THE EFFECT OF ABSORPTION BY PLANTS ON THE CONCENTRATION OF THE SOIL SOLUTION [1]

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INTRODUCTION

In many irrigated regions the force of circumstances operates in the direction of requiring the most economical and efficient use of irrigation water. In some situations the area of available land is greater than the supply of water. In others, where water must be lifted to reach the land, the cost of pumping is a powerful incentive to sparing use. There are still other situations where it is believed that the extravagant application of water contributes to the saturation of the subsoil, a condition popularly known as water-logging. Many of the troubles that occur on irrigated land are believed to be due either directly or indirectly to the excessive use of irrigation water.

Although there are many cogent reasons for advocating the most sparing use of water in irrigation, there are also reasons why enough water should be used to prevent the accumulation of injurious quantities of soluble salts in the root zone of the soil. Nearly all irrigation waters carry in solution appreciable quantities of salts. Certain of these salts are absorbed by crop plants to a limited extent, but others are used very little if at all. Where the system of irrigation is such that all the water applied to the soil is held within the root zone, the salts brought to the land by the irrigation water remain in the root zone, largely dissolved in the solution.

There are two assumptions with respect to irrigation practice that are very generally accepted but which do not appear to be well supported. These may be stated as follows:

(1) That crop plants absorb the soil solution, including both the water and its dissolved salts, substantially as it occurs in the soil.

(2) That the ideal system of irrigation is one in which only enough water is applied to the soil to moisten the root zone to its water-holding capacity, in order to supply the needs of crop plants and to meet the unavoidable losses of direct evaporation.

These two assumptions are very closely related. The second is really based on the first. If the first is not well founded, the second is certainly open to question.

Persons who have studied the physiology of plants or who are familiar with the literature of that subject do not generally hold the view that plants absorb the soil solution as it exists in the soil. To them the phenomenon of selective absorption is readily accepted as a fact. They conceive that a plant may absorb water or any dissolved electrolytes or gases according to its needs and almost if not quite independently of the relative abundance of the various constituents in the solution. Numerous experiments have been made, the results of which support this view. For the most part these

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experiments have been designed to show the selective absorption by plants as between certain electrolytes in the solution, and it seems generally to have been taken for granted that the rate of water absorption is also independent of the rate of absorption of the dissolved substances. From what is known of the phenomena of absorption by plants it is entirely conceivable that a crop plant might absorb water from a soil solution and at the same time not absorb corresponding quantities of the substances dissolved in that solution. In other words, a plant having its roots in contact with a soil solution might, during its period of growth, modify the character of the solution in the direction of increased concentration—a result similar to that which would follow if water were lost from the solution by evaporation.

Although such a result of absorption by plants is entirely in accord with known facts, there does not appear to be in the literature of the subject very much in the way of direct evidence on this point. For that reason it seemed desirable to conduct experiments that should yield such evidence. The experiments described in the following pages were designed with that end in view. They were planned in detail by the writer but were conducted by James F. Breazeale at the University of Arizona, who prepared and analyzed the culture solutions and who was also responsible for the care of the cultures and for making the various observations, except the conductance determinations, which were made by H. V. Smith, also of the University of Arizona.

PURPOSE OF THE EXPERIMENTS

The experiments were planned to give unequivocal answers to the following questions:

1. Does the plant absorb its nutrient solution as the solution is presented to the roots?

2. If water and electrolytes are absorbed from the nutrient solution at different relative rates, are these rates influenced by the concentration of the nutrient solution?

These questions may be stated in another way:

3. Does the plant, when its roots are in contact with a concentrated nutrient solution, absorb the water and the electrolytes at the same rate?

4. If, even from a dilute solution, the water is absorbed faster than the electrolytes, is the difference in rate of absorption greater as the solution is made more concentrated?

For the information of those who may not have the time or the inclination to read the details of the description of the experiments and the discussion of its results, it may be said here that questions 1 and 3 are answered in the negative and questions 2 and 4 in the affirmative.

