

THE RELATIVE ABSORPTION BY SOIL OF SODIUM CARBONATE AND SODIUM CHLORIDE

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Received for publication March 1, 1920

A number of papers have been published recently which describe investigations of the effect upon plant growth of "alkali" salts when added to the soil and in which conclusions as to the relative toxicity of the different salts are based upon the quantity of salt added (5, 7, 12).¹ The disadvantage of this method of interpreting the results is that it does not take into account differences in the proportion of the solute which is withdrawn from the solution when different salts are brought into contact with a soil. This source of error was noted several years ago by Mr. W. H. Heileman, formerly of the Bureau of Soils, United States Department of Agriculture, in the course of experiments with seedling plants grown in soils to which salts of sodium had been added. He observed that under these conditions sodium carbonate appeared to be much less toxic in comparison with sodium chloride than had been indicated by numerous observations upon plants growing in natural alkali soils and by the results of water culture experiments.²

It has been shown by Headley, Curtis and Scofield (8) that when sodium carbonate is added to a soil, upon analysis of the soil extract after several weeks, the quantity recovered is much less than the quantity which had been added, even when allowance is made for the increase in the content of bicarbonates which has taken place. In the case of sand, to which had been added solutions of sodium carbonate in eight concentrations ranging from 0.05 to 0.40 per cent, the quantity recovered of sodium carbonate plus excess of sodium bicarbonate reckoned as carbonate averaged 69.0 ± 2.9 per cent. In the case of a loam soil to which had been added solution of sodium carbonate in 10 concentrations ranging from 0.05 to 0.60 per cent, the quantity recovered averaged only 26.0 ± 1.7 per cent.³ In other words the sand had

¹ The readiness with which sodium carbonate is absorbed, and the necessity of considering this factor in relation to the toxicity of soils to which this salt has been added, are recognized in other publications by Harris and Pittman (6, 11).

² Thus Kearney and Cameron (9, p. 19, 24, 33, 36) found that both in pure solution and in the presence of an excess of calcium carbonate and of calcium sulfate, sodium carbonate was much more toxic to the roots of white lupine than was sodium chloride. Similar results with various crop plants were obtained by Kearney and Harter (10).

³ These percentages have been computed from data given in table 3, p. 863 of the publication cited.

absorbed 31 per cent and the loam had absorbed 74 per cent of the sodium carbonate which had been added to the soil.

Very different results with sodium chloride were obtained by the same investigators. This salt was added to a loam soil in six concentrations of solution ranging from 0.05 to 0.60 per cent and when the soil extract was analyzed several weeks later the quantity of sodium chloride recovered averaged 84.0 ± 1.5 per cent.⁴ In a parallel experiment with the same soil to which had been added sodium carbonate solutions in eight concentrations ranging from 0.05 to 0.40 per cent, the quantity recovered of sodium carbonate, plus excess sodium bicarbonate reckoned as the carbonate, averaged only 23.5 ± 2.3 per cent.⁵ In other words, the loam soil had absorbed 76.5 per cent of the sodium carbonate and only 16 per cent of the sodium chloride which had been added.

A further source of error, in experiments dealing with the relative toxicity of sodium carbonate, when conclusions are based solely upon the quantity of salt which has been added to the soil, lies in leaving out of account the reaction which takes place with carbon dioxide, resulting in the formation of the bicarbonate at the expense of the normal carbonate. It was demonstrated by Cameron and Briggs (3) that in solutions of sodium carbonate at a temperature of 25°C. and in concentrations ranging from 0.2 to 0.6 per cent, approximately half of the normal carbonate is replaced by the bicarbonate. In the above cited publication by Headley, Curtis and Scofield, evidence is given that a similar reaction occurs when sodium carbonate is added to soil, a large proportion of the salt being recovered in the form of bicarbonate. Sodium bicarbonate is less toxic than the normal carbonate, as was shown by the results of an experiment performed by Kearney and Cameron (9, p. 19 and 20; see also ref. 10) in which roots of the white lupine were exposed to solutions of sodium bicarbonate wherein the formation of the normal carbonate was prevented by the presence of an excess of carbon dioxide. Therefore when sodium carbonate is added to a soil, not only is the total concentration of the soil solution much smaller than would be assumed from the quantity of salt added, but much of the salt which remains in the soil solution is in the form of the less toxic bicarbonate.⁶

