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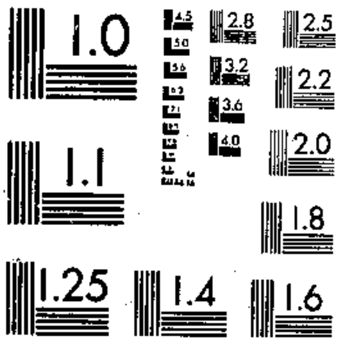

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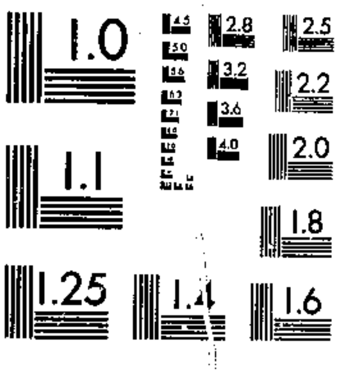

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Some Soil Properties Related to the Sodium Salt Problem in Irrigated Soils [1]

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CONTENTS

THE topography of the Western States, the composition of the soil-forming minerals, the climate, and irrigation have all contributed to a serious salinity or alkali problem in many areas. Saline areas usually are situated in the comparatively level valleys, where the land is most accessible to irrigation. Abandonment of any of the land as the result of salinity is a serious loss to the agriculture of the West. Furthermore, the salt conditions have frequently developed, or have been discovered, after large expenditures have been made on irrigation structures and land improvements. The problem applies to saving not only the land but also the capital invested and the homes of many people.

Since the introduction of irrigation, water movement in the surface soils and in the subsoils has greatly changed the distribution of salts on the land. Under normal irrigation practices more water is added to the land than is consumed by crops or lost by evaporation. Much of the excess passes into the subsoil and increases the ground-water supply. Some of the ground water either eventually flows back to the streams through substrata or seeps to the surface of the soil in low areas. In these processes

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salts are dissolved from the surface soil and subsoil and are carried to the streams to increase their salt content or, rising to the surface of the soil, they produce the well-known alkali areas, or "seep" lands.

These seep lands represent the most common and the most baffling phase of the salinity problem. The process of reclaiming them involves the installation of drains to remove the salts and excess water. The success of the drains depends upon the topographic features of the land, the porosity of the substrata, and the properties of the soils. Many drainage projects have been unsuccessful, because the soil failed to respond to drainage. Successful drainage depends upon the application of methods suited to local soil variations. Classification of saline soils of the irrigated areas with respect to the most suitable methods to be used in their improvement is a major problem.

An attempt therefore was made, during a study of some of the physical and chemical properties of soils as affected by salinity, to evaluate some of the factors that might be used as a basis for the classification of saline soils and for making soil-improvement plans. The results are reported in detail in this bulletin.

SUMMARY

The settling volume of soils suspended in 0.1 normal solutions containing both calcium and sodium chloride increased slightly as the sodium percentage increased, but the increase was not statistically significant for sodium percentages below 70 percent.

When the concentration of the solution was decreased to approximately 0.002 normal or less after equilibrium had been reached, the soils tended to disperse, not as a linear function of the sodium percentage in the 0.1 normal solution used for treatment but as a function of a higher power of the sodium percentage.

When the electrolyte content was again increased, with the sodium percentages constant, the disperse soil flocculated and settled out of suspension again but after dilution the increase in settling volume as affected by sodium percentage was very much greater.

The increase in settling volume was statistically significant above 30 percent sodium in the samples that had first been diluted to cause dispersion and were then again concentrated to cause flocculation.

The settling volume was related directly to the extent to which the soil had been dispersed. A correlation coefficient of 0.96 was found between the settling volume after dispersion and the percentage of dispersion for five soils.

When the sodium was replaced by calcium in soils that had previously been treated with varying ratios of sodium and calcium and then diluted, the settling volume was not changed to any appreciable extent but remained proportional to the extent to which the soil had been previously dispersed.

When samples that had been treated with sodium and calcium

salt solutions containing varying percentages of sodium were dispersed by dilution, treated with calcium salt solutions to replace the sodium, and then dried and brought back into suspension, the ability to swell and increase in volume was destroyed. The settling volumes of all samples were the same as that of the soil originally treated with 100-percent calcium solution. The samples not treated with calcium to replace the sodium still retained the increased settling volumes they had before drying.

Mechanical puddling resulted in settling volumes approximately the same as the 100-percent sodium treatment and dispersion by dilution, regardless of whether the soils had been previously treated with sodium salts.

The pH of all the soils studied increased with the sodium percentage of the solutions used in the soil treatments and with the dilution subsequent to treatment. The pH, like the settling volume and the percentage of dispersion, was not a straight-line function of the sodium percentage but varied with a higher power of the sodium percentage.

Changes from the granular to the disperse phase were found to occur readily in the moist, or suspension, condition; but the evidence indicates that the change from the disperse or the floccular state to the granular occurs only at low moisture. At the low moisture the formation of stable granules apparently depends upon the type of base either in the solution or combined with the colloid.

The rate of wetting by capillary movement of water and the rate of water conductance under a hydraulic head were both found to be closely related to the poor structure resulting from salinity.

The results indicate that either the rate of wetting or the permeability of samples treated with soil amendments can be used to indicate whether a soil will respond to amendments in the field and how much amendment material will be necessary.

Permeability data from a lysimeter experiment with a group of saline soils of varying quantities of replaceable sodium showed that replaceable sodium was probably only one of several factors that determined the permeability and other physical properties of the soil. Variations in concentration of solution sufficient to cause dispersion or puddling were also shown to be contributing factors.

In the lysimeter experiment, sweetclover as a green manure apparently improved the crop that followed, more from the nitrogen it supplied than from its effect on the base status or physical properties of the soils. Application of phosphate also resulted in improving the growth of both the sweetclover and the following crops. From these results, it appears that fertility may be a large factor in the improvement of many saline soils after drainage.

It is concluded that the poor physical condition of many saline soils is modified by so many other factors that it is not always directly correlated with either the percentage of replaceable sodium or the concentration of salts found in the soil. A classification of saline soils, therefore, must take into account these other factors. It is thought that a combination of such physical tests as settling volume and degree of dispersion used in connection with pH and electrical-conductance determinations can be used to improve the methods of classifying saline soils.

INFORMATION NEEDED FOR A SOLUTION OF THE SALINITY PROBLEM

Salt accumulations and their associated detrimental effects on the physical and chemical properties of the soil result from features inherent in the soil or from conditions imposed upon it by the environment. These features or conditions include texture of the soil and of the substrata, quality of the water, and any of a number of other contributing factors. To make the experiences gained in improving a saline tract of land applicable to other tracts, it is evidently necessary to modify the methods to suit local environmental conditions and inherent soil features. A survey to determine the local conditions is necessary to assure the success of methods designed either to prevent or to correct injury from salinity. The present available information regarding the factors involved in salt accumulation and their effects on the soil, however, is not an adequate basis for making surveys of saline soils. Further research is necessary.

One of the greatest difficulties in the classification of saline soils is associated with their tendency to change from a granular to a disperse structure as a result of contact with sodium salt solutions. It is well known qualitatively that sodium salts contribute to the disperse and impermeable condition so frequently found in saline soils, but the rate of change in physical properties with the rate of change in salt concentration or in the proportion of sodium in the salt complex is not so well known. There is also a lack of adequate information regarding the factors necessary to restore structure after the removal of salts by drainage.

The physical properties of saline soils are closely related to soil microstructure, which, in turn, depends upon the state of aggregation of the clay crystals. Since a major aspect of the salinity problem is the unfavorable physical soil properties associated with sodium-salt accumulation, a solution of the problem requires a knowledge of the factors affecting aggregation. This bulletin is concerned primarily with a study of these factors.

SCOPE OF THE STUDY

The degree of clay dispersion, the settling volume of floccular or granular soil in water, the permeability of soil to water, and the rate of wetting by capillary movement of soil moisture are closely related to the extent and type of aggregation of the clay crystals. These properties, therefore, are capable of being utilized as a measure of the effect of soluble salts, wetting and drying, organic matter, living plants, and other factors on soil aggregates. One or more of these was used in this study as a measure of the effects of each of the following factors: Different ratios of sodium and calcium salts, different salt concentrations, mechanical puddling, drying of disperse and floccular soils, application of gypsum and organic-matter amendments, and growing plants on the soil. The soil reaction is also related to the effects of some of these treatments and was utilized in the study.