DESCRIPTION OF THE EXPERIMENTS

The experiments involved the use of 25 seedlings of barley or wheat, grown as one lot, with their roots immersed in 950 c. c. of nutrient solution. During the period of the experiment the seedlings were supported on a perforated disk covering the glass jar containing the solution. This disk was covered with a soft wax in such a way as to hold the seedlings in position and at the same time to seal the

mouth of the jar and prevent the loss of water from the solution by direct evaporation.

The seedlings were obtained by sprouting a large number of seeds on perforated aluminum disks floating in tap water. When the seeds were well sprouted, with plumules about an inch long, it was possible to pick out lots of 25 that were apparently uniform in size and vigor. These were then transferred to the nutrient solutions and sealed in. The cultures were grown during the latter part of March, 1927, in a greenhouse at the university at Tucson, Ariz.

The culture solutions were obtained in the following manner: A quantity of surface soil taken from a field near Jaynes Station in the Santa Cruz Valley, near Tucson, Ariz., was leached with distilled water through a filter. The percolate was diluted to have a concentration of total salts estimated as approximately 0.5 per cent. This percolate was then analyzed, with the result shown in the second column of Table 2. It was also tested electrically for its specific conductance at 25° C. and for its alkalinity as expressed by the P_H scale. One portion was tested in its natural condition and another portion after it had been boiled and its volume restored by the addition of distilled water.

A part of the original stock solution, found by analysis to contain 5,760 parts per million of total solids, was diluted with an equal quantity of distilled water to obtain a culture solution of one-half that concentration, or 2,880 parts per million. Another part was diluted with 3 parts of distilled water to make a culture solution having 1,440 parts per million. These two diluted solutions were also tested electrically both in the natural condition and after boiling. The results of the electrical tests for all three culture solutions are shown in Table 1.

TABLE 1.—*Total solids, specific conductance, and alkalinity of the three culture solutions before and after boiling*

Solution No.	Total solids (parts per million)	Specific conductance at 25° C.		Alkalinity (P_H)	
		Before boiling	After boiling	Before boiling	After boiling
1	5,760	0.006873	0.007193	8.0	8.0
2	2,880	.003844	.003907	7.9	7.8
3	1,440	.002008	.002075	7.9	7.8

In the experiment of March, 1927, four lots of seedlings of 25 plants each of barley and of wheat were placed in jars of solution No. 3, containing 1,440 parts per million total solids. There were two lots each of barley and wheat in jars of solution No. 2, containing 2,880 parts per million of total solids, and three lots each of barley and wheat in jars of the original solution containing 5,760 parts per million. The seedlings were left in contact with the solution for 11 days, during which period a portion of it was absorbed by the roots and the water was transpired by the leaves. At the end of this period each jar was weighed, and the loss was taken as the measure of the quantity of the solution absorbed and of water transpired.

At the end of this first period also the seal of each jar was broken and a portion of the solution was withdrawn to be tested electrically for conductance and alkalinity, both in its natural condition and after boiling. After these tests the solution that had been withdrawn was then returned to the jar, and enough distilled water was added to replace the quantity that had been transpired. After this addition of distilled water another sample of the culture solution was withdrawn to be tested electrometrically as before. This tested portion was then returned to the culture jar, the jar was again sealed, and the seedlings were allowed to absorb the solution for a period of 13 days.

At the end of this second period of growth each solution jar was again weighed to determine the transpiration loss. The seedlings were then removed from the solution, and each lot was weighed in the fresh condition and again after drying to constant weight at 100° C. The solution remaining in each jar was sampled to be tested electrometrically, following which test each solution was again made up to its original volume by the addition of distilled water and again tested electrometrically. After this test each set of solutions of the same original concentration as used for each kind of seedlings were composited and samples were taken for analysis. In these analyses the six chief constituents were determined for each of the three solution concentrations as shown in Table 2.