RELATIVE ABSORPTION AS INDICATED BY ELECTRICAL RESISTANCE

A comparison of different salts of sodium in respect to the relative degree of absorption in a soil, as measured by the electrical resistance of the system, was made by Davis and Bryan (4), who, however, apparently made their

⁴ As computed from data given in table 5, p. 867.

⁵ As computed from data given in table 2, p. 861.

⁶ It might be thought that owing to the unstable equilibrium between the carbonate and bicarbonate, the relative toxicity of the two salts is of no practical importance. As a matter of fact, however, bicarbonates are sometimes present in large quantity in soils which do not give the hydroxyl reaction with phenolphthalein.

readings immediately after the solutions were added to the soil. In order to test adequately the usefulness of the electrical resistance method for determining differences in absorption of different salts by a soil, more time should be allowed for the system to reach an equilibrium. This has been done in an experiment performed by the writer, which is described below.

Solutions of sodium chloride and sodium carbonate, of concentrations ranging from 0.05 to 1.00 per cent, were added to air-dry sand in sufficient quantity to supersaturate it slightly.

The sand used had a moisture equivalent⁷ of 2.4 per cent, indicating a moisture-holding capacity of 25 per cent and the quantity of solution added was 26 per cent of the dry weight of the sand. This sand was relatively free from readily soluble material, as is indicated by the fact that when saturated

TABLE 1

Electrical resistances at 60°F. of the free solutions when the cup is filled to 40 per cent and to 100 per cent of its capacity (20 cc. and 50 cc., respectively)

CONCENTRATION OF SOLUTION	SODIUM CARBONATE			SODIUM CHLORIDE		
	Resistance of solution		Ratio of resistance of 20 cc. to that of 50 cc.	Resistance of solution		Ratio of resistance of 20 cc. to that of 50 cc.
	20 cc.	50 cc.		20 cc.	50 cc.	
<i>per cent</i>	<i>ohms</i>	<i>ohms</i>		<i>ohms</i>	<i>ohms</i>	
1.00	63	22	2.86	53	19	2.79
0.80	75	28	2.68	65	24	2.71
0.60	98	34	2.88	89	32	2.78
0.40	135	49	2.75	126	46	2.74
0.20	246	90	2.73	240	85	2.82
0.10	500	167	2.99	467	171	2.73
0.05	872	328	2.65	872	323	2.70
Average ratio 2.79 \pm 0.03				Average ratio 2.75 \pm 0.01		

with distilled water and allowed to stand 24 hours, its electrical resistance was about 2500 ohms. When the sand was moistened with the solution the mixture was thoroughly stirred and was allowed to stand for 24 hours, when it was again stirred. The cup of the electric bridge was then filled with the wet sand and the electrical resistance of the latter was determined and was corrected to a temperature of 60°F.

The electrical resistances of the different concentrations of the free solution of each salt also were determined, both with the bridge cup full (50 cc.) and with only 20 cc. of solution in the cup, the latter corresponding to the moisture content of the cup when filled with the wet sand.

The resistances of 20 cc. and of 50 cc. of each concentration of solution of the two salts are stated in table 1, which also gives for each concentration the

⁷ As determined by the centrifugal method (1). A formula for computing the moisture-holding capacity from the moisture equivalent is given by Briggs and Shantz (2).

ratio of the two resistances. It is evident that, for the range of concentrations used, this ratio is practically a constant. It is also evident that with an equal concentration and volume of solution the resistances of the two salts differ only slightly.