The investigation was limited to a study of 13 soil samples, except for a minor study of bentonite and calcite, but included only two subsoil samples. The soils were either saline or highly alkaline. No attempt was made to include all the factors related to the reclamation of the land from which the samples were taken or to study the complete soil profile. It will be obvious that the materials in the various horizons of the soil and the substrata should be considered when an attempt is made to apply any of the results of the investigation to the problem of reclamation.

The textural grade and some of the physical and chemical properties of the saline and alkaline soils studied are given in tables 1 and 2 *(20)*.[3]

TABLE 1.—*Location and type of soils studied*

Soil No.	Approximate location	Series	Class
58	Coachella, Calif	Coachella	Very fine sandy loam.
62	Delta, Utah	Oasis	Silty clay loam.
63	do	do	Clay (subsoil of 62).
68	Vale, Oreg	Vale	Silty clay loam.
80	Gila Bend, Ariz	Gila	Do.
87	Alamosa, Colo	Alamosa	Sandy loam.
88	do	do	Sandy clay (subsoil of 87).
373	Grand Junction, Colo	Billings	Clay loam.
374	Delta, Utah	Oasis	Silty clay loam.
375	Perris, Calif	Las Flores	Clay.
385	Lamar, Colo	Las Animas	Clay loam.
386	Niland, Calif	Imperial	Clay.
387	Coachella, Calif	Coachella	Very fine sandy loam.

EFFECT OF SODIUM AND CALCIUM ON SOIL DISPERSION AND SETTLING VOLUME

To study the effect of sodium and calcium on dispersion and settling volume, soil samples were treated with salt solutions containing different ratios of these elements. Samples of 20 gm. each were used for the purpose and were washed by decantation in 500-ml. bottles 7 to 12 times with 100- to 200-ml. portions of solution for each washing. The salt solutions used were 0.01 normal, 0.1 normal, and 1.0 normal in concentration and ranged from 100 percent calcium salts to 100 percent sodium salts. After these washings, it was thought that the soils were approximately at equilibrium with the solutions. When the solutions were diluted, a part of the supernatant liquid was removed and replaced with water to keep the volume constant.

The settling volume of treated soils increased slightly as the sodium percentage of the solutions increased. The high sodium treatments began to disperse and form relatively stable suspensions as the solutions were diluted. The quantity of disperse soil and the concentration at which dispersion took place varied with the sodium percentages of the solutions. When the solu-

[3] Italic numbers in parentheses refer to Literature Cited, p. 27.

TABLE 2.—*Some of the chemical and physical properties of soils studied*

Soil No.[1]	Chemical and physical properties															
	Clay		Exchange capacity	Percentage of exchangeable sodium	Total carbonates	Ions in saturation extract[2]								H_2O in saturation extract	Soluble, exchangeable and carbonate	
	<5Mu	<2Mu				Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl		Ca	Mg
	Pct.	*Pct.*	*M.e.*[3]*/100 gm.*	*Percent*	*M.e./100 gm.*	*E.p.m.*[4]	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*Pct.*	*M.e./ 100 gm.*	*M.e./ 100 gm.*
58	13.4		7.5	29	118	1		17							113	28
62	32.7	13.5	14.8	54	655	64	71	1,127	35		3	113	1,156	39	545	195
63	48.8		22.0	56	786	16		357							640	211
68	27.3		10.6	92	69	0		522							38	27
80	33.6		21.6	95	229	0		197							186	61
87	12.0	6.0	7.3	24	10										10	6
88	37.9	29.1	23.9	61	136	1	1	39			16	20	6	47	92	44
373	21.0	14.4	8.8	12	240	53	81	133	8	0	6	72	189	42	185	100
374	32.7	22.2	14.7	64	667	30	29	1,265	35	1	4	873	458	40	542	193
375	56.3	40.7	28.8	51	79	2	2	80	1	3	12	14	55	57	66	87
385	21.9	17.8	14.5	33	81	30	54	514	6	0	3	294	249	41	83	86
386	62.6	49.4	28.6	24		77	53	196			1	49	278	78	120	82
387	17.9	11.7	8.7	26	162	25	4	77			3	87	19	44	158	28

[1] Location and type given in table 1.
[2] Saturation extract and saturation percentage determined according to the methods of Scofield (*20*).
[3] M.e. = milliequivalent.
[4] E.p.m. = equivalent per million.

tions were diluted to approach 0.001 to 0.002 normal, slight dispersion occurred in treatments with as low as 10 percent sodium, but with sodium percentages below 50 or 60 most of the suspended material soon settled. The suspensions in solutions with sodium percentages above 60 were comparatively stable at the low concentrations.

When the solutions were again concentrated, the material in suspension flocculated and settled but formed a much larger apparent volume than before treatment. Regardless of the concentration of the solutions or the percentages of sodium, dilution subsequent to washing with the salt solutions seemed necessary to disrupt the aggregates and to bring about maximum dispersion. When the disperse phase was flocculated, loosely packed voluminous floccules of low apparent density rather than compact granules of high density were formed. These facts are indicated by the data in tables 3, 4, and 5.

TABLE 3.—*Relative settling volumes of soil samples treated with 0.1 normal solutions of sodium and calcium chloride of varying proportions of sodium and calcium; the volume for 0.0 percentage sodium for each soil is considered as 100.0*

SAMPLE DILUTED TO 0.05 NORMAL

Soil No.	Sodium (percent in solution)										
	0	10	20	30	40	50	60	70	80	90	100
88	100	100	100	100	100	100	100	100	100	109	127
373	100	100	115	127	127	127	127	127	130	154	382
375	100	100	100	100	100	107	107	107	107	121	170
374	100	100	100	100	100	100	100	100	100	110	130
386	100	100	100	107	107	100	100	107	127	120	260
Average	100.0	101.8	103.0	106.8	106.8	106.8	106.8	108.2	114.0	122.8	215.6

SAME SAMPLES DILUTED TO 0.002 NORMAL AND THEN CONCENTRATED, BY ADDING SALTS, TO 0.05 NOR. .AL

Soil No.	0	10	20	30	40	50	60	70	80	90	100
88	100	100	100	100	100	100	100	100	118	155	336
373	100	117	117	117	125	125	125	125	142	175	326
375	100	100	107	107	107	114	114	121	136	250	307
374	100	100	100	111	111	133	133	178	178	255	311
386	100	106	113	113	120	120	127	141	167	207	433
Average	100.0	104.6	107.4	109.6	112.6	118.4	119.8	133.0	148.2	208.4	342.6

TABLE 4.—*Percentages of soil*[1] *remaining in suspension at 3 cm. after 2 hours*

Soil No.	Normality	Sodium (percent)										
		0	10	20	30	40	50	60	70	80	90	100
68	0.0050	0.30	0.35	0.00	0.80	2.10	5.00	6.40	7.05	8.00	8.30	10.00
88	.0027	.02	.02	.05	.10	.30	.90	2.30	3.05	6.55	6.20	19.65
373	.0028	.15	.20	.15	.25	.35	.50	1.00	1.85	4.70	11.30	14.40
375	.0027	.20	.20	.30	.30	.30	.30	.35	.85	1.00	6.55	29.53
374	.0027	.30	.55	.05	.60	.85	1.10	2.00	8.50	13.75	18.45	....
386	.0010	.10	.10	.30	.70	1.70	8.50	15.80	18.20	21.70	33.20	38.70
Bentonite	.0020	1.60	1.80	2.80	3.20	5.00	9.40	24.80	28.20	30.80	33.20	50.40

[1] The samples had first been treated with 0.1-normal solutions of $CaCl_2$ and NaCl in sufficient quantities to give the sodium percentages shown and were then diluted to the indicated normality. The term normality refers to the chemical equivalents of salt per liter of solution.

TABLE 5.—*Relative settling volume and percentage of dispersion of soil samples of soil No. 386, as affected by percentage of sodium and concentration of solutions*

Sodium (percent)	Settling volume [1] of soil washed with—		Dispersion [3] of soil washed with—	
	0.1 normal diluted solution [2]	0.01 normal solution	0.1 normal diluted solution [4]	0.01 normal diluted solution [5]
			Percent	*Percent*
10	100	100	0.10	0.30
30	113	92	.70	.70
50	120	92	8.50	1.01
70	141	92	18.20	0.74
90	207	100	21.70	25.62
100	433	192	38.70	------

[1] By settling volume is meant the apparent volume of the soil material after it has settled from suspension.
[2] Diluted to 0.05 normal.
[3] The percentage of dispersion refers to the percentage of the soil that had not settled from suspension.
[4] Diluted to 0.0015 normal.
[5] Diluted to 0.001 normal.

