. in about 5 days, and at the other depths it increased to 180 cm. in 9 to 10 days. If corrections are made for depth of cups below ground surface, soil-moisture tensions at field capacity may be considered to range from about 100 to 150 cm. of water.

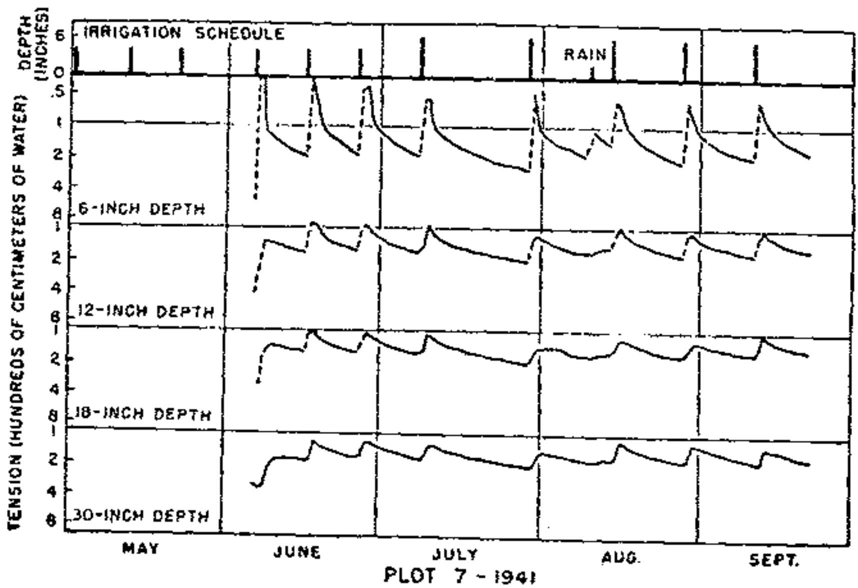

FIGURE 5.—Record for tensiometer set A in isolated soil columns of plot 7, 1941.

LABORATORY STUDIES

Following the growing seasons of 1941 and 1942, the soil of all the experimental plots was sampled for laboratory investigations. On September 24 and 25, 1941, two sampling holes, 6 inches in diameter, were made in each tensiometer basin. One of each pair of holes was at a site halfway between the palm trunk and the southwest corner of the basin (A), the other halfway between the trunk and the northeast corner of the basin (B). The soil occurring at the following depths was placed in glass jars: 3 to 9 inches (hereinafter referred to as the surface-soil sample), 15 to 21, 27 to 33, and 39 to 45 inches. At Riverside these samples were passed through a ¼-inch sieve, subsampled for moisture determination, and returned to the jars.

On November 4, 1942, the same general sampling scheme was followed, except that 2-inch holes were made 1 foot south of the 1941 sampling sites and only one was dug in each plot—in the A locations in plots 10, 12, and 14, and in the B locations in plots

4, 6, 8, 16, 18, and 20. The south basin of plot 19, which had been frequently irrigated, was sampled also, halfway between the palm trunk and the northwest corner of the basin.

Samples of irrigation water were taken at each irrigation during the 1941 season.

Measurements and Methods

SOLUBLE SALTS

All 1 : 1 extracts (*17*) on the oven-dry soil basis of the 72 1941 samples and the 40 1942 samples were analyzed for calcium, magnesium, sodium, carbonate-bicarbonate, sulfate, and chloride. Potassium and nitrate also were determined on the 1941 extracts. Analyses of the extracts and the irrigation water were made by semimicroanalytical methods described elsewhere (*28*), except that sodium was determined gravimetrically as sodium uranyl zinc acetate (*17*).

Ion concentrations in waters, soil solutions and extracts, and oven-dry soil are expressed as equivalents per million (e. p. m.). The unit "equivalent per million" represents 1 gram-equivalent weight of an ion in 1 million grams of soil or solution (*17*). When the specific gravity of the solution is 1, this unit is exactly equal to the unit "milliequivalent per liter." Ion concentrations in a 1 : 1 extract thus expressed are numerically equal to those on the oven-dry soil basis.

