Use of Sodium Acetate and Ammonium Carbonate in the Determination of the Cation-Exchange Capacity of Soils

VERNON C. BUSHNELL
Regional Laboratory, Region 1
Bureau of Reclamation, Boise, Idaho

SINCE ITS organization in 1946, the Regional Laboratory of Region 1 of the Bureau of Reclamation has used cation-exchange data extensively in predicting how nonirrigated soils would react to irrigation. The total cation-exchange capacity is an essential part of such studies. It provides an index to the productivity of soils to be intensively cropped under irrigation, and is particularly useful in determining the irrigability of light-textured soils. It is also useful in determining the relative quantity of an exchangeable cation compared to the total exchangeable cations, such as the per cent of exchangeable sodium.

The irrigability of soils in the arid areas of the Northwest frequently depends upon the per cent of exchangeable sodium present, and the efficiency of available waters in the removal of excessive amounts of this ion by leaching. The investigation of these soil properties requires large numbers of cation-exchange capacity determinations, and it is necessary that such analyses should be done rapidly with a reasonable degree of accuracy.

In earlier work in this laboratory, the use of neutral, normal ammonium acetate in determining the total cation-exchange capacity was questioned on the grounds that the solubility of $CaCO_3$ in this reagent prevented the complete saturation of the exchange complex with ammonium ions, thus causing low results. Further, work by Hosking (1948) indicated that the maximum cation-exchange capacity should be determined at a pH of 9.0 rather than 7.0. The use of normal ammonium acetate buffered at pH 9.0 by adding ammonium hydroxide appeared to be a reasonable solution to both problems. In this case the NH_4 ion was replaced by leaching with normal KCL and determined by the Kjeldahl method.

Later, a Perkin-Elmer Model 52C flame photometer was obtained for the laboratory. Dr. C. A. Bower of the U.S. Salinity Laboratory advised that normal sodium acetate at a pH of 8.5 would meet our requirements and would permit the use of the flame photometer to speed up the determinations. This method was published later (Bower, Reitemeier, and Fireman, 1952).

The sodium acetate method as used in our laboratory was as follows:

Ten grams of soil (dry basis) were leached five times with 50 ml. portions of normal sodium acetate to saturate the soil with sodium ions. The excess sodium acetate was removed by leaching three times with 50 ml. portions of ethanol. The soil was then leached five times with 50 ml. portions of normal ammonium acetate at pH 9, and the leachate was evaporated to dryness to remove the ammonium salts. The solution was made up to 250 ml. after 2.5 me. of lithium nitrate were added. The sodium was determined on the flame photometer and reported in me./100 g. of soil.

The use of this method presented two new problems. First, a question arose as to the efficiency of sodium ions in replacing exchangeable potassium in soils thought to contain montmorillonitic clays. Second, the slow evaporation of the extracts used to remove the ammonium acetate rendered laboratory space and equipment unusable for other work. A solution to the latter problem appeared possible by substituting a normal solution of ammonium carbonate as recommended by Puri (1949) for the ammonium acetate. The ammonium carbonate can be easily removed by boiling and is effective in suppressing the solubility of $CaCO_3$.

Since the replacement efficiency of both sodium acetate and ammonium carbonate was in doubt, an investigation was made, using 14 calcareous soil samples ranging in texture from sandy loams to silt loams. The sodium acetate method was compared with the ammonium acetate method as described earlier, except that in the latter case, the soil, after rinsing with ethanol, was transferred directly to a Kjeldahl flask to determine the exchangeable ammonia. Another set of the same soil samples was treated with normal ammonium carbonate in the same manner as the ammonium acetate. The results are shown in Table 1.

Statistical analyses of these data show that both sodium acetate and amonium carbonate methods give higher cation-exchange capacities than ammonium acetate at pH 9. Therefore, if the ammonium acetate reagent is acceptable in replacing power and ability to be absorbed, the other two reagents must also be acceptable. For this reason, this laboratory now uses ammonium carbonate to replace sodium ions from soils saturated with sodium through leaching with sodium acetate.