The settling volumes of five soils treated with 0.1 normal solutions and diluted to 0.05 normal are shown in the upper part of table 3, and the settling volumes of the same samples in solutions diluted to between 0.001 and 0.002 normal and then increased to 0.05 normal are shown in the lower part. Table 4 applies to the same set of samples at 0.001 to 0.002 normal but shows the percentages of material in suspension at 3 cm. depth 2 hours after shaking. Table 5 shows the comparative effects of 0.1 and 0.01 normal salt solutions on one of those samples (No. 386).

The behavior of the soils in the high sodium-percentage solutions that were dispersed by dilution and again flocculated by the addition of electrolyte is thought to offer a qualitative explanation of many of the characteristics of saline soils under field conditions and to furnish a clue to practices that might improve the soils. Calcium soils evidently consist normally of comparatively dense microaggregates that settle rapidly from suspension to form a small apparent volume. The soils deflocculated after treatment with high percentages of sodium salt, however, form massive aggregates of low density that settle slowly to form large settling volumes of a gelatinous consistency. As previously stated, the presence of such material in the field would tend to close all large soil pores and restrict water and air movement.

In the past there has not always been a clear differentiation between the granular particles of soil of good structure and the bulky floccules of a soil of poor structure (*4*, *16*). The opinion has been somewhat prevalent that because a sodium salt, if sufficiently concentrated, will cause flocculation, it follows that the structure will be good while the salts are present (*16*). It is likely, however, that under most field conditions there is sufficient electrolyte to flocculate the soil and that the poor physical properties are due to the properties of the floccular state rather than to the disperse, or sol, state. Other writers have emphasized this fact (*1*, *5*, *6*). A study of the conditions that result in these unfavorable floccules rather than formation of compact granules is important. The fact that the condition is not entirely related to the quantity of sodium on the clay complex in the replaceable form is indicated from the difference in settling volume caused by changing the salt concentration from high to low and then back to the original concentration without changing the ratio of sodium and calcium.

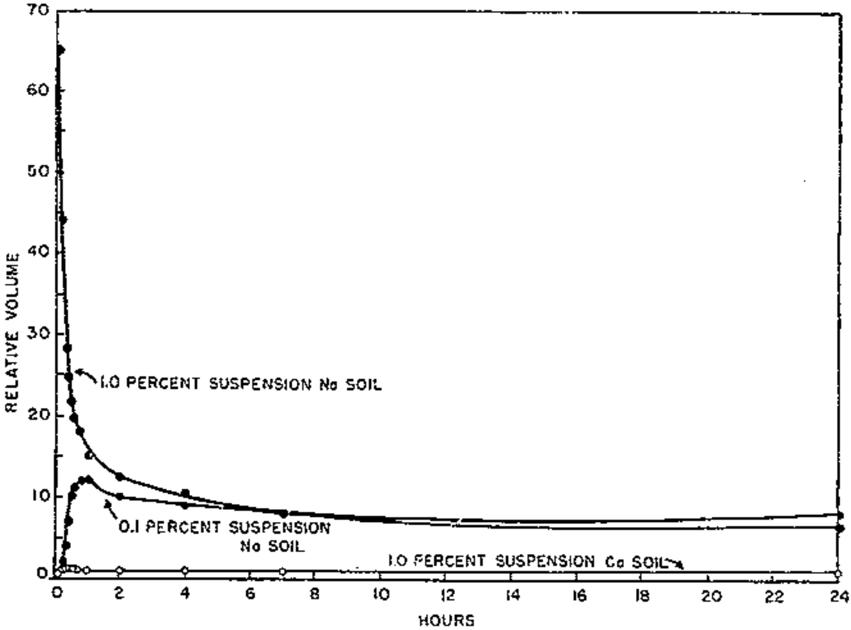

FIGURE 1.—Comparisons of settling volumes of 1.0 percent and 0.1 percent suspensions of sodium soil and 1.0 percent suspension of calcium soil of sample No. 386. The curve for the 1.0 percent sodium soil shows the change in volume of the settling mass of soil floccules below the clear solution. The curves for the 0.1 percent sodium soil and the 1.0 percent calcium soil show the volume of the portion of the suspended material that had settled out of suspension.

The graph in figure 1 is presented to indicate further the behavior of floccular soils previously treated with sodium. The curve for the 1.0 percent sodium soil shows the change in volume of the contracting mass of soil floccules below the clear solution. The curves for the 0.1 percent sodium soil and the 1.0 percent calcium soil show the volume of the portion of the particles that had settled out of suspension and rested on the bottom of the container. Even in a floccular suspension as dilute as 1 part soil to 100 parts solution, the large irregular floccules of the sodium soil interlocked sufficiently to prevent their settling as individuals. The settling took place by contraction of the mass. As the mass contracted a definite line formed, separating the clear solution above from the floccular soil below. In the case of the 1.0 percent suspension of calcium soil the particles settled as individuals and the settling volume built up quickly from the bottom to a maximum, after which a slight contraction occurred. The 0.1 percent suspension of the sodium soil also settled as individual floccules similar to the fine calcium soil particles but formed a much larger settling volume. The floccules of sodium soil were so large that the descent of many of them could be followed without the aid of a microscope.

There is no intention to infer from the preceding discussion of the dispersion and settling volume data that treatment with salt solutions at moisture percentages comparable with those in the field would produce physical changes of the same magnitude as those produced in suspensions of soils in water. The extent to which dispersion could occur and the density of the floccular mass naturally would be restricted by the space limitations. The work of other investigators (*11*), however, has shown that flocculation of suspension is relatively independent of the proportions of clay and solution and depends mainly upon the concentration and composition of the solution separating the clay crystals. It seems reasonable, therefore, to conclude that with comparable solutions the tendency to disperse or flocculate in wet soils would be closely correlated with that in suspensions. This conclusion seems to be in complete harmony with the well-known fact that the clay in sodium soils does tend to disperse to a considerable extent and become mobile under field conditions, especially if the salts are leached from the soil and water low in salts is used for irrigation.

On the basis of these facts it is tentatively assumed that curves representing the change in apparent volume of clay minerals in the soil as affected by percentage of sodium would tend to show the same trends as those given in the tables. If this assumption is correct, then settling-volume data should be of value in determining how a soil would respond physically in the field to changes in salt content following drainage.

The data in table 3 show that the apparent volume and the degree of dispersion are not straight-line functions of the sodium percentage, but that they vary with some power of the sodium percentage and therefore comparatively large changes in sodium percentage in the lower percentage range produce small effects, while comparatively small changes in the higher percentage range produce large effects. A statistical analysis of the data shows that treatment with 0.1 normal solutions containing 30 percent sodium followed by dilution to approximately 0.001 normal resulted in a small but significant increase in settling volume of the average of the five soils. A correlation coefficient of 0.96 was found between the average settling volumes in table 3 and the averages of the percentages of dispersion in table 4 for the same five soils. The increase in settling volume with sodium percentage below 70 was not statistically significant in the samples before dilution.

Other investigators (*2*, *3*, *9*) have shown that the greater the degree of dispersion and the smaller the size of the final particle of a particular clay, the greater will be the size and the lower will be the apparent density of the flocs. Since clays of the montmorillonite type are composed of very small crystals that are easily dispersed when sodium-saturated, they form very large low-density flocs and have large settling volumes. The wide distribution of montmorillonite type of clays in arid soils is evidently related to the poor structure of many saline areas.

EFFECT OF SODIUM NOT COMPLETELY REVERSED BY ADDING CALCIUM

The question arises as to what extent the unfavorable physical properties of a floccular sodium soil can be corrected by replacing the sodium with calcium. To study this point a set of soil samples previously treated with sodium and calcium in varying ratios were thoroughly washed with 0.1-normal $CaCl_2$ solutions, the results of which are shown in table 6. It is evident that

TABLE 6.—*Residual effect on settling volume of calcium-saturated soil (No. 386)* [1] *from previous treatments with salt solutions of varying sodium and calcium percentages*

Test No.	First treatment		Second treatment, $CaCl_2$ normality	Settling volume	
	$CaCl_2$ normality	NaCl normality		After first treatment	After second treatment
1	0.10	0.00	0.10	100	100
2	.09	.01	.10	108	111
3	.08	.02	.10	112	111
4	.07	.03	.10	112	111
5	.06	.04	.10	118	111
6	.05	.05	.10	118	111
7	.04	.06	.10	124	124
8	.03	.07	.10	141	136
9	.02	.08	.10	174	239
10	.01	.09	.10	300	400
11	.00	.10	.10	441	400

[1] Relative settling volumes after settling 30 minutes in 0.1-normal $CaCl_2$ solution.

merely replacing the sodium on the gel with calcium had very slight effect upon the volume of the material and so far as could be observed the soils retained most of their physical properties after the exchange that they had when the sodium was present. Similar results have been observed by Falconer and Mattson (*10*), but little application of the phenomenon has been made to field conditions in planning the improvement of saline soils. The results show that more than merely saturating the soils with calcium may be required to correct the undesirable physical properties that have been caused by sodium.