EXCHANGEABLE BASE STATUS AT 100-PERCENT MOISTURE

Exchangeable sodium and base exchange capacity were determined on 40 selected samples. Base exchange capacity was determined by a semimicroanalytical method involving ammonium acetate, centrifugation, and straight nesslerization. The appreciable solubility of calcium carbonate in ammonium acetate causes values to be low by 10 percent because of nonsaturation of the base exchange complex with ammonia, as shown by Chapman and Kelley (*8*) and experiments of Reitemeier and Fireman. Because the samples in the present study had a high content of carbonates, the capacity values reported include a positive correction of 10 percent.

Ammonium-acetate-extractable sodium was removed by a leaching procedure and determined gravimetrically as sodium uranyl zinc acetate (*17*). Exchangeable sodium was obtained by subtracting the soluble sodium found in the 1 : 1 extract from the total extractable sodium.

pH VALUES

Subsamples of the 1941 samples were moistened to the saturation percentage (*17*), and after 1 hour the pH values were measured with a glass electrode. The pH values of the 1 : 1 extracts of the 1942 samples were similarly determined.

ORGANIC-MATTER CONTENT

The organic carbon of 36 selected samples was determined by a chromic acid method essentially that of Schollenberger (*34*) but utilizing the modified phosphoric acid reagent of Purvis and Higson (*27*).

FLOCCULATION OBSERVATIONS

After the 1 : 1 suspensions prepared for chemical analysis had stood overnight without disturbance, their condition with respect to flocculation, turbidity, and appearance of the sedimented part was noted and sketched. In addition, suspensions of 36 1942 samples (all but those of plot 19) were photographed directly in the wide-mouthed pint bottles in which the suspensions were prepared.

DISPERSION RATIOS

The extent of dispersion of the silt and clay fractions of the 3- to 9-inch horizons of the 1941 samples of plots 4, 6, and 8 was determined by a procedure utilizing the principles of the dispersion ratio described by Middleton (*21*) and a hydrometer method of Peele (*24*). Duplicate moist samples equivalent to 50 gm. of oven-dry soil were slaked overnight and were then agitated differently, one treated with sodium silicate and sodium oxalate in an electrical mechanical-analysis mixer of the Bouyoucos type, the other in 1 liter of water merely by inverting the cylinder end over end 20 times. After appropriate time had been allowed for the clay plus silt (<0.05 mm. diameter) and the clay (<0.005 mm. diameter) to settle, specific gravity readings were taken by means of a calibrated specific gravity hydrometer. The dispersion ratio of each size fraction was obtained by dividing the suspension percentage of the completely dispersed sample into that of the relatively undisturbed sample.

PERMEABILITY MEASUREMENTS

The method of measurement was the constant-head downward-flow technique described by Fireman (*6*), using a synthetic water of virtually the same composition as that of the natural irrigation water. Permeabilities expressed in centimeters per hour were calculated from the following form of the Darcy equation (*5, 31*) : $P = \frac{QL}{AH}$, where P is the Darcy coefficient of permeability, Q the flow (volume per unit time), L the length of the soil column, A the cross-sectional area of the column, and H the decrease in hydraulic head through length L. The permeability value reported is that existing after 300 ml. of water (2.86-inch depth) had passed through the 200 gm. of soil.

In the spring of 1942, permeability measurements were made on all the moist 1941 samples. In December 1944, permeability was redetermined on subsamples of the 18 3- to 9-inch samples after they had been air-dried and passed through a 2-mm. round-hole screen.

Results

SOLUBLE SALTS

The 1 : 1 extracts of the 3- to 9-inch samples of the control and alfalfa-treated plots were of similar composition (table 12). Sodium represents 82 percent of the cations in the irrigation water but only about 40 percent of the extract cations. This reduction in sodium percentage results from the low total salt content and the presence of calcium carbonate. The carbon dioxide of the soil reacts with the solid-phase carbonate to form calcium bicarbonate, and because of the low level of other salts the resulting calcium concentration comprises a high proportion of the total bases. The composition of the extract of the intensively irrigated plot 19 is very similar to those of plots that received far less irrigation water. A low concentration of salt existed in plot 19 down to 39 to 45 inches, in which horizon the total salt content was the same, but the sodium percentage was 88.