TABLE 2.—*Results of analyses of original culture solutions Nos. 1, 2, and 3 and of composites as restored to original volume at the conclusion of the experiment*

[Data in parts per million]

Solids and ions identified	Solution No. 1			Solution No. 2			Solution No. 3		
	Original solution	After barley	After wheat	Original solution	After barley	After wheat	Original solution	After barley	After wheat
Total solids	5,760	5,240	5,280	2,880	2,472	2,456	1,440	1,128	1,200
Calcium	325	291	292	162	147	147	81	66	60
Magnesium	52	44	45	26	17	15	13	9	8
Bicarbonate	112	288	264	56	168	192	28	72	96
Chloride	588	616	588	294	280	266	147	112	112
Sulphate	2,688	2,542	2,545	1,344	1,224	1,205	672	574	570
Nitrate	266	144	160	133	0	0	66	0	0
Total ions identified	4,031	3,925	3,894	2,015	1,836	1,825	1,007	833	846

Table 2 shows that the solutions when restored to original volume were slightly less concentrated at the end of the experiment than at the beginning. It must be realized, however, that the quantity of water absorbed by the seedlings during the 24 days of the experiment was approximately equal to the original volume in each case. This result makes it very evident that the plants did not absorb the solution as it existed in contact with their roots, but that they absorbed chiefly the water and only a small proportion of the dissolved material. In general, each of the ionic constituents was partially absorbed by the plants. The exception was the bicarbonate. With this constituent in every case the quantity identified at the end of the experiment was greater than at the beginning. This increase was probably due to the evolution of carbon dioxide from the plant

roots.   The effect of this process was also indicated by a comparison of the P_H values of the solutions at the beginning and at the end of the experiment.   The average P_H value of the original solutions was 7.9, whereas at the end it had dropped to 7.6 for the barley solutions and 7.5 for the wheat solutions.   This increase in the bicarbonate anion was partly offset by decreases in the sulphate and nitrate anions, both of which were taken up to a greater extent than the chloride anion.   The nitrate was completely absorbed from the more dilute solutions.

INTERPRETATION OF RESULTS

The primary aim of this experiment was to observe the effect of the absorption by the plants upon the concentration of the solution. In order to avoid unnecessary complications, it seemed desirable not to use up any of the solution for analysis during the progress of the experiment.   Yet it was important to compare the solution concentrations at the end of each growth period with the initial concentrations.   For this purpose it seemed practicable to use the method of electrical conductance.   With this method a sample of the solution could be withdrawn from each culture jar, its conductance measured, and the sample returned to the jar without appreciable alteration.

In order to standardize these conductance determinations for each solution, each sample that was analyzed gravimetrically for total solids at the beginning and at the end of the experiment was also tested electrometrically.   For example, solution No. 1 at the beginning of the experiment showed by evaporation 5,760 mgm. per liter of total solids.   The same sample showed a specific conductance at 25° C. of 0.006873 reciprocal ohm.   Whence: $\frac{0.5760}{0.006873} = 83.8$, or $83.8 \times 0.006873 = 0.5760$.   At the conclusion of the experiment the three solutions of No. 1 in which barley seedlings had been grown were restored to their original volume by the addition of distilled water and tested for conductance.   The mean of these three observations gave a specific conductance at 25° C. of 0.006653 reciprocal ohm. These three solutions were then composited and a sample taken for analysis, which showed total solids of 5,240 mgm. per liter.   Whence: $\frac{0.5240}{0.006653} = 78.7$.   The mean of these two factors, i. e., 81.3, was taken as the conversion factor for interpreting the conductance determinations made on cultures of barley in solution No. 1 during the progress of the experiment.   By the same method conversion factors were obtained for each of the other culture solutions.

The detailed interpretation of the observations made during the experiment may be followed through by reference to Table 3, which gives the results obtained from three lots each of barley and wheat seedlings grown in solution No. 1.   The volume of solution used for each culture was 950 c. c., and this contained originally 5,472 mgm. of salts or total solids.