The ability of sodium acetate to replace "fixed" potassium in soils high in exchangeable potassium still was unknown. It had been generally assumed that ammonium ions were superior to sodium ions in this respect. If this assumption were correct, it appeared evident that the potassium not replaced by sodium would be replaced by ammonium ions and appear in the ammonium carbonate leachate. A series of 12 soil samples ranging from high to low in exchangeable potassium were saturated with sodium, rinsed with ethanol, and leached with ammonium carbonate. The resulting leachate was analyzed for both exchangeable sodium and potassium. These results are shown in Table 2 in comparison with the results obtained at an earlier date where only sodium was determined. Thus, all laboratory errors are included in the data.

The statistical test of the significance of the difference of the means as shown in Table 2 clearly indicates that sodium acetate does not replace all of the exchangeable potassium. Thus, for maximum accuracy in determining the cation-exchange capacity of soils high in exchangeable potassium, the ammonium carbonate leachate should be analyzed for both sodium and potassium. Where a flame photometer is available this requires very little extra time.

Shortly after the normal sodium acetate and ammonium carbonate reagents were adapted by this laboratory for the determination of cation-exchange capacities of soils, the procedure was used on some noncalcareous soils from the

TABLE 1. Cation-Exchange Capacities of Calcareous Soils in Milliequivalents per 100 Grams as Determined by Three Methods

	Method Used		
Sample No.	N NH_4Ac. at pH 9	N Na Ac. at pH 8.5	N $(NH_4)_2CO_3$ at pH 8.2
1	20.0	21.7	21.0
2	17.8	19.3	17.6
3	12.5	13.9	13.3
4	7.9	8.1	7.9
5	17.6	18.7	17.7
6	18.0	18.2	18.8
7	9.9	10.7	10.6
8	12.2	13.4	12.7
9	15.4	15.7	15.5
10	8.1	8.4	8.0
11	7.9	8.6	7.8
12	14.6	15.5	14.6
13	15.4	15.5	15.8
14	15.9	17.8	16.7
Mean	13.80	14.68	14.14
t (compared to NH_4Ac)		5.47	3.04
L.S.D. of methods at 5-per-cent level		0.35	0.24
L.S.D. of methods at 1-per-cent level		0.48	0.34

high-rainfall area of western Washington and western Oregon. These are well-drained soils. They are gravelly, but since gravels over 2 mm. were screened out of the samples, gravel corrections were not made on the data reported in Table 3. The results from the sodium acetate method appeared to be unreasonably high for the textures involved. As a check, the soils were saturated with ammonium ions from normal ammonium carbonate, and the exchangeable ammonium ions in turn were determined by the Kjeldahl procedure. These results were even higher than those obtained by the sodium acetate method. Finally, the exchangeable cations were determined by the NH_4Ac method and totaled to find the cation-exchange capacities. These results are summarized in Table 3.

The data in Table 3 show that both the sodium acetate and ammonium carbonate reagents give high and erratic results when compared with the sum of the exchangeable cations. This observation is substantiated statistically by the "t" test. The cation-exchange capacity of these same soils was determined by using Brown's (1943) semiquantitative method. A comparison of these results

TABLE 2. THE EFFICIENCY OF SODIUM ACETATE IN THE REPLACEMENT OF EXCHANGEABLE POTASSIUM

Sample No.	Exchangeable K in me./100 g.[1]	C.E. Capacity in me./100 g.[2]	
		Na only	Na + K
1	7.0	12.0	13.5
2	4.4	12.9	14.0
3	1.6	8.6	8.7
4	4.4	20.1	21.9
5	3.5	22.2	25.8
6	1.9	24.1	25.5
7	1.0	20.1	21.1
8	0.5	16.6	17.4
9	0.5	17.6	18.2
10	0.9	29.4	31.5
11	0.5	16.8	15.7
12	0.3	9.0	8.9
Mean		17.45	18.52
t		3.12	
L.S.D. of method at 1-per-cent level		1.07	

[1] Replaced by NH_4Ac method.

