A Simple Method for Estimating Cation Exchange Capacity Across a Wide Range of Soils

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ABSTRACT

Cation exchange capacity (CEC) is an important soil characteristic. The $BaCl_2$-compulsive exchange method is the recommended method for measuring the effective CEC (ECEC) of a soil at its native pH and solution ionic strength. However, this method is also a very time-consuming and expensive, and generates a hazardous waste ($BaCl_2.2H_2O$). As a result, soil testing laboratories do not usually measure the effective CEC, but rather estimate it from standard agronomic soil test results (summation method). The latter method is known to result in inaccurate estimates for calcareous soils. The objective of the present study was to evaluate single and double consecutive extractions with 0.01 *M* $SrCl_2$ (1:10 ratio and 5 min shaking time) for their ability to estimate ECEC. Fifty New York agricultural soils were analyzed using the $BaCl_2$-compulsive exchange method, and results were compared to those obtained with agronomic soil test summation methods (both Morgan and Mehlich-3) and the single and double extractions with 0.01 *M* $SrCl_2$. The soils ranged in pH from 5.1-8.4, with an organic matter level from 11-98 g kg^{-1}. Texture varied from sand to clay. The CEC_{sum} estimates based on Mehlich 3 or Morgan greatly overestimated the ECEC, mostly (but not exclusively) due to dissolution of calcium carbonate. The single extraction with 0.01 *M* $SrCl_2$ correlated well with the compulsive exchange method across all soils (slope=1.04, r^2=0.85, n=50). This method resulted in more accurate estimates of cation saturation ratios as well. A double extraction did not add to the accuracy of the prediction. We conclude a single 0.01 *M* $SrCl_2$ extraction is a simple and inexpensive method of estimating ECEC and nutrient saturation levels.

INTRODUCTION

- The $BaCl_2$-compulsive exchange method is the recommended method for measuring the effective CEC (ECEC) of a soil, but this method is a very time-consuming and expensive, and generates a hazardous waste ($BaCl_2.2H_2O$).
- Soil testing laboratories do not usually measure the ECEC, but rather estimate it from standard agronomic soil test results (summation method).
- The summation method is known to result in inaccurate estimates for calcareous soils.
- The objectives of the present study were to (1) evaluate single and double consecutive extractions with 0.01 *M* $SrCl_2$ for their ability to estimate ECEC, (2) assess the accuracy of ECEC with summation of all cations versus Ca, Mg and K only, and (3) compare the accuracy of the summation method in determining base saturation ratios for Ca, Mg and K.

MATERIALS AND METHODS

- Fifty New York agricultural soils were used for this study.
- The soils ranged in pH from 5.1-8.4, with an organic matter level from 11-98 g kg^{-1}. Texture varied from sand to clay (Table 1).

MATERIALS AND METHODS

- Soils were analyzed for effective CEC using the $BaCl_2$ compulsive exchange methodology.
- The results were compared to those obtained with agronomic soil test summation methods (both Morgan and Mehlich-3 soil test methodologies) and the single and double extractions with 0.01 *M* $SrCl_2$.
- The shaking time with 0.01 *M* $SrCl_2$ was 5 minutes.
- Soil:solution was maintained at 1:10 (2 g soil and 20 mL 0.01 *M* $SrCl_2$).
- Samples were centrifuged for 10 minutes at 1800 g.
- All solutions were analyzed for non-acid cations using inductively coupled plasma spectrometry.

Table 1. List of soil samples with their pH and organic matter content.