TABLE 3.—*Results of growing barley and wheat seedlings in salt solution No. 1*

[25 plants in 950 c. c. culture solution containing 5,472 mgm. of salt]

Growth period and item	Barley seedlings			Wheat seedlings		
	Lot No. 10	Lot No. 11	Lot No. 12	Lot No. 10	Lot No. 11	Lot No. 12
First growth period, 11 days:						
Water transpired_____c. c._	232	215	228	241	263	332
Salts__mgm__{Residual [a]_____	5,105	5,165	5,144	5,159	5,219	5,107
Salts__mgm__{Restored [b]_____	5,232	5,269	5,246	5,421	5,249	5,202
Mean_____	5,168	5,217	5,195	5,290	5,234	5,154
Salts absorbed_____mgm__	304	255	277	182	238	318
Concentration of original solution_____ppm.[c]__	5,760	5,760	5,760	5,760	5,760	5,760
Concentration of absorbed solution_____do___	1,310	1,177	1,215	755	905	958
Second growth period, 13 days:						
Original salt content_____mgm__	5,168	5,217	5,195	5,290	5,234	5,154
Water transpired_____c. c._	466	434	406	596	575	639
Salts__mgm__{Residual [a]_____	4,890	4,906	4,779	_____	4,904	4,553
Salts__mgm__{Restored [b]_____	5,073	5,168	5,173	5,059	5,127	5,160
Mean_____	4,981	5,037	4,976	5,059	5,015	4,856
Salts absorbed_____mgm__	187	180	219	231	219	298
Concentration of original solution_____ppm.[c]__	5,440	5,492	5,468	5,568	5,509	5,425
Concentration of absorbed solution_____do___	401	415	539	387	381	466
Total growth period, 24 days:						
Total water transpired_____c. c._	698	649	634	837	838	971
Total salts absorbed_____mgm__	491	435	496	413	457	616
Concentration of absorbed solution_____ppm.[c]__	703	670	782	493	545	634
Dry weight of 25 plants_____gm__	2.47	2.14	2.23	2.44	2.77	2.85

[a] Computed from conductance of residual solutions.
[b] Computed from conductance of restored solutions.
[c] Parts per million.

During the first 11 days of the growth period the barley plants of lot No. 10 transpired 232 c. c. of water, as determined by weighing the culture jar at the beginning and at the end of that growth period. There remained, therefore, 718 c. c. of solution in the culture jar. A sample of this residual solution when tested showed a specific conductance at 25° C. of 0.008747 reciprocal ohm. This value multiplied by the conversion factor 81.3 and the product multiplied by the volume of the residual solution, 718, gives a figure for the quantity of salt left in the solution, viz, 5,105 mgm.

The sample of the residual solution that was tested for conductance was then returned to its culture jar, and distilled water was added to restore the solution to its original volume. After this restoration, another sample was taken for a conductance determination. This sample showed a specific conductance at 25° C. of 0.006774 reciprocal ohm. This figure when multiplied by the conversion factor 81.3 and the product multiplied by the solution volume, 950, gives 5,232 as another figure for the quantity in milligrams of salt in the culture solution. It was deemed advisable to make these two conductance determinations partly as a check against errors of observation and partly because it was thought that the culture solution might be near the saturation point with respect to one or more of its constituent salts, and if this were true the absorption of water by the plants might result in the precipitation of a portion of the dissolved material in the residual solution. The mean of these two results was taken as the best estimate of the quantity of salt remaining in the solution at the end of the first growth period.

The quantity of salt originally in the solution was known to be 5,472 mgm. From this was subtracted the quantity estimated to be in the residual solution, giving a difference of 304 mgm. as the quantity of salt absorbed by the plants. This quantity of salt in relation to the quantity of water transpired, 232 c. c., gives 1,310 mgm. per liter, for the concentration of the absorbed solution. For convenient comparison, this figure is placed in the table in close proximity to that for the concentration of the original solution.