The addition of gypsum raised the calcium and sulfate concentrations to about 31 e. p. m. and the total to 34 e. p. m. The composition of a 1 : 1 extract of a soil containing excess gypsum or calcium carbonate necessarily is somewhat artificial, compared with that of a soil solution extracted at field moisture (*29*). At lower moisture contents, the proportion of ions other than calcium, sulfate, and bicarbonate increases. During the 1942 season the gypsum was completely leached from the 3- to 9-inch horizons of plots 12 and 18 and all but 15 e. p. m. from plot 6 (the total quantity applied to the 0- to 9-inch horizon was approximately 75 e. p. m.).

Whereas the 3- to 9-inch horizons of replicated plots agreed satisfactorily with respect to soluble ion composition, the lower horizons varied considerably both within and between treatments (table 13). The total salt content ranged from 3 to 53 e. p. m. (0.02 to 0.37 percent), the sodium percentage from 4 to 99. Part of the experimental area had been treated with sulfur and gypsum prior to this experiment, which resulted in an accumulation of sodium sulfate below the 1-foot level; consequently, the vertical movement of ions resulting from the subsequent treatments is obscured. Additionally, variations in texture complicate the movement of salts even within a plot.

In general, both total salt content and sodium percentage increase with depth. In gypsum plots the accumulated salt is usually sodium sulfate and in the other plots sodium bicarbonate (except where sulfate has accumulated from prior amendments). The increase in soluble sodium results from its low base-replacing ability as compared with calcium and magnesium. Under soil conditions the calcium carbonate is sufficiently soluble for calcium to be adsorbed on the base exchange complex and the replaced sodium together with sulfate or bicarbonate moves downward in the percolating water.

The 1941 irrigation regime was insufficient to remove the salts from the 4-foot profiles. Even in the gypsum plots water

TABLE 12.—*Average composition of irrigation water and of 1 : 1 extracts of 3- to 9-inch samples*

Sample	pH	K[1] x 10^5 at 25° C.	Na percentage	Cations					Anions				
				Ca	Mg	Na	K	Total	CO_3—HCO_3	SO_4	Cl—	NO_3	Total
				E.p.m.	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*
Water, 1941	8.3	25	82	0.30	0.08	1.98	0.06	2.42	1.57	0.50	0.33	0.04	2.44
Control plots, 1941-42	8.3	31	47	1.2	.2	1.6	.4	3.4	2.4	.1	.3	.2	3.0
Plot 19, 1942	8.3	29	45	1.4	.3	1.4		3.1	2.3	.4	.1		2.8
Alfalfa-treated plots, 1941-42	8.3	35	39	1.5	.3	1.6	.8	4.2	2.9	.1	.2	.4	3.6
Gypsum-treated plots, 1941	8.0	250	4	30.6	1.1	1.5	.6	33.8	1.1	32.9	.3	.2	34.5

[1] Specific electrical conductance.

TABLE 13.—*Composition of salts in 1 : 1 soil extracts*

TOTAL SALT CONCENTRATION

Depth and year	Soil samples from —									
	Alfalfa plots			Gypsum plots			Control plots			Plot
	4b	10a	16b	6b	12a	18b	8a	14a	20b	19
3 to 9 inches:	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*
1941	3.2	4.5	2.8	35.5	34.3	33.9	3.8	3.1	2.9	—
1942	3.2	3.5	2.9	18.3	2.6	2.7	2.7	3.1	3.1	3.1
15 to 21 inches:										
1941	3.7	11.1	25.0	18.5	12.0	13.5	5.3	4.1	9.3	—
1942	2.5	14.7	2.7	30.4	2.7	17.4	5.4	2.8	5.2	2.5
27 to 33 inches:										
1941	6.0	24.2	27.4	8.1	18.7	31.7	11.1	9.8	34.7	—
1942	2.5	19.5	34.8	13.4	6.9	24.5	19.5	5.1	23.6	3.5
39 to 45 inches:										
1941	15.5	13.0	16.8	8.1	20.1	26.4	7.6	20.7	28.2	—
1942	6.4	9.6	27.3	13.3	15.7	25.0	13.6	11.3	44.0	2.7