In table 2 are given, for each concentration of each salt, the resistance of the saturated sand (containing 20 cc. of the solution), the resistance of 20 cc. of the free solution and the ratio of the first to the second resistance. The ratios are graphically expressed in figure 1.

If the presence of the sand had had no effect upon the resistance of the solution in contact with it, the ratio of the two resistances for each concentration of each salt should have been 1.0, since the quantity and the original concentration of solution were the same in both cases. The degree

TABLE 2
Resistances at 60°F. of the saturated sand (cup full) and of 20 cc. of the corresponding free solution

CONCENTRATION OF SOLUTION	SODIUM CARBONATE			SODIUM CHLORIDE		
	Resistance of		Ratio of re- sistance of sand to solution	Resistance of		Ratio of re- sistance of sand to solution
	Saturated sand	Solution (20 cc.)		Saturated sand	Solution (20 cc.)	
<i>per cent</i>	<i>ohms</i>	<i>ohms</i>		<i>ohms</i>	<i>ohms</i>	
1.00	146	63	2.3	77	53	1.5
0.80	198	75	2.6	90	65	1.4
0.60	234	98	2.4	116	89	1.3
0.40	416	135	3.1	180	126	1.4
0.20	765	246	3.1	317	240	1.3
0.10	1159	500	2.3	594	467	1.3
0.05	1539	872	1.8	1014	872	1.2
0	2488*			2488*		
Average ratio 2.5 \pm 0.12				Average ratio 1.3 \pm 0.02		

* Control, sand saturated with distilled water.

to which the ratio exceeds unity therefore indicates the degree to which the resistance of the solution in contact with the sand has been increased by withdrawal of a portion of the solute. It is evident that in the case of sodium carbonate much more of the solute has been withdrawn than in the case of sodium chloride, the dilution due to contact with the sand having increased the resistance, for the several concentrations, nearly twice as much in the former case as in the latter.

A glance at figure 1 shows that the curves representing the ratios of the two resistances differ greatly for the two salts, that for sodium chloride being much flatter than the curve for sodium carbonate, which shows a conspicuous maximum at concentrations of 0.20 and 0.40 per cent. Discussion of this difference, the significance of which could be ascertained only by

repeated determinations, is beside the purpose of the present article, since the data given sufficiently answer the question whether sodium carbonate is withdrawn from solution in greater proportion than sodium chloride, when in contact with soil.

It should be noted that the resistances of sand saturated with solutions of corresponding concentration of sodium carbonate and of sodium chloride, as given in the publication of Davis and Bryan (4, p. 13, table 1), are much