EFFECT OF REPLACEABLE SODIUM PERCENTAGE ON SOIL AGGREGATION

Table 7 shows the electrolyte content, replaceable sodium, quantities of soil in suspension, and the settling volumes of a series of samples of soil No. 386 treated with sodium and calcium chlorides and then diluted. It will be observed that the settling volume and the percentage dispersion are comparatively

TABLE 7.—*Percentages of sodium saturation and of soil No. 886 in suspension and settling volume resulting from treating with normal and 0.01-normal solutions and then diluting the solutions*

Test No.	Treatment				Sodium saturation	Soil in suspension 3 hours at 3 cm.	Settling volume
	Normality of treating solutions		Normality after dilution				
	Na	Ca	Na	Cl			
					Percent	*Percent*	
1	0.1	0.9	0.0003	0.0018	2.1	0.7	100
2	.3	.7	.0009	.0018	2.5	2.0	105
3	.5	.5	.0016	.0021	3.7	13.1	116
4	.7	.3	.0028	.0028	6.4	26.7	132
5	.9	.1	.0031	.0022	9.3	20.7	258
6	1.0	.0	.0128	.0112	42.0	28.0	411
7	.001	.009	.0003	.0013	1.5	.3	100
8	.003	.007	.0007	.0012	2.2	.8	92
9	.005	.005	.0011	.0012	3.0	1.0	92
10	.007	.003	.0016	.0012	4.1	0.7	92
11	.009	.001	.0022	.0015	6.0	25.6	100
12	.010	.0	.0028	.0019	10.7	....	192

large, considering the relatively low percentages of replaceable sodium.

The evidence seems to support the conclusion that the bad physical condition of saline soils following salinity is due to the low apparent density of clay, which is generally associated with high sodium percentages in the replaceable base complex. If drying or other forces necessary to restore structure have not been active, the physical condition may persist after the sodium has been replaced with calcium. Replaceable sodium evidently is not the only factor responsible for the bad physical condition with which it is closely associated.

Another fact brought out in the table is the higher percentage of replaceable sodium in the soils treated with the more concentrated solutions, though the percentage of sodium in the solution remained the same.

EFFECT OF DRYING ON RESTORING STRUCTURE TO DISPERSE SOILS

Since the change from a sodium to a calcium system does not necessarily restore a desirable physical condition, the effect of other possible factors must be considered. Among these is the process of drying. It has been observed that drying often has a very beneficial effect upon the soil structure both in the field (*18*) and in the laboratory (*10*).

Table 8 shows the effect of a number of salt combinations and drying on settling volumes. Comparison of Nos. 1 and 2 in table 8 show that the sodium gel retained a large settling volume after drying and then wetting, while the sample first treated with sodium and washed with calcium salts to replace the sodium with calcium was restored to the normal small settling volume of the original soil. Sample Nos. 3, 4, and 5 were first treated with the sodium salts to saturate the soil and were then diluted to cause dispersion but were concentrated again before drying so that a high concentration of sodium salts was in the system while drying. The results show that in the presence of a high concentration of sodium salts, calcium chloride was more effective than gypsum in reducing the settling volume.

The data in tables 8 and 9 show that gypsum and a high concentration of sodium salts in contact with the soil during the process of drying produce a soil with a higher settling volume than the normal calcium soil. This offers an explanation of the poor physical structure frequently observed in saline soils where gypsum is present and confirms previous conclusions (*12*).

TABLE 8.—*Effect of previous treatment and drying on the settling volume of soil No. 386*

Test No.	Treatment	Settling volume [1]	
		Before drying	After drying
1	0.1-normal NaCl	625	542
2	0.1-normal NaCl followed by 0.1-normal $CaCl_2$	625	100
3	0.1-normal Na_2SO_4, 2 gm. $CaSO_4.2H_2O$; the $CaSO_4.2H_2O$ added before drying	650	210
4	0.1-normal NaCl, 2 gm. $CaCl_2.2H_2O$; the $CaCl_2$ added before drying	450	120
5	0.1-normal Na_2SO_4, 2 gm. $CaSO_4.2H_2O$; the $CaSO_4.2H_2O$ added before drying	650	170
6	0.1-normal $CaCl_2$	100	100
7	0.03-normal $CaCl_2$	130	110
8	Saturated $CaSO_4.2H_2O$	140	110
9	0.03-normal $MgSO_4$	140	140

[1] Relative settling volumes after 30 minutes.

TABLE 9.—*Effect of drying on settling volume of soil sample No. 386 previously treated with an excess of $CaSO_4.2H_2O$ and washed to approach equilibrium with the salt solution indicated*

Test No.	Constant ratio of Na_2SO_4 and $CaCl_2$				Variable ratio of $NaSO_4$ and NaCl				
	Normality treatment		Relative volumes [2]		Normality treatment		Relative volumes [2]		
	Na_2SO_4	$CaCl_2$	Before drying	After drying	Na_2SO_4	NaCl	Before drying	After drying	After drying and removing $CaSO_4.2H_2O$
1	0.00	0.00	100	100	0.10	0.00	316	150	342
2	.05	.05	113	100	.09	.01	308	150	317
3	.10	.10	113	100	.08	.02	292	133	308
4	.15	.15	127	100	.07	.03	250	133	275
5	.20	.20	127	100	.06	.04	258	133	292
6	.25	.25	120	108	.05	.05	225	125	258
7	.30	.30	120	108	.04	.06	250	125	283
8	.35	.35	113	108	.03	.07	208	117	233
9	.40	.40	113	117	.02	.08	208	117	250
10	.45	.45	107	125	.01	.09	208	108	208
11	.50	.50	107	150	.00	.10	208	108	233

[2] Settling volumes after 30 minutes.

MECHANICAL PUDDLING COMPARED WITH SODIUM SALTS IN CHANGING SOIL STRUCTURE

The question next arises regarding the effect of factors other than replaceable bases, dilution, and drying on the physical state of saline soils. The phenomenon of puddling is of particular interest in this connection. In a study of this phase of the problem, triplicate 20-gm. samples of each of seven of the saline soils under consideration were prepared and one of each subjected to the following treatments. The separate constituents of each treatment were added in the order mentioned, and the mixture was shaken after each constituent was added.

Sample 1. 150 ml. 0.1-normal $CaCl_2$ solution and 150 ml. distilled water.

Sample 2. 150 ml. distilled water and 150 ml. of 0.1-normal $CaCl_2$ solution.

Sample 3. Mechanical puddling with a spatula, as described by Buehrer and Rose *(7)*, of samples moistened with 0.1-normal $CaCl_2$ solution, addition of 150 ml. $CaCl_2$ solution and 150 ml. water.

The treatments were therefore the same in final composition, differing only in the method of preparation. The replaceable sodium presumably was the same in all three samples of each soil after treatment.

Some of the soils high in replaceable sodium and low in electrolyte were dispersed to an appreciable extent by the addition of water before adding calcium chloride solution. These soils formed a large settling volume when flocculated with the calcium chloride. When the calcium chloride was added first the settling volume was much smaller. The settling volume of the soils dispersed by mechanical puddling was greatly increased in all cases, regardless of the extent of sodium saturation. The other visible properties of the floccular material were apparently identical with those of floccular high sodium soils. The results are shown in table 10.