[2] Replaced by NaAc and $(NH_4)_2CO_3$ method.

TABLE 3. CATION-EXCHANGE CAPACITY IRREGULARITIES WITH NONCALCAREOUS SOILS HIGH IN ORGANIC MATTER

Sample No.	Organic matter (Per cent)	Texture of fines[1]	pH		Exchangeable Cations in me./100 g. of Soil						C.E. Capacity in me./100 g. of Soil by		
			Sat.	1-5 Dilution	Ca	Mg	Na	K	H	NH_4	Sodium acetate	Ammonium carbonate	Sum of cations
1	3.34	C.S.L.	5.98	6.26	0.58	0.24	0.06	0.54	1.13	0.52	10.06	18.12	3.07
2	3.63	C.S.L.	6.10	6.20	1.33	0.29	0.02	0.28	1.40	0.53	10.86	19.62	3.85
3	[2]	L.C.S.	6.56	6.50	0.85	0.30	0.03	0.30	0.46	0.24	6.53	9.88	2.18
4	3.33	L.S. to S.L.	5.90	6.10	1.15	0.29	0.05	0.30	0.00	0.85	9.47	15.15	2.64
5	[2]	L.S.	6.18	6.38	1.27	0.18	0.07	0.29	0.59	0.26	7.01	10.35	2.66
6	4.29	F.S.L.	5.96	6.14	1.19	0.18	0.08	0.37	0.79	0.62	15.77	31.27	3.23
7	5.07	S.L.	5.62	5.92	0.27	0.16	0.09	0.25	0.65	0.61	14.58	28.57	2.03
Mean											10.61	18.99	2.81
t (compared to the sum of the cations)											7.88	5.19	
L.S.D. of methods at 1-per-cent level											3.67	11.58	

[1] Symbols used are: C—coarse; S—sandy; L—loam; F—fine.

[2] Subsoil samples.

with the sum of the exchangeable cations is shown in Table 4. As a result, this laboratory has restricted the use of the sodium acetate method to calcareous soils, or to soils with a pH value above 7.

TABLE 4. A COMPARISON OF CATION-EXCHANGE CAPACITY BY BROWN'S METHOD AND THE SUMS OF THE EXCHANGEABLE CATIONS

Sample No.	Cation Exchange Capacity in me./100 g. Brown's method	Cation Exchange Capacity in me./100 g. Sum of cations method
1	3.3	3.07
2	4.0	3.85
3	1.6	2.18
4	1.8	2.64
5	2.2	2.66
6	3.9	3.23
7	4.0	2.03

Summary

Data have been presented to show that a normal solution of sodium acetate can replace the exchangeable cations and saturate the cation-exchange capacity with sodium in most calcareous soils. It is not reliably effective in replacing what appears to be "fixed" exchangeable potassium. In the latter case *both* sodium and potassium must be determined on the final leachate obtained by leaching a sodium-saturated soil with an ammonium salt solution.

Ammonium carbonate appears to be as effective as ammonium acetate in replacing exchangeable cations, and can be used advantageously with sodium acetate in the determination of the total cation-exchange capacity.

These reagents are not suitable for the determination of the cation-exchange capacity of certain noncalcareous soils, since the results as shown, tend to be high and erratic. The use of the sum of the exchangeable cations, when determined, for the cation-exchange capacity of such soils is acceptable.

Literature Cited

Bower, C. A., R. F. Reitemeier, and F. Fireman. 1952. Exchangeable cation analysis of saline and alkali soils. Soil Sci., 73:251-263.

Brown, Irvin C. 1943. A rapid method of determining exchangeable hydrogen and total exchangeable bases in soils. Soil Sci., 56:353-357.

Hosking, J. S. 1948. The cation exchange capacity of soils and soil colloids; 1. Variation with hydrogen ion concentration. Jour. Council Sci. Ind. Research, 21: 21-37.

Puri, A. N. 1949. Soils, their physics and chemistry, Reinbold Publishing Corp., New York. xv + 550 pp. (see p. 79).

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