EQUIVALENT SODIUM PERCENTAGE

Depth and year	4b	10a	16b	6b	12a	18b	8a	14a	20b	19
3 to 9 inches:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1941	47	58	54	5	5	4	47	58	62	—
1942	40	49	45	11	50	52	48	58	52	45
15 to 21 inches:										
1941	73	92	34	68	41	20	85	80	92	—
1942	46	97	52	5	48	10	69	64	73	36
27 to 33 inches:										
1941	95	92	84	68	99	60	94	96	92	—
1942	71	97	65	15	88	10	94	92	94	54
39 to 45 inches:										
1941	88	98	94	86	99	74	95	72	94	—
1942	91	99	94	71	99	57	86	96	96	88

EQUIVALENT SULFATE PERCENTAGE

3 to 9 inches:										
1941	1	1	1	96	91	97	7	3	1	—
1942	6	1	4	88	1	19	4	7	4	14
15 to 21 inches:										
1941	1	31	90	89	89	91	1	6	47	—
1942	1	21	16	95	37	92	13	15	17	8
27 to 33 inches:										
1941	3	44	88	71	56	94	35	48	88	—
1942	1	34	92	84	77	95	60	9	75	14
39 to 45 inches:										
1941	71	28	52	39	22	82	19	64	54	—
1942	40	25	73	84	65	94	60	43	76	1

did not penetrate the fourth foot that year. The 1942 analyses show a more pronounced migration of salts downward but no general leaching of the salts past the 4-foot depth. This was accomplished only in plot 19, receiving the excess water, in which plot the total ionic concentration throughout the profile was only 3 e. p. m. This study indicates the importance of heavier applications of water than had been used previously.

EXCHANGEABLE BASE STATUS AT 100-PERCENT MOISTURE

The exchangeable sodium and base exchange capacities of 40 soil samples are listed in table 14. The values for samples of high soluble sodium content are subject to errors involved in the subtraction of this figure from total extractable sodium to obtain exchangeable sodium.

The base exchange capacity of the upper horizon ranges from 6.7 to 11.7, average 9.7; and that of the lower horizons from 2.8 to 9.5. In the surface soil the sodium percentage of the exchangeable bases ranges from 2 to 8, average 5; and in the subsoil

TABLE 14.—*Exchangeable base status of selected soil samples at 100-percent moisture*

Depth and treatment	Plot No. and site	Exchangeable sodium [1]		Base exchange capacity [1 2]		Sodium percentage	
		1941	1942	1941	1942	1941	1942
8 to 9 inches:							
Alfalfa	4B	0.28	0.47	9.0	9.6	3	5
	10A	.23	.61	10.9	10.7	2	6
	16B	.66	.52	11.3	10.7	6	5
Gypsum	6B	.28	.52	10.5	11.7	3	4
	12A	.26	.57	7.4	7.3	4	8
	18B	.44	.46	9.9	9.6	4	5
Control	8B	.33	.59	9.8	10.7	3	6
	14A	.36	.43	6.7	7.4	5	6
	20B	.49	.44	10.7	10.7	5	4
Leached	19	----	.36	----	9.4	----	4
15 to 21 inches:							
Alfalfa	10A	1.48	3.60	8.5	9.5	17	38
Gypsum	12A	.68	.57	4.3	3.6	16	16
Control	14A	.77	.27	4.8	2.8	16	10
Leached	19	----	.39	----	6.6	----	6
27 to 33 inches:							
Alfalfa	10A	2.25	4.90	7.9	9.5	28	52
Gypsum	12A	2.61	1.07	4.2	4.0	62	27
Control	14A	1.62	1.04	4.5	5.2	36	20
Leached	19	----	.79	----	6.7	----	12
39 to 45 inches:							
Alfalfa	10A	1.05	1.67	3.6	3.4	29	49
Gypsum	12A	4.20	3.28	5.1	5.5	82	60
Control	14A	1.16	2.03	5.7	5.4	20	38
Leached	19	----	.87	----	6.2	----	14

[1] Milliequivalents per 100 grams of oven-dry soil.
[2] Determined base exchange capacity times 1.10.