TABLE 10.—*Effect of dispersion by dilution and destruction of granules by mechanical puddling on the settling volume*

Soil No.	$CaCl_2$ solution before H_2O	H_2O before $CaCl_2$ solution	Puddled before $CaCl_2$ solution and H_2O
68	100	125	188
80	100	303	303
88	100	136	275
371	100	100	250
374	100	157	300
375	100	318	380
386	100	100	350

It appears from the behavior of these samples that, with the possible exception of soils No. 80 and No. 375, the soils had not been highly dispersed in the field, probably because the salt content had remained continuously high, but from the high percentage of sodium saturation shown in table 1 most of the soils could be expected to become highly dispersed if treated with irrigation water low in salt content. This is supported by the fact that adding distilled water before adding $CaCl_2$ solution resulted in an increased settling volume of all soils, except No. 386, which contained gypsum. The extreme change in Nos. 80 and 375 when distilled water was added before the $CaCl_2$ solution indicates that the state of aggregation of these two soils was very unstable.

HYDROLYSIS OF SODIUM AND CALCIUM SOILS

A factor related to high percentages of replaceable sodium is the tendency of sodium clays to hydrolyze. The high alkalinity reduces the solubility of the carbonates and other compounds of the divalent cations. This in turn reduces the flocculating power of the solutes and probably directly affects flocculation by the change in hydrogen- and hydroxyl-ion concentrations. The pH is also affected by an increased hydrolysis of the soil carbonates resulting from low calcium-ion concentration.

The data in table 11 show the pH of six soils, bentonite, and

TABLE 11.—*pH of suspension as affected by sodium percentage and concentration of electrolyte*

Soil No.	Normality[1]	Sodium (percent) in solution										
		0	10	20	30	40	50	60	70	80	90	100
68	0.060	8.90	8.93	8.94	8.96	8.98	9.01	9.03	9.15	9.20	9.46	9.55
	.010	9.14	9.23	9.31	9.35	9.42	9.45	9.59	9.71	9.96	10.19	—
	.025	9.56	9.57	9.62	9.68	9.75	9.82	9.92	10.03	—	—	—
88	.058	8.00	8.07	8.07	8.06	8.08	8.12	8.11	8.15	8.20	8.44	9.19
	.008	8.36	8.47	8.46	8.49	8.51	8.57	8.63	8.62	8.82	9.09	9.74
	.0025	8.44	8.49	8.63	8.67	8.70	8.81	8.95	9.03	9.31	9.58	10.14
373	.058	7.34	7.31	7.34	7.43	7.42	7.43	7.49	7.49	7.42	7.05	8.22
	.008	7.65	7.65	7.72	7.72	7.69	7.74	7.80	7.80	7.89	7.92	8.83
	.0032	7.62	7.52	7.16	7.79	7.38	7.75	7.29	7.29	7.40	8.18	9.20
374	.058	8.21	8.26	8.26	8.25	8.27	8.28	8.29	8.25	8.35	8.56	9.26
	.008	8.61	8.73	8.73	8.68	8.70	8.77	8.80	8.85	8.94	9.17	9.74
	.0025	8.99	9.13	9.15	9.17	9.12	9.30	9.35	9.39	9.40	9.68	10.12
375	.058	7.35	7.42	7.43	7.41	7.47	7.50	7.55	7.65	7.76	7.93	8.54
	.008	7.60	7.69	7.69	7.65	7.75	7.79	7.88	7.95	8.15	8.65	8.98
	.0032	7.74	7.92	7.99	7.90	8.00	8.06	8.14	8.18	8.65	8.98	9.68
386 $CaCl_2$	.0015	8.03	8.35	8.39	8.23	8.33	8.33	8.54	8.92	9.14	9.26	9.94
386 $MgCl_2$	.0015	8.62	8.75	8.80	8.70	8.81	8.86	8.93	8.97	9.17	9.28	9.99
Bentonite	.050	7.85	7.77	7.76	7.82	7.86	7.93	7.99	8.06	8.21	8.32	8.38
	.010	8.27	8.06	8.00	8.02	8.04	8.06	8.10	8.21	8.30	8.51	8.50
	.002	8.05	7.90	7.85	7.86	7.87	7.92	8.04	8.09	8.46	—	—
Calcite	.05	7.85	7.86	7.87	7.94	8.02	8.09	8.20	8.32	8.35	8.48	9.31
	.005	7.96	7.97	8.05	8.06	8.13	8.19	8.27	8.35	8.46	8.65	8.73

[1] All samples previously treated with 0.1 normal solution.

calcite as affected by sodium salt treatment. The original salt treatments were 0.1 normal solutions of calcium and sodium chlorides, with the percentages of sodium shown at the top of the table. The solutions were diluted by successive steps, and the pH is given for three different dilutions in most cases. The effect of increasing percentages of sodium in the solution was to raise the pH values. The pH also increased with dilution. A difference between soils, however, apparently is due to a constant property of each soil. The use of pH data as an indication of the base status of soils, therefore, seems dependent upon a knowledge of the concentration of the solution and a constant characteristic of the soil.

Used in this light pH data should be valuable in interpreting the base status of soils. The comparatively low pH values in the table for bentonite and the high values for the carbonates indicate that the high pH of sodium-saturated calcareous soils may be more closely related to the hydrolysis of the carbonates than of the clay minerals. This is in agreement with other investigators (*8, 17, 18*). Because of this fact and because CO_2 was not carefully controlled during the measurements, no attempt was made to use the data to calculate hydrolysis constants for the clay minerals. Although CO_2 was not carefully controlled, all pH measurements were made under similar conditions, so the relative values should be significant. The very high value for soil No. 68 can probably be attributed to the high percentages of magnesium carbonate, as indicated in table 1, or to some residual effect of the sodium carbonate in the soil before leaching.

PERMEABILITY AND CAPILLARY MOVEMENT OF MOISTURE AS AFFECTED BY SALINITY

Drainage to remove accumulated salts is evidently a necessary step in the improvement of a saline soil. When this has been done, and sometimes before it can be effectively accomplished, treatment to improve the permeability and other properties of the soil may be necessary. The production of vegetation on the land where possible is thought to be the most generally economical method of improving permeability. Next to growing crops on the land, the use of gypsum or sulfur as a soil amendment has received the most attention. It is frequently a question of whether to depend upon growing crops or to use gypsum or sulfur or of whether any of these practices can be relied upon to produce results. Gypsum has sometimes been effective and, for reasons not always clear, at other times has failed to give good results. The production of crops or the application of organic matter in other forms are practices that are in good repute among farmers as a means of improving saline land, but it is not known just what these factors specifically contribute to the improvement of land or what conditions they correct.

Probably the principal functions of gypsum as applied to soil reclamation are to reduce alkalinity and to increase soil permeability by neutralizing sodium carbonate and furnishing calcium to replace exchangeable sodium. Gypsum applications to the field, however, have not always functioned effectively in increasing soil permeability. Since this is the case, some method of determining whether it will be effective is needed before it is applied. For this purpose the effect of gypsum on the permeability of the soil in question could be measured in the laboratory. This may be done by placing treated samples in suitable percolation tubes and measuring the rate of flow through the samples under a constant hydraulic head. Accordingly, a number of soil samples of the soils listed in table 1 were treated with varying quantities of gypsum mixed with the dry soil and the permeability of each was determined. The results are shown in table 12.

The most striking features shown by the table is that gypsum is very effective in increasing permeability in some of the soils, soil No. 88 in particular, but that it caused little effect on other

TABLE 12.—*Effect of gypsum treatments on soil permeability and capillary rise of soil moisture*