After determining the conductance of the restored solution at the end of the first growth period, the jars were resealed for the second growth period of 13 days. For lot No. 10 the figure for the original salt content for this period was taken as the same as at the end of the first period, 5,168 mgm. During the second period the plants transpired 466 c. c. of water. At the conclusion of this period the quantity of salt remaining in the culture solution was again determined by two conductance readings, and the mean of these was taken as representing the final salt content of the solution. By subtracting this figure from that for the original salt content the quantity absorbed by the plants was obtained, and from this and the quantity of water transpired the concentration of the absorbed solution was computed. Finally the quantity of water transpired for the whole period of growth is given, together with the quantity of salt absorbed, and from these two is computed the concentration of the absorbed solution.

TABLE 4.—*Results of growing barley and wheat seedlings in salt solution No. 2*

[25 plants in 950 c. c. culture solution containing 2,736 mgm. of salt]

Growth period and item		Barley seedlings		Wheat seedlings	
		Lot No. 8	Lot No. 9	Lot No. 8	Lot No. 9
First growth period, 11 days:					
Water transpired _____c. c__		256	288	328	340
Salts_____mgm. {Residual [a]__		[b] 2,524	1,853	2,407	2,516
{Restored [c]__		2,746	[b] 2,579	2,459	2,524
Mean_____		2,524	2,580	2,433	2,520
Salts absorbed_____mgm__		212	156	303	216
Concentration of original solution_____ppm [d]__		2,880	2,880	2,880	2,880
Concentration of absorbed solution_____ppm [d]__		828	542	924	635
Second growth period, 13 days:					
Original salt content_____mgm__		2,524	2,580	2,433	2,520
Water transpired_____c. c__		578	653	712	747
Salts_____mgm. {Residual [a]__		2,253	2,249	2,252	--------
{Restored [c]__		2,284	2,369	2,278	2,444
Mean_____		2,268	2,309	2,265	2,444
Salts absorbed_____mgm__		256	271	168	76
Concentration of original solution_____ppm [d]__		2,657	2,716	2,561	2,653
Concentration of absorbed solution_____ppm [d]__		443	415	236	102
Total growth period, 24 days:					
Total water transpired_____c. c__		834	941	1,040	1,087
Total salts absorbed_____mgm__		468	427	471	292
Concentration of absorbed solution_____ppm [d]__		561	454	453	269
Dry weight of 25 plants_____gm__		2.34	2.65	2.70	2.83

[a] Computed from conductance of residual solutions.
[b] Only one observation used.
[c] Computed from conductance of restored solutions.
[d] Parts per million.

Besides the three lots of barley seedlings grown in solution No. 1, with the results shown in Table 3, three lots of wheat seedlings also were grown in cultures of the same solution concentration, and the results for these are also given in Table 3, Two lots of barley were grown in solution No. 2, containing 2,880 mgm. of salts per liter, for which the results are given in Table 4. With the same solution there were two lots of wheat seedlings, the results from which are also shown in Table 4. Solution No. 3, made by dilution of No. 1 with three parts of distilled water, was used for four lots of barley and four of wheat, the results for which are given in Table 5.

TABLE 5.—*Results of growing barley and wheat seedlings in salt solution No. 3*

[25 plants in 950 c. c. culture solution containing 1,368 mgm. of salt]