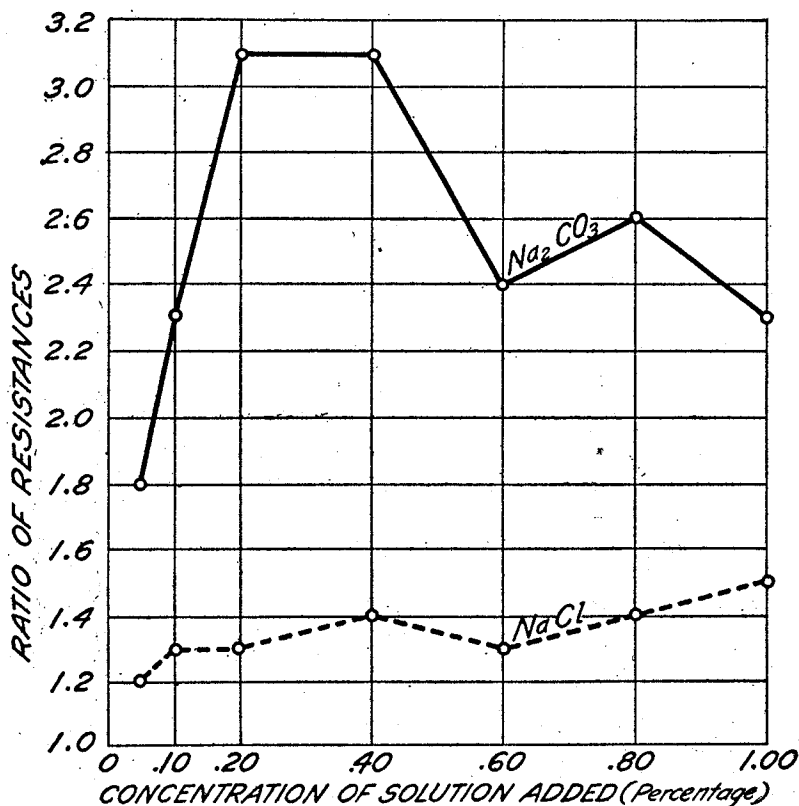


FIG. 1. RATIO OF RESISTANCE OF SAND PLUS 20 CC. OF SOLUTION TO THAT OF 20 CC. OF FREE SOLUTION

lower than the resistances in sand obtained by the writer, and also show little difference as between the two salts. The probable explanation is that Davis and Bryan determined the resistance immediately after adding the solution to the soil, while in the writer's experiment the readings were made after solution and soil had remained in contact during 24 hours.

Inspection of table 2 shows that when this amount of time is allowed, sand to which sodium carbonate has been added at concentrations of 0.10 to 1.00 per cent, gives a resistance about double that of sand to which like con-

centrations of sodium chloride have been added. Roughly speaking, the soil solution in the latter case is about twice as concentrated as in the former, yet if unaware of how differently the two salts are absorbed by the sand, one might assume that the soil solutions, like the original solutions, were of equal concentration in both cases.

In order to obtain some idea of the actual concentration, of the solution present in the sand to which sodium carbonate had been added 24 hours previously, a curve was plotted for the electrical resistances of 20 cc. of the free solution at the several concentrations which had been added. The curve was extended so as to include resistances as high as those of the sand to which the two most dilute solutions had been added, by determining the resistances of 20 cc. each of 0.04 per cent and 0.03 per cent sodium carbonate in free solution, the resistances obtained for these concentrations having been 1120 and 1580 ohms, respectively. By reading on the curve the concentration corresponding to the electrical resistance of the saturated sand, an approximate idea was obtained of the concentration of the solution present in the latter. For the 6 concentrations 0.10 to 1.00 per cent, the concentration of the solution present in the sand as thus estimated averaged 37 per cent (range 34 to 40 per cent) of that which had been added, indicating that approximately 63 per cent of the salt had been withdrawn from the solution when in contact with the sand. A similar calculation in the case of sodium chloride indicated an average absorption of only 23 per cent of the salt which had been added.

CONCLUSIONS

When equal volumes of solution of equal concentration of sodium carbonate and of sodium chloride are added to sand and the solution and soil are allowed to remain in contact during several hours, the electrical resistance of the sand to which sodium carbonate has been added is much higher than that of the sand to which sodium chloride has been added.

Since the greater resistance in the case of sodium carbonate must be due to proportionately greater withdrawal of the solute by the sand, it follows that plants growing in soils to which equal quantities of the two salts have been added are in contact with soil solutions of very unequal concentration.

As a result of overlooking this factor, as well as the reaction which takes place in solutions of sodium carbonate resulting in the formation of the less harmful bicarbonate, certain investigators of the effects of "alkali" salts upon plant growth have concluded that sodium carbonate is less toxic than sodium chloride. Observations upon plants growing in natural alkali soils and experiments with seedlings exposed to pure solutions of these salts have shown the contrary to be true.

The results of the experiment described in this paper indicate that the electrical bridge affords a convenient means for determining the degree to which different salts are withdrawn from a solution which has been added to

a soil. In the case of sodium carbonate and sodium chloride, equivalent solutions of which (at the concentrations ordinarily encountered in alkali soils) do not differ greatly in electrical resistance, the bridge method permits direct comparison of the concentration of the solution in soils to which these salts have been added.

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