from 6 to 82. The narrow low range of exchangeable sodium in the surface soil results from the solubility of calcium carbonate and the low salinity of this horizon. The addition of gypsum cannot appreciably improve the exchangeable base status of the 3- to 9-inch horizon, in which all sodium percentages are below 10, a frequently assumed threshold value for alkali soils. Conversely, the subsoil samples, except two, have values of more than 10 percent, and the highest of these are in the gypsum plot. This occurs from the increase of soluble sodium in the subsoil by migration from the surface soil. More water must pass through the profile to remove the sodium salts and reduce the exchangeable sodium. This is demonstrated by plot 19, in which the excessive irrigation has resulted in replaceable sodium values of 4, 6, 12, and 14 percent, respectively. The accumulation of sodium sulfate and replaceable sodium in the subsoil of the gypsum plots is an undesirable situation because of its effect on both the plant and the soil, and a more thorough leaching is required to remove it. No effect of the alfalfa treatment on exchangeable bases is apparent.

pH VALUES

The pH values of the 1941 samples at the saturation percentage are listed in table 15. The over-all range of values is 7.5 to 9.3. The values of the four horizons, with increasing depth, respectively, are 7.5 to 8.2, 7.9 to 8.9, 7.9 to 9.1, and 7.8 to 9.3. In most plots the pH increases with depth. This is correlated positively with the increase in sodium percentage of the soluble salts and the exchangeable bases. A pH range of 8.8 to 9.3 corresponds to a range of soluble sodium percentage of 84 to 98 in the 1 : 1 extract. Gardner (*9*) found that the pH of soil suspensions increased with the sodium percentage of the solution. No correlation exists between pH and either the total salt content or the soluble sodium content of the 1 : 1 extract, which agrees with results obtained by McGeorge (*18*). The pH range of calcareous nonalkali soils from other localities of the West is 7.5 to 8.0, and the surface soil of these plots in general falls within this range. The values for the subsoil, with few exceptions, extend above this range to the maximum value of 9.3, an effect of an undesirably high proportion of sodium.

The pH range of the 1 : 1 extracts of the 1942 samples was 7.8 to 9.2. The pH was positively correlated with the sodium percentage of the extract, the range 8.7 to 9.2 occurring with a sodium percentage of 92 to 99. The extracts having sodium percentage values from 40 to 70 were grouped in the pH range 8.1 to 8.5.

TABLE 15.—*pH values of 1941 soil samples*

Depth (inches)	pH at saturation percentage in —																	
	Alfalfa plots						Gypsum plots						Control plots					
	4a	4b	10a	10b	16a	16b	6a	6b	12a	12b	18a	18b	8a	8b	14a	14b	20a	20b
3–9	8.0	7.8	8.0	7.6	7.7	7.5	7.6	7.6	7.7	7.8	7.6	7.5	8.1	7.9	8.2	7.9	8.2	7.9
15–21	8.6	8.3	8.4	8.1	8.4	8.1	8.0	8.0	8.2	8.2	7.9	8.3	8.4	8.6	8.6	8.6	8.5	8.9
27–33	9.1	8.8	8.4	8.4	8.1	8.4	7.9	8.2	9.1	9.1	8.0	8.3	8.9	9.0	8.8	8.9	8.1	8.7
39–45	9.2	8.2	8.9	9.1	8.4	8.4	8.2	8.2	9.3	9.3	8.0	8.3	8.8	9.0	8.2	9.3	7.8	8.6

ORGANIC-MATTER CONTENT

The organic carbon content of 36 selected soil samples is shown in table 16. The values for the surface-soil samples range from 0.48 to 0.95 percent. These figures multiplied by 2 approximate the percentage of organic matter. Only slight variation between the 2 years is shown, which is also true of the 15- to 21-inch horizons. In most plots a sharp decrease in organic matter occurs between the upper two horizons.

The 3- to 9-inch horizons of the alfalfa-treated plots do not differ significantly from those of the control and gypsum plots. This is to be expected from the rapid decomposition of added organic materials in the arid Southwest (*23*). Since the addition of 10 tons of chopped alfalfa to an acre of soil, however, would increase the carbon content of the top 9 inches by only 0.1 to 0.2 percent, it is difficult to establish any increase or decrease.