Growth period and item	Barley seedlings				Wheat seedlings			
	Lot No. 4	Lot No. 5	Lot No. 6	Lot No. 7	Lot No. 4	Lot No. 5	Lot No. 6	Lot No. 1
First growth period, 11 days:								
Water transpired_____c. c.__	408	341	267	351	340	337	393	305
Salts_____mgm__ {Residual [a]_	1,131	1,219	1,329	1,122	1,253	1,194	1,223	1,276
{Restored [b]_	1,305	1,228	1,263	1,279	1,257	1,207	1,271	1,236
Mean_____	1,218	1,223	1,296	1,200	1,255	1,200	1,247	1,256
Salts absorbed_____mgm__	150	145	72	168	113	168	121	112
Concentration of original solution__ppm [c]_	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440
Concentration of absorbed solution_ppm [c]_	368	425	269	479	333	498	308	367
Second growth period, 13 days:								
Original salt content_____mgm__	1,218	1,223	1,296	1,200	1,255	1,200	1,247	1,256
Water transpired_____c. c.__	671	385	596	681	750	620	723	717
Salts_____mgm__ {Residual [a]_	956	1,155	957	995	1,068	1,198	1,119	1,209
{Restored [b]_	1,011	1,110	1,093	1,038	1,096	1,097	1,148	1,184
Mean_____	983	1,132	1,025	1,016	1,082	[d]1,097	1,133	1,196
Salts absorbed_____mgm__	235	91	271	184	173	103	114	60
Concentration of original solution__ppm [c]_	1,282	1,287	1,364	1,263	1,356	1,263	1,313	1,322
Concentration of absorbed solution_ppm [c]_	350	236	455	270	231	166	158	84
Total growth period, 24 days:								
Total water transpired_____c. c.__	1,079	726	863	1,032	1,090	957	1,116	1,022
Total salts absorbed_____mgm__	385	236	343	352	286	271	235	172
Concentration of absorbed solution _____ppm [c]_	356	325	397	341	262	283	211	168
Dry weight of 25 plants_____gm__	2. 80	1. 94	2. 36	2. 65	2. 55	2. 42	2. 62	2. 21

[a] Computed from conductance of residual solutions.
[b] Computed from conductance of restored solutions.
[c] Parts per million.
[d] Only one determination used.

Tables 3 to 5, inclusive, each include the results for individual lots of seedlings, and it is to be expected that they would show a certain diversity, even though the conditions of the experiment were made as uniform as practicable. In order to summarize these results and also to facilitate comparison between the results obtained from the barley and the wheat seedlings when grown in solutions of the same concentrations, the results from comparable individual lots have been averaged and are shown for solution No. 1 in Table 6. This table includes, in addition to the averages of the quantity and concentration of the absorbed solution, a comparison of the average quantity of salts absorbed as determined by conductance and by gravimetric measurements. This comparison gives some indication as to the degree of confidence that may be placed in the final results. A similar comparison of averages for the barley and wheat seedlings

grown in solution Nos. 2, and 3 is also given.   These comparisons between barley and wheat show certain differences that may be noted, but probably should not be greatly stressed because the numbers of cultures involved are not large and the differences may not be significant.   However, it may be seen that in all three comparisons the wheat seedlings transpired slightly more water than the barley seedlings and also that they produced slightly more dry matter. There are not, however, any consistent differences between the two classes of seedlings with respect to the quantities of salt absorbed.

TABLE 6.—*Average results obtained with separate lots of barley and wheat seedlings grown in culture solutions Nos. 1, 2, and 3, having initial concentrations respectively of 5,760, 2,880, and 1,440 parts per million*

Growth period and item	Solution No. 1 (3 lots averaged)		Solution No. 2 (2 lots averaged)		Solution No. 3 (4 lots averaged)	
	Barley	Wheat	Barley	Wheat	Barley	Wheat
First growth period, 11 days:						
Solution absorbed_____c. c__	225	279	272	334	342	344
Cocentration of absorbed solution_____ppm. ª__	1,234	873	685	779	385	376
Second growth period, 13 days:						
Solution absorbed_____c. c__	435	603	615	729	583	702
Concentration of absorbed solution_____ppm. ª__	452	411	429	169	328	160
Total growth period 24 days:						
Solution absorbed_____c. c__	660	882	887	1,063	925	1,046
Concentration of absorbed solution_____ppm. ª__	718	557	507	361	355	231
Salts absorbed, conductance_____mgm__	474	495	447	381	329	241
Salts absorbed, gravimetric_____do____	494	456	388	403	296	228
Dry weight of 25 plants_____gm__	2.28	2.69	2.49	2.76	2.44	2.45

ª Parts per million.