Soil No.	Tons per acre of gypsum						
	0	0.50	1.00	2.00	4.00	8.00	16.00
PERMEABILITY AFTER LEACHING WITH 4.6 CM. WATER							
	Cm./hr.	*Cm./hr.*	*Cm./hr.*	*Cm./hr.*	*Cm./hr.*	*Cm./hr.*	*Cm./hr.*
58	0.125	0.236	0.471	0.649	0.925	0.081	0.083
63	.010	.013	.013	.015	.120	.015	.562
68	.024	.150	.144	.130	.115	.221	.515
87	.114	.122	.114	.101	.232	.318	.409
88	.002	.190	.200	2.070	2.610	7.230	7.880
373	.209	.263	.215	.245	.243	.230	.208
374	.045	.082	.103	.185	.272	.324	.315
375	.001	----	----	.002	.004	.005	.074
385	1.035	.975	1.020	.983	.810	.719	.763
386	.083	----	.111	----	.146	----	.150
PERMEABILITY AFTER LEACHING WITH 13.9 CM. WATER							
58	0.054	0.190	0.420	0.645	0.828	0.900	0.020
63	.005	.007	.008	.009	.007	.010	.555
68	.030	.016	.015	.011	.005	.018	.212
87	.009	.071	.069	.049	.088	.172	.294
88	.001	.001	.001	.020	.120	.180	6.590
373	.164	.209	.185	.248	.226	.197	.183
374	.033	.060	.075	.165	.258	.306	.295
375	.001	.001	.001	.001	.001	.002	.030
385	1.070	.007	1.130	.985	.862	.765	.805
386	.070	----	.091	----	.142	----	.148
CAPILLARY RISE AFTER 1 HOUR							
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
58	10.6	9.6	13.8	14.2	1.0	9.0	9.0
63	2.0	2.0	2.2	2.5	3.0	3.9	4.3
68	8.0	7.2	6.8	7.5	7.5	7.5	7.7
80	2.3	1.8	2.1	1.8	2.5	3.2	4.1
87	4.0	6.7	7.3	8.7	8.7	9.0	9.7
88	2.0	2.5	3.0	2.3	6.0	6.5	9.2
373	6.2	7.1	5.9	7.1	7.1	7.1	5.0
374	6.0	6.0	6.4	7.3	7.3	8.0	8.0
375	2.6	----	3.1	3.1	4.3	4.3	11.0
385	13.3	13.1	12.7	13.1	11.7	11.7	11.7
386	2.4	----	2.1	----	2.1	----	2.4
CAPILLARY RISE AFTER 3 HOURS							
58	15.6	18.4	20.2	22.5	19.3	19.3	19.4
63	2.6	2.6	2.8	3.0	6.7	5.7	6.5
68	15.1	14.5	14.3	14.8	15.9	15.9	18.3
80	2.6	2.2	2.4	2.2	4.4	4.4	7.6
87	7.8	12.0	12.5	14.9	15.1	15.1	15.7
88	2.3	2.7	3.4	2.8	8.4	8.4	13.4
373	10.4	10.9	9.8	10.9	10.9	10.9	9.4
374	10.3	10.3	11.1	12.0	12.9	12.9	12.9
375	2.8	----	3.3	3.3	4.5	4.5	12.0
385	21.0	20.8	20.2	20.8	19.2	19.2	19.2
386	4.0	----	3.7	----	3.7	----	4.0

soils, for example soil No. 375, which was similar in clay content and in the percentages of sodium saturation. The quantity of gypsum required to effect improvement was generally much greater than a normal field application.

A second method of estimating the effect of treatments is based on the capillary rise of soil moisture in vertical columns of soil with the lower end of the columns dipped in water. For the small number of soils studied, a high correlation was found between increase in capillary movement of moisture caused by gypsum treatment and increased permeability as measured by rate of flow through the soils.

The capillary movement of water in soil is very important under field conditions. While a dry soil is wetting, the capillary forces are probably very important, whether the movement of water be downward from surface irrigation or upward from subirrigation. The outstanding examples of this are the so-called bad spots widely distributed through the subirrigated soils of the San Luis Valley of Colorado and the slick spots of western Colorado. The bad spots in the subirrigated soils have a high pH and do not "sub" readily but remain dry when the other parts of the field are wet. The slick spots are surface-irrigated and are very difficult to wet when once dried.

In studying the rate of capillary rise of soil moisture the soils were ground to pass through a 1-mm. sieve to provide for more uniform packing. Samples were then mixed dry with the required quantity of gypsum in a small mechanical mixer and packed in glass tubes. To compact the soil the ends of the tubes were tapped on the table a given number of times. The bottom end of the tube was then placed in water. The water used was of similar composition to that of the irrigation water in the area where the soil was obtained. The composition is given in table 13. The tubes were 1½ cm. inside diameter and 45 cm. long with

TABLE 13.—*Composition of water used for irrigating soil samples*

Soil No.	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	Na
	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.*	*Equiv. pct.* [1]
62 [2]	2.56	1.39	1.22	0.11		3.50	1.12	0.64	0.02	23.1
62 [3]	3.70	6.60	12.70		0.20	4.10	11.80	7.00		56.2
87	.73	.23	.25	.07		.98	.15	.15		19.5
88	.72	.23	.25	.07		.98	.15	.15		19.5
373	4.60	2.34	6.93	.12	.10	3.39	4.62	5.76	.12	49.5
374	3.70	6.60	12.70		.20	4.10	11.80	7.00		66.2
375	1.44	.27	1.81			2.14	.76	.65	.01	52.1
385	13.63	6.73	13.43			1.86	26.98	2.92		39.7
386	3.15	2.32	4.62		.14	2.45	7.09	2.43		39.2
387	3.12	2.32	4.62		.14	2.45	7.09	2.43		39.2

[1] $\frac{\text{Equivalents of Na} \times 100}{\text{Total equivalents of bases}}$

[2] Upper Sevier River water.

[3] Lower Sevier River water.

the bottom end slightly restricted. A cotton plug in the bottom of the tube retained the soil. Varying quantities of gypsum were used to determine the requirement for satisfactory results. They are shown in table 12.

As in the permeability tests, the most pronounced effect of gypsum was obtained with soil No. 88, a subsoil from the San Luis Valley. Without treatment this soil was almost impermeable to water, but with a heavy gypsum application it became very permeable. On the other hand, soil No. 375, which was similar in clay content and in the percentage of replaceable sodium, showed only slight response. The apparent explanation is that soil No. 375 had been deflocculated in the field by flooding with rain water while No. 88 had not. Soils similar to Nos. 385 and 386, which already contained gypsum, were slightly affected. The data from these tests show why results in the field are often erratic. First, the results indicate that larger applications than are ever applied in the field are required for some of the soils to give satisfactory results; and second, as has been shown in the previous discussion, the physical condition of the soil once injured by sodium salts is not completely reversible until drying takes place subsequent to the addition of the calcium when calcium salts are added.

MINIATURE LYSIMETER STUDIES OF LEACHED SALINE SOILS

Before drawing final conclusions regarding the application of principles of soil improvement derived from laboratory studies, it usually is necessary to test these principles under field conditions. An approach to field experiments, however, can be accomplished to some extent by the use of small-plant culture pots, lysimeters, or other laboratory devices. Where a large number of soils from widely separated areas are involved, field experiments are often too expensive to be used. In the laboratory studies described it was considered advisable to attempt an application of some of the principles to growing crops.

The conditions required that the study include several soils and be limited to small quantities of soil and a short time period. These conditions naturally restricted the study to a small-sample experiment. Because it was necessary to leach the salts from the soil as a first step and because of the low permeability of the soil, metal containers with a drain at the bottom to which suction could be attached were chosen. These small lysimeters were constructed of 1-quart cans with a short piece of copper tubing at the bottom for a drain. With this equipment, suction could be applied to increase the rate of leaching and to reduce the moisture content of the soil at the end of the leaching period. Also, samples of the leachate could be collected for analysis.

In setting up the experiment, about an inch of sand and gravel was placed in the bottom of each lysimeter and a kilogram of treated soil placed above the gravel. The soils were then leached with water of composition similar to that used in the field (see table 13) until most of the salts were removed. As soon as the soil was sufficiently dry, the crops to be grown were planted. At intervals during the experiment the soils were again leached with irrigation water, but between leachings, except during the early part of the experiment, the plants were irrigated with distilled water to prevent salt accumulation. This was necessary because of the small quantity of soil and high evaporation and transpiration loss of water.

The soil treatments, applied in duplicate, are listed in table 14.

TABLE 14.—*Soil treatments in lysimeter experiments*

Treatment No.	Green-manure crop	Amendment	
		Kind	Per acre 6 inches (pounds)
1	None	None	
2	Sweetclover	do	
3	do	Gypsum	1,500
4	do	do	7,500
5	do	do	15,000
6	None	do	1,500
7	Sweetclover	do	1,500
		$Ca(H_2PO_4)_2.H_2O$	450
8	do	do	450
9	do	do	2,000
10	do	do	10,000
11	do	do	20,000
12	do	$NaH_2PO_4.H_2O$	450
13	do	$CaCl_2.2H_2O$	1,200
14	do	do	12,000
15	Green bur-clover	None	

Not all were used for all soils but were varied somewhat, according to the apparent needs. Sweetclover was planted first as a green-manure crop. After the clover had grown approximately 6 months it was cut and worked into the soil and the soil planted to oats. The clover produced an average of about 10 gm. of green clover per container. Per unit of soil, this is about equal to a good yield of green manure in the field.