TABLE 16.—*Organic carbon content of selected soil samples*

Depth and year	Organic carbon content of soil samples from —								
	Alfalfa plots			Gypsum plots			Control plots		
	4b	10a	16b	6b	12a	18b	8b	14a	20b
3 to 9 inches:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1941	0.79	0.80	0.88	0.78	0.48	0.73	0.70	0.48	0.80
1942	.74	.74	.88	.95	.50	.76	.75	.52	.76
15 to 21 inches:									
1941	.25	.25	.23	.22	.13	.14	.59	.12	.42
1942	.20	.24	.23	.28	.15	.21	.63	.15	.54

FLOCCULATION OBSERVATIONS

The criterion of flocculation after overnight standing was the existence of a clear supernatant solution above the soil. The depth of this layer varied from 2 to 27 mm., while the total height of the 1 : 1 suspension was 80 mm. The settling volume was correlated positively with the sodium percentage of the soluble salts; thus, of 15 flocculated 1942 samples, 9 having small settling volumes had sodium percentages of 5 to 86, while 6 with larger settling volumes had sodium percentages of 94 to 97. Such relationships have been investigated in greater detail by Gardner (*9*).

To obtain qualitative correlation of the occurrence of flocculation with (1) calcium and magnesium percentage of the soluble salts, (2) concentration of soluble calcium and magnesium in equivalents per million, and (3) total concentration of soluble salts in equivalents per million, these quantities were listed in increasing order and the grouping of the flocculated samples was observed. By means of chi-square distribution the 6 lists were analyzed for significance with respect to flocculation as an attribute (*35*). For this purpose, the 72 or 36 samples were divided into blocks of 6 each and chi-square calculated for each block on the assumption that 2.5 ($= 15/36 \times 6$) flocculated samples might be expected in each block in completely homogeneous distribution. For both years, greater significance was shown with regard to equivalents per million of Ca + Mg and total equivalents per million than with regard to percentage of Ca + Mg.

A fourth listing was prepared from the product obtained by multiplying the calcium and magnesium concentration by total salt concentration, i. e., (2) × (3) above. On this basis only one sample of 1941 and none of 1942 was out of order. Chi-square values for this listing show increased significance, which indicates that a combination of these two factors may cause flocculation where one alone would not. With respect to flocculation of clays, Jenny and Reitemeier (*14*) state that, although the addition of sufficient quantities of any electrolyte will cause a colloidal system to settle out, the quantity of electrolyte required is a function of the properties of the coagulating cation.

The flocculation observations demonstrate that the concentration of soluble calcium provided by gypsum is far in excess of that required to flocculate the soil colloids. Bradfield (*1*) has stated that the concentration of calcium derived from calcium carbonate is sufficient to flocculate clay. His systems may have involved a higher carbon dioxide pressure than existed in the surface soil flocculation systems of this investigation. An increase in exchangeable sodium raises the total electrolyte concentration required for flocculation.

DISPERSION RATIOS

The silt and clay content and dispersion ratios for six samples are listed in table 17. The clay content (<0.005 mm.) varied from 10.4 to 17.5 percent, the silt plus clay content from 49.4 to 70.9 percent. The dispersion ratios for silt plus clay varied from 0.73 to 0.87, with no significant difference resulting from the three treatments. The clay dispersion ratio for the gypsum treatment, however, was 0.06, compared with a range of 0.30 to 0.46 for the alfalfa and control samples. This indicates that gypsum promotes coalescence of soil particles less than 5μ in diameter but not appreciably of the entire mass of particles less than 50μ in diameter. Childs (*4*) has suggested that the replacement of sodium by the calcium of gypsum may be accompanied by oriented coagulation and an increase in the size of the primary particles of the clay fraction.

Myers and Jones (*22*) reported that excess soluble calcium added as the nitrate does not promote aggregation. Their findings were based on particle sizes greater than clay, and the present work indicates that excess calcium added as gypsum does cause coalescence of finer soil particles. The negative results on the silt fraction obtained in this study agree with the results of Myers and Jones on particles less than 0.1 mm. in diameter. The work of Browning, Russell, and McHenry (*2*) indicated that results of the dispersion ratio technique for silt are correlated significantly with other methods of aggregate determination.