Another comparison of the results is shown in Table 7, where the averages for the three sets of barley seedlings are given.   Each lot of barley was grown in a solution of different concentration.   It will be observed that with a single exception—solution No. 2 for the second growth period—the barley plants absorbed less water from the more concentrated solutions.   Also, the concentration of the absorbed solution increased with the concentration of the culture solution in all cases.   Correspondingly, the quantity of salt absorbed by the plants increased with the concentration of the solutions.

TABLE 7.—*Average results obtained from growing barley and wheat seedlings in three different solutions, Nos. 3, 2, and 1, having concentrations, respectively, of 1,440, 2,880, and 5,760 parts per million*

Growth period and item	Barley seedlings			Wheat seedlings		
	Solution No. 3	Solution No. 2	Solution No. 1	Solution No. 3	Solution No. 2	Solution No. 1
First growth period, 11 days:						
Solution absorbed_____c. c__	342	272	225	344	334	279
Concentration of absorbed solution _ppm.ª__	385	685	1,234	376	779	873
Second growth period, 13 days:						
Solution absorbed _____c. c__	583	615	435	702	729	603
Concentration of absorbed solution_ppm.ª__	328	429	452	160	169	411
Total growth period, 24 days:						
Solution absorbed_____c. c__	925	887	660	1,046	1,063	882
Concentration of absorbed solution _ppm.ª__	355	507	718	231	361	557
Salts absorbed, conductance_____mgm__	329	447	474	241	381	495
Salts absorbed, gravimetric_____do____	296	388	494	228	403	456
Dry weight of 25 plants_____gm__	2.44	2.49	2.28	2.45	2.76	2.69

ª Parts per million.

A similar comparison is made in Table 7 for the three sets of wheat seedlings. In this series there are two exceptions to the rule that more water was absorbed from the more dilute solutions. With but one exception the concentration of the absorbed solution was higher with the more concentrated solutions and also more salt was absorbed by the plants from the more concentrated solutions. There appears not to have been any correlation between the dry weight of the plants and the solution conditions, perhaps because the range of solution concentrations was well within the range to which these plants are able to adapt themselves.

RANGE OF SOLUTION CONCENTRATIONS

In planning this series of experiments it was aimed to keep the concentrations of the solutions well within the limits which occur commonly in the root zone of irrigated soils. It must be kept in mind that the concentration of the soil solution is computed from factors that are different from those used in computing the salt content of the soil. In the latter computation the quantity of soluble material is referred to the dry weight of the soil. Thus when a soil is said to contain 1,440 parts per million of soluble salts, the implication is that for each million pounds of dry soil there are 1,440 pounds of salt. The percentage of water is also usually referred to the dry soil. Therefore, if a soil has a field-carrying capacity for water of 25 per cent, the relationship is such that for each 100 pounds of soil (dry weight) there is held in suspension 25 pounds of water. If in such a soil it were found that each 100 pounds of dry soil contained 0.144 pound of soluble salts, it is assumed that this salt would all be dissolved in the water held in the soil; so that the concentration of the soil solution would be said to be four times that of the salt content of the soil, or 5,760 parts per million.

From this explanation it will be evident that the highest solution concentration developed in these experiments, i. e., at the end of the second growth period of the wheat seedlings in lot No. 12, when the concentration was 15,614 parts per million, or about 1.56 per cent, was not higher than often occurs in the solution of an irrigated soil. A similar solution concentration might be assumed to exist in a soil containing 0.2 per cent of readily soluble salts and about 14 per cent of water. On the other hand, the lowest solution concentration occurring in this experiment, i. e., about 1,300 parts per million, is probably rather higher than that existing in a soil that has been heavily irrigated or saturated with rain.

DISCUSSION OF RESULTS

The results of these experiments appear to warrant the conclusion that crop plants do not absorb water and dissolved substances from the soil solution in the same proportions that these constituents occur together in that solution. With the range of solution concentrations used, and under the conditions of the experiments here described, the residual solutions were definitely more concentrated than the original solutions. The quantity of water absorbed by the plants during the 24 days of the experiments was approximately equivalent to the original volume of the culture solutions, yet at the end of that period

the residual solutions contained 78 to 91 per cent of the salts originally present.