The comparative oat yields are given in table 15. These yields

TABLE 15.—*Relative green weights of oats in lysimeter experiment expressed as percentage of yields from treatment 1 (check) for each soil*

Soil No.	Treatment No.[1]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
02	100	133	126			121		121							137
87	100	223	217	222	328	133	350	361				383			255
88	100	143	157	130	165	87			187	234	191		91	147	
373	100	140	114			97	126	151	87			151			123
374	100	130	148	130	177	77	227	193				177			93
375	100	127	100	138	122	78			117	128	133		78	161	140
385	100	200	175				275	300				275			

[1] See table 14.

indicate that under the conditions of the experiment, plant nutrients were the greatest limiting factor in growth, though some of the soils were in a very poor physical condition. Nitrogen and phosphorus were the pronounced limiting factors. No marked increase in growth resulted from the addition of gypsum, although large gypsum applications greatly improved the physical condition of some of the soils. The growth of clover on the soil and the addition of phosphate resulted in marked increase in growth of oats.

The effect of the treatments on the physical condition of the soil is indicated by the effect on the rate of wetting by capillary movement shown in figures 2 and 3 and by permeability given

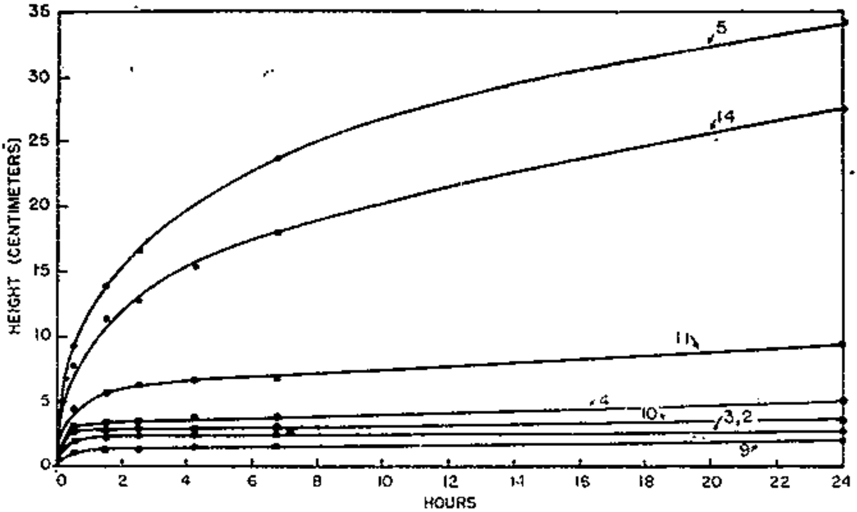

FIGURE 2.—Effect of soil treatments on the rate of rise of soil moisture by capillary movement in soil No. 88. Figures on the curves refer to eight of the soil treatments in table 14.

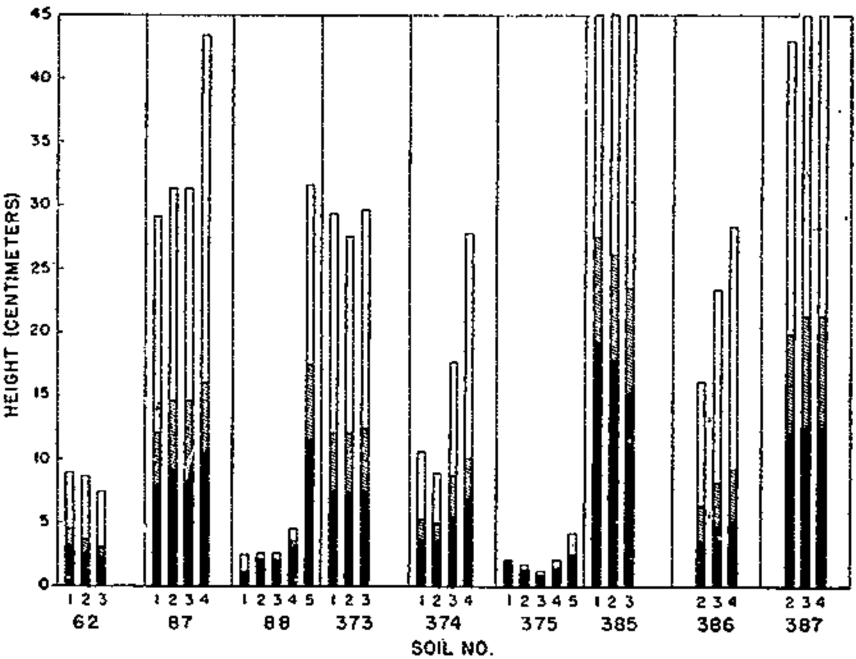

FIGURE 3.—Capilary rise of moisture in columns of soil from lysimeter experiment. Small figures on the abscissa represent the treatment numbers and large figures the soil numbers. The height of moisture is shown in black at 1 hour, cross-hatched at 3 hours, and in white at 20 hours.

in table 16. Figure 3 gives a comparison of the rate of wetting of the green-manure and the gypsum treatments with the untreated fallow soil, and table 16 shows the effect of gypsum on

TABLE 16.—*Permeability as affected by treatment in lysimeter experiment (cm./100 hours)* [1]

Soil No.	Treatment No. [2]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
62	0.08	0.19	0.11			0.07		0.11							
87	.59	.83	.87	13.20	19.10	.76	0.97	1.06				0.95			0.71
88	.20	.30	.20	41.30	112.30			.10	1.30	27.20	50.10		0.10	123.10	
373	21.00	15.00	25.00			25.00	10.00	13.00				10.00			38.00
374	3.80	2.60	3.40	16.80	25.80	6.60	6.70	2.10				2.25			6.30
375	.10	.10	.10	.50	.70	.10			.10	.20	.20		.10	.60	
385	24.50	33.10	32.80			30.30	34.70	30.60				35.00			20.50
386		142.00	98.00	157.00	144.00										
387		28.00	44.00	50.00	28.00										

[1] In obtaining the data in this table many of the soils were found so low in permeability that suction was necessary. Apparatus was devised to maintain any desired pressure difference. In some cases as much as half an atmosphere was used. The results are all calculated on the basis of 1 cm. drop in hydraulic head per cm. The measurements were made with the soils in place in the lysimeters.

[2] See table 14, page 20.

permeability in the lysimeters. Soil No. 88 gave a marked response in physical condition to the gypsum and calcium chloride treatments and a somewhat lower response to calcium phosphate. The large applications of gypsum and calcium chloride made the soil very friable, as compared with the extremely unfriable untreated soil.

There was little evidence that the poor physical condition of the soil or the high pH had any direct adverse effect on the plant growth, as irrigation could be controlled to prevent waterlogging in most cases. In a few cases the plants died when waterlogging occurred. It would be impossible because of low permeability to irrigate some of the soils studied in the field without waterlogging. If some of the soils ever became dry in the field, they probably would never again become wet.

Comparisons of the replaceable sodium percentages in table 2 with the composition of the irrigation water given in table 13 and the changes in permeability due to gypsum shown in table 16 reveal some facts that not only may have an important bearing on the improvement of saline soils but, studied in connection with the previous treatment of the soils, may be still more important. Soils No. 88 and No. 375 are both heavy and both are high in replaceable sodium. Without amendments, both are very impermeable to the irrigation water used, and both were irrigated with low salt waters. Soil No. 88 gave a remarkable response to gypsum, while No. 375 gave very little response. What seems to be a plausible explanation of the difference in response of the two soils is that No. 375 had been flooded with very low salt water from the previous season's heavy rains and had become somewhat dispersed, while No. 88, being a virgin subsoil over a high water table, had been subjected to a fairly uniform salt concentration.

Soils No. 373, No. 385, and No. 386 all contain an excess of gypsum and, therefore, showed little effect from gypsum treatments. The remarkable fact is that these soils contained, respectively, 12, 33, and 24 percent of replaceable sodium, in spite of the gypsum. On the basis of clay content and replaceable sodium, soils No. 385 and No. 386 could be expected to be very impermeable; both, however, are quite permeable. This fact might be explained on the basis of the low rainfall of the Imperial and Arkansas River Valleys, which gave no opportunity for the soils to become dispersed. Soil No. 373 had been flooded with comparatively low salt irrigation water.

Only soil No. 373 has a lower percentage of replaceable sodium than No. 87. Although No. 87 has the lightest texture of any of the soils studied, it ranks among the lowest in permeability. A probable reason for this is that the irrigation water is very low in salts and causes the clay to disperse. The permeability was greatly improved by adding gypsum but was still less than that of the heavy subsoil, No. 88. As previously stated, this is a virgin soil lying over a high water table. Each year the surface soil is leached to some extent by rainfall, which probably does not pass through the subsoil. The clay in the surface, therefore becomes more highly dispersed than that of the subsoil.