The alfalfa treatment used in this study might not be expected to be positively correlated with aggregation on the date

TABLE 17.—*Dispersion ratios of selected 3- to 9-inch soil samples, 1941*

Plot and sample site	Treatment	Silt + clay		Clay (<0.005 mm.)		Dispersion ratio	
		Not agitated	Total	Not agitated	Total	Silt + clay	Clay
		Percent	*Percent*	*Percent*	*Percent*		
4A	Alfalfa	38.0	49.4	4.2	10.4	0.77	0.41
4B	do	48.7	59.0	3.2	11.0	.83	.30
6A	Gypsum	46.9	57.0	.65	10.7	.82	.06
6B	do	51.4	70.9	.98	17.5	.73	.06
8A	Control	53.0	61.1	5.2	11.4	.87	.46
8B	do	52.0	63.1	3.6	11.1	.82	.32

the samples were removed from the plots, as added organic matter is quickly decomposed in this climate and its effect on aggregation is usually dissipated when the organic matter has disappeared (*19, 20*).

PERMEABILITY MEASUREMENTS

A prolonged permeability test usually involves three phases: (1) An initial period of decreasing permeability, (2) a period of increasing permeability to a maximum value, and (3) a second period of decreasing permeability. The increase to a maximum value during the second phase has been explained as the result of solution in the percolating water of the entrapped air in the soil pores (*5, 26*). In the present work the tests were not carried past the first stage.

The stratification of the subsoil precludes satisfactory sampling for laboratory measurements of permeability. As the samples removed at the end of the season were not taken according to strata, difficulties could be expected from the mixing of lenses of different texture. The permeability results confirmed this, and serious discrepancies between duplicate plot samples, especially those of lower depths, rendered the subsoil results of little value. The results indicate that the 27- to 33- and 39- to 45-inch horizons possess the lowest permeabilities, the 15- to 21-inch horizons intermediate values, and the 3- to 9-inch horizon the highest. This trend is opposite to that of particle size, which in general increases with depth, and is attributed to the accumulation of sodium in the lower horizons. Percolates of many subsoil samples of high sodium content were opaque because of suspended clay and silt.

The permeability values of the 3- to 9-inch samples for 1941 are listed in table 18. These results should be used only with relation to each other, and no absolute comparison with field infiltration rates is intended.

The permeability of the moist samples increases in the order of (1) control, (2) alfalfa, (3) gypsum. According to analysis of variance, the permeability is highly significant with respect to treatment but not significant with respect to block or sample

TABLE 18.—*Permeability values of 3- to 9-inch soil samples after percolation of 300 ml. of water, 1941*

Moisture status and site	Permeability (centimeters per hour)								
	Alfalfa plots			Gypsum plots			Control plots		
	4	10	16	6	12	18	8	14	20
Moist samples:									
A	1.48	1.25	1.57	2.12	2.03	2.72	0.62	0.65	1.45
B	1.06	1.35	1.64	1.53	2.09	1.77	.79	1.99	1.06
Average	1.27	1.30	1.61	1.83	2.06	2.25	.71	1.32	1.26
Air-dry samples:									
A	4.25	1.28	4.67	3.12	5.8	4.55	1.84	3.90	3.10
B	4.55	8.11	2.88	4.32	7.15	5.5	1.99	7.2	1.97
Average	4.4	4.7	3.8	3.7	6.5	5.0	1.9	5.6	2.5

site. The mean values for the three treatments are 1.09, 1.39, and 2.04 cm. per hour. Differences required for significance between means at the 5-percent and 1-percent levels of probability are 0.49 and 0.68. On this basis, the gypsum values are significantly greater than the alfalfa values and highly significant with respect to the controls. The alfalfa and control values do not differ significantly, possibly because the samples were taken at the end of the season, when most of the added organic matter probably had been decomposed.