It is true that these experiments were conducted in a laboratory and not in the field, and that plants were grown in culture solutions and not in soil; yet it is believed that the results are fairly applicable to field conditions. Furthermore, there is abundant field evidence to show that when saline irrigation water is used so sparingly that the root zone is seldom or never leached, it is merely a question of time until the soil solution of the root zone becomes so concentrated that crop plants can not absorb from it the water required to make normal growth.

Irrigators are sometimes inclined to believe that if it is necessary to use salty irrigation water it should be used sparingly, so as to avoid carrying to the field more salt than is necessary. In the light of such evidence as is available, this method of procedure is not to be recommended. The only known way to remove soluble salt from the soil of the root zone is by leaching. Consequently, if saline water must be used for irrigation, it should be applied in sufficient quantities not only to supply crop needs and to meet evaporation losses but also to leach the root zone and thus carry away the salts that are left by the water that is evaporated from the soil and absorbed by the plants. In other words, the more salt there is in irrigation water the more water should be used in irrigating. Most of the ordinary crop plants are not able to absorb the water needed for normal growth from a soil solution containing more the 1.5 to 2 per cent of salts. This means that if the irrigation water contains as much as 1,500 to 2,000 parts per million of salt, a sufficient quantity of it should be used so that at least 10 per cent of the quantity applied to the surface of the soil will percolate down through the root zone.

In actual irrigation practice with such water it would be necessary to use more than would be required to insure an average of 10 per cent percolation. The reason for this is that the soil of the root zone of a whole field is seldom uniform in texture or permeability. If only 10 per cent of the water applied were to percolate through the root zone, there would be spots in the field where much less than 10 per cent would percolate; and in those spots there would be grave danger of accumulating excessive concentrations in the soil solution. In order to insure effective percolation and consequent leaching of the root zone, it would be necessary to follow one of two courses—either to apply enough water to the whole field to insure leaching in the areas of least permeable soil, or by a system of interior borders provide a means of holding the water longer on the less permeable areas.

It is not necessary, of course, to use water enough to·leach the root zone at every irrigation, particularly where the water is not very salty or when the salts in solution are in part salts of low solubility. With many irrigation waters as much as 60 to 80 per cent of the total salt content consists of salts of such low solubility that they are precipitated from the soil solution before injurious concentrations are reached. This fact needs to be taken into account in estimating what proportion of the irrigation water should be forced through the root zone.

It will be readily understood that in order to leach the root zone the conditions of the subsoil below it must be such that the percolating water may pass away through either natural or artificial

channels.   Soils that are underlain by strata of impermeable material such as hardpan, rock, or tight clay, or below which the subsoil is already saturated with stagnant water, can not be leached and consequently are almost certain to become unproductive if irrigated with saline water.   This fact makes it essential to take into account the subsoil conditions of irrigable land if the plans for its utilization contemplate its long-continued productivity.

It is coming to be generally recognized that irrigated lands need to have an assured and effective system of drainage, either natural or artificial.   Unfortunately, it is not yet so generally recognized that the real function of a drainage system is quite as much to remove surplus salt as to remove surplus water.   It is now regarded as normal and routine engineering practice to measure the quantity of water that is delivered to the land for irrigation or that is discharged from irrigated land as drainage, but there are as yet relatively few irrigation engineers who appreciate the need of, or who are equipped to make, determinations of the salt content of irrigation water or of the drainage.   With respect to any area of irrigated land there should be available, not only to the farmer but also to the investor, accurate information as to the quantity and character of the salts that are being carried to the land by the irrigation water and also as to the ultimate disposition that is being made of this salt.   If the conditions of the subsoil or the methods of irrigation are such that the salt is largely remaining in the root zone, then it is inevitable that the land must ultimately become unproductive.   On the other hand, if it can be shown that drainage conditions are such that the salts of high solubility brought in by the irrigation water are being carried away in the drainage, there can be reasonable assurance that the irrigated lands should long continue to be productive.