Soils No. 62 and No. 374 are from the same locality and are very similar in most respects, as is shown in table 2, but No. 62 has been saline longer, is more highly dispersed, and is much more impermeable.

Table 17 shows the salt concentration of the last leachates

TABLE 17.—*Concentration of leachate from some of the lysimeters*

Soil No.	Treatment No.[1]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	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.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*	*E.p.m.*
62	73	75	73			73		70							79
87	8	7	8			10	8	8				8			15
88	20		27	56	45				23		87			7	
373	36	57	35			32	56	44				56			28
374	33	43	34			36	25	55				55			28
375	47	47	50	82	40	68			50	59	40		82	31	
385	60	57	53			61	57	59				55			70

[1] See table 14, p. 20.

TABLE 18.—*pH of the leachates from the lysimeters*

Soil No.	Treatment No.[1]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
62	8.9	9.0	9.0			9.1		9.0							9.1
87	8.2	8.2	8.2			8.1	7.9	8.8				8.2			8.1
88	8.0	8.5	8.2	8.2	8.0	8.2			8.7	8.0	8.0		8.0	8.4	
373	8.5	8.3	8.4			8.5	8.2	8.3				8.2			8.5
374	8.5	8.2	8.1			8.4	8.3	8.1				8.1			8.4
375	9.0	8.7	8.8	8.3	8.3	8.7			8.7	8.4	8.8		8.8	8.7	
385	8.1	8.2	8.3			8.3	8.0	8.1					8.3		8.3
386	8.3	8.2	8.2	8.0											
387	8.2	8.1	8.1	8.0											

[1] See table 14, p. 20.

taken from the lysimeters, and table 18 the pH of the leachates. The salt content is apparently high enough to keep the pH from becoming excessively high, in spite of the high exchangeable sodium percentages. Some injury to plant growth, no doubt, resulted from the high salt content of some of the soils. Definite oat-tip burning occurred on samples of soils No. 62, No. 374, and No. 375.

The vast difference in the behavior of these soils toward treatment indicates that a wide variety of conditions must be considered in reclaiming saline soils in the field and that generalizations from one or a few experiments should be made with extreme caution.

The results of the lysimeter experiment indicate that many of the beneficial effects of green manures in improving saline soils may be due to the increase in plant nutrients rather than entirely to the change they help to cause in the base status of soils having large proportions of absorbed sodium. That the green manures did not greatly change the physical condition or base status of the soil is indicated by the rates of wetting in figure 2 and by the pH values in table 19. Comparing these pH values with those

Table 19.—*pH and salt concentration (normality) of 10-percent suspensions of soil samples from lysimeters at conclusion of the experiment*

pH VALUE

Soil No.	Treatment No. [1]													
	1	2	3	4	5	6	7	8	9	10	11	12	14	15
62	9.78	9.70	9.69			9.76		9.76						9.69
87	8.94	8.65	8.50	8.51	7.64	8.88	8.63	8.52				8.53		8.75
88		9.60	9.84	9.50	9.10				9.72	9.54	9.40		9.26	
373	8.79	8.68	8.08			8.69	8.59	8.58				8.54		8.64
374	9.27	9.30	9.16	9.40	9.49	9.15	9.03	9.24				9.34		9.23
375		9.96	9.81	9.76	9.51				9.70	9.78	9.51		9.63	
385	8.31	8.22	8.22			8.36	8.15	8.18				8.15		8.22
386		8.82	8.66	8.30	8.66									
387		8.39	8.38	8.29	8.32									

NORMALITY

Soil No.	1	2	3	4	5	6	7	8	9	10	11	12	14	15
62	0.0035	0.0037	0.0033			0.0035		0.0040						0.0035
87	.0012	.0011	.0010	0.0005	0.0004	.0011	0.0011	.0011				0.0012		.0016
88		.0037	.0048	.0032	.0016				0.0012	0.0037	0.0030		0.0018	
373	.0019	.0018	.0017			.0023	.0023	.0023				.0022		.0021
374	.0020	.0024	.0018	.0021	.0022	.0016	.0018	.0022				.0022		.0020
375		.0018	.0044	.0035	.0029				.0050	.0043	.0045		.0029	
385	.0088	.0091	.0094			.0092	.0091	.0089				.0088		.0106
386		.0031	.0048	.0066	.0035									
387		.0051	.0061	.0071	.0053									

[1] See table 14, p. 20.

in table 11 discloses that in table 11 they correspond to values for relatively high sodium. The bottom half of table 19 shows the approximate salt concentration of the suspensions. Comparisons of tables 19 and 11 should be made on the basis of similar salt concentrations.

EFFECT OF ELECTROLYTES ON SOIL AGGREGATION

In attempting this study of the soil salinity problem, the writer has held to the opinion that one of the most important aspects is the effect that sodium salts have on the physical properties of many saline soils. He has also had the opinion that the effect of electrolytes on the state of aggregation of clay crystals is the fundamental cause of most of the variation in physical properties associated with soil salinity and that control of the physical properties lies in the control of the factors that affect the state of aggregation.

It is well recognized that the clay minerals of the soil may exist as individual crystals dispersed through the solution, as loosely aggregated floccules, or as granular aggregates. Many physical properties of the soil depend upon the balance between these three states. The factors that control dispersion, flocculation, and granulation are therefore of fundamental importance.

In the earlier years of the study of these processes by students of colloidal chemistry, interest was generally focused on the colloidal micells and their replaceable ions, and more recently on the clay crystals. Much less attention was given to the surrounding solution than in more recent years *(13, 14, 15, 19)*. Some theories now explain flocculation almost entirely on the basis of the solution *(19)*.

The tendency has been to attach far more importance to the replaceable bases than to the solution when attempting to explain the effect of salts on the physical properties of the soil. The writer considers this unfortunate for several reasons. In the first place, if the physical properties are a function of the replaceable bases they are also a function of the solution, because the replaceable bases vary with the composition of the solution and, this being true, the direct relationship might as well be established between the solution and the physical properties without the necessity of base-exchange determinations. A far more important reason is that the composition and the concentration of the solution exert an important effect upon flocculation and granulation in addition to their effect upon the type of bases on the clay crystals. Variations in the concentration of the solution may change the state of aggregation greatly, while the ratio of the replaceable bases is held relatively constant.

THE DISPERSE FLOCCULAR AND GRANULAR SOIL PHASES

The results of these and other investigations *(19)* indicate that the physical conditions of the soil associated with salinity are not necessarily proportional either to the replaceable bases or to the concentration or composition of the solution. Some of these physical changes, particularly the change from floccules to granules, are not readily reversible and may not change when the base status changes. Considering the disperse, the granular, and the floccular conditions as three separate phases, it seems that the change from the disperse to the floccular phases is a process that can be readily reversed by changing the composition or concentration of the solution. The change from the granular to the disperse condition is not completely reversible by changing the concentration or composition of the solution.

To differentiate completely between the changes of physical state, it might be well to make use of the term "degranulation." Then flocculation and deflocculation can be considered as the changes affecting only the disperse and the floccular states, while degranulation and granulation can be considered as the changes between either the floccular or the disperse state and the granular state. A soil high in sodium tends to swell as the electrolyte content is reduced until it reaches a condition similar to the floccular phase, and at sufficiently low electrolyte content it may become dispersed through the medium. It is well known that increasing the electrolyte content will cause flocculation but will not cause immediate granulation (*1*, *5*, *6*). This investigation indicates that when the ratio of calcium ions to sodium ions is high in the system, drying will assist greatly in granulation. There probably are many other factors involved in the granulation process. Degranulation may be caused by mechanical manipulation, changing the concentration or kind of electrolyte, and possibly other conditions.

SUGGESTIONS FOR A SCHEME OF SALINE SOIL CLASSIFICATION

In considering the problem from the standpoint of classification of saline soils, the data presented indicate that several of their easily measured properties are related to the measures necessary to correct or prevent deterioration of soil structure by the salt conditions and that they might be used in a soil-classification scheme. These tests might include pH, electrical conductance, rate of wetting, permeability, settling volume, and dispersion. The use of pH and electrical conductance, however, will involve a different interpretation from that ordinarily applied to these measurements.

No attempt has been made to apply the results of this study to any scheme for classifying saline soils, as it is thought that this can be accomplished better in cooperation with some agency actually engaged in soil classification.

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