Analysis of variance of the permeability values of the dry samples showed no significance with respect to treatment, block, or sample site. This indicates that drying as an additional treatment outweighs the effects of the alfalfa and gypsum treatments. Unfortunately, the results on the air-dried samples cannot be compared in detail with those on the moist soils. Repeated measurements on some moist samples in 1944 were much higher than in 1942, an indication of changes in structure during storage in a moist condition. Also, it has not been possible to handle moist and dry soils in the laboratory in such way that the difference in results can be attributed to moisture content alone. Thus, although the dried samples indicate higher permeability values than the moist samples, it cannot be concluded that this resulted only from the change in moisture status.

DISCUSSION AND CONCLUSIONS

During the 2-year experiment, the infiltration rate of the soil was increased by the three field treatments studied: (1) Application of gypsum, (2) application of chopped alfalfa, and (3) drying of the soil to the wilting range. The gypsum and alfalfa treatments approximately doubled the rate of infiltration of water. Increasing the average rate from 0.1 to 0.2 inch per hour by such treatment is of practical importance, as thereby the time necessary for a 6-inch irrigation to enter the soil is reduced from 60 to 30 hours. The average loss of water by direct evaporation from a free-water surface in the Coachella Valley during the summer months is about 0.5 inch per day. The rate of evaporation from the soil decreases rapidly as the surface dries.

Prolonged drying of the soil by the date palm roots increased the subsequent infiltration rates even more than did the gypsum and alfalfa treatments. The initial effect of the desiccation decreased with successive irrigations. This drying had no apparent adverse effect on the growth of the palms or on the formation of fruit. The apparently sufficient supply of water may have resulted from lateral movement of moisture from adjacent basins because of the alternate irrigation of basins and overlapping of root systems.

The beneficial effects of drying the soil on subsequent moisture penetration observed in these studies suggest that this method of improving infiltration should be given more attention by research workers in attempts to improve irrigation practices in problem areas with such permanent crops as dates. The possibility of applying relatively heavy irrigations at longer intervals and allowing the soil moisture to approach the wilting range between irrigations should be evaluated. During the winter and spring months, when water requirements are at a minimum, the practice of irrigating alternate middles or rows might be followed, which should permit thorough drying of the soil without risk of injury to palms or other permanent crops.

Heavy applications of water are required to obtain adequate penetration. Soil-moisture measurements indicate that more than 10 inches of available water can be stored in the upper 4 feet of the soil profile. In some of the plots receiving light applications at frequent intervals (4 inches every 10 days) the upper 2 feet of soil remained relatively moist all the time, but water did not penetrate to 30 inches.

Accumulation of sodium salts in the subsoil would not occur if sufficient water were used to leach them below the root zone. Although the irrigation water has a high sodium percentage, the content of sodium is so low that the water must be concentrated many times to attain toxic accumulations. The presence of calcium carbonate, the relatively low absorption of sodium by plants, and the irrigation practice employed prior to this experiment had resulted in a surface soil of low salt content and high exchangeable calcium and a subsoil of higher salt content and high exchangeable sodium. The intensive leaching of plot 19 (*8*) demonstrated that prolonged application of water does remove the salt from the 4-foot profile without injury to the palms.

The laboratory measurements of surface-soil permeability confirmed the beneficial effects of the gypsum and drying treatments. The alfalfa treatment did not result in significantly improved permeability. The negative results of this treatment on permeability and also on aggregation and flocculation can be attributed partly to the late date of sampling and to lack of special care in sampling for physical measurements. Whether the carbon dioxide formed in the decomposition of the alfalfa temporarily increased the soluble calcium concentration cannot be determined from the present data. It has been demonstrated that increased particle aggregation resulting from decomposition of alfalfa is due to microbiological activities (*19*, *20*). The disappearance of the added organic matter through this process presumably is accompanied by a return to a less desirable structure.

Both the surface soil and the subsoil of this area tend to be dispersed, the former from a deficiency of soluble cations, the latter from a high proportion of sodium in the soluble salts. One beneficial effect of gypsum on the surface soil is the flocculation of the colloids. Removal of the added gypsum by leaching restores this layer to the dispersed condition, as shown by the fact that at the end of the experiment the surface-soil samples from which all gypsum had been leached were as dispersed as those of the control plots. The replacement of sodium by the calcium of gypsum and the subsequent accumulation of sodium salts in the subsoil may be injurious to plant growth if they are not leached below the root zone. Any soil treatment may have to be repeated periodically.

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