S.N.	Name	Series	%OM	pH
1	Chenango	Chenango Loamy-Skeletal, Mixed, Superactive, Mesic Typic Dystrudepts	2.7	5.1
2	Volusia	Volusia Fine-Loamy, Mixed, Active, Mesic Aeric Fragiaquepts	2.7	5.2
3	Bath	Bath Coarse-Loamy, Mixed, Active, Mesic Typic Fragiudepts	3.7	5.8
4	Madalin	Madalin Fine, Illitic, Mesic Mollic Endoaqualfs	3.2	5.9
5	Braceville	Braceville Coarse-Loamy, Mixed, Active, Mesic Typic Fragiudepts	2.9	6.0
6	Ovid	Ovid Fine-Loamy, Mixed, Active, Mesic Aeric Endoaqualfs	1.8	6.1
7	Rhinebeck	Rhinebeck Fine, Illitic, Mesic Aeric Endoaqualfs	1.5	6.3
8	Madrid	Madrid Coarse-Loamy, Mixed, Active, Mesic Haplic Glossudalfs	2.3	6.3
9	Lordstown	Lordstown Coarse-Loamy, Mixed, Active, Mesic Typic Dystrudepts	4.4	6.3
10	Volusia	Volusia Fine-Loamy, Mixed, Active, Mesic Aeric Fragiaquepts	3.5	6.4
11	Trout River	Trout River Sandy-Skeletal, Mixed, Frigid Entic Haplorthods	5.5	6.4
12	Hamlin	Hamlin Coarse-Silty, Mixed, Active, Mesic Dystric Fluventic Eutrudepts	2.8	6.5
13	Malone	Malone Coarse-Loamy, Mixed, Active, Nonacid, Frigid Aeric Epiaquepts	3.7	6.6
14	Niagara	Niagara Fine-Silty, Mixed, Active, Mesic Aeric Endoaqualfs	1.5	6.6
15	Mardin	Mardin Coarse-Loamy, Mixed, Active, Mesic Typic Fragiudepts	8.6	6.6
16	Bath	Bath Coarse-Loamy, Mixed, Active, Mesic Typic Fragiudepts	3.1	6.8
17	Arkport	Arkport Coarse-Loamy, Mixed, Active, Mesic Lamellic Hapludalfs	1.1	6.8
18	Ontario	Ontario Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	1.8	6.9
19	Colonie	Colonie Mixed, Mesic Lamellic Udipsamments	1.6	7.0
20	Lima	Lima Fine-Loamy, Mixed, Active, Mesic Oxyaquic Hapludalfs	5.1	7.0
21	Adjidaumo	Adjidaumo Fine, Mixed, Active, Nonacid, Frigid Mollic Endoaquepts	2.9	7.1
22	lupton	Lupton Euic, Frigid Typic Haplosaprists	9.8	7.1
23	Munuscong	Munuscong Coarse-Loamy Over Clayey, Nonacid, Frigid Mollic Epiaquepts	5.9	7.1
24	Hogansburg	Hogansburg Coarse-Loamy, Mixed, Semiactive, Frigid Aquic Eutrudepts	3.6	7.2
25	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	5.0	7.2
26	Hogansburg	Hogansburg Coarse-Loamy, Mixed, Semiactive, Frigid Aquic Eutrudepts	4.4	7.3
27	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	1.1	7.3
28	Mardin	Mardin Coarse-Loamy, Mixed, Active, Mesic Typic Fragiudepts	2.6	7.4
29	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	3.8	7.4
30	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	2.3	7.4
31	Ontario	Ontario Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	2.9	7.5
32	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	4.5	7.5
33	Hogansburg	Hogansburg Coarse-Loamy, Mixed, Semiactive, Frigid Aquic Eutrudepts	5.3	7.5
34	Hogansburg	Hogansburg Coarse-Loamy, Mixed, Semiactive, Frigid Aquic Eutrudepts	4.1	7.5
35	Ontario	Ontario Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	2.5	7.5
36	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	4.4	7.5
37	Hudson	Hudson Fine, Illitic, Mesic Glossaquic Hapludalfs	2.2	7.5
38	Appleton	Appleton Fine-Loamy, Mixed, Active, Mesic Aeric Endoaqualfs	1.8	7.6
39	Rhinebeck	Rhinebeck Fine, Illitic, Mesic Aeric Endoaqualfs	3.8	7.6
40	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	4.8	7.6
41	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	2.9	7.6
42	Appleton	Appleton Fine-Loamy, Mixed, Active, Mesic Aeric Endoaqualfs	4.9	7.6
43	Hudson	Hudson Fine, Illitic, Mesic Glossaquic Hapludalfs	2.1	7.6
44	Ontario	Ontario Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	2.1	7.7
45	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	4.3	7.9
46	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	4.2	8.0
47	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	3.2	8.2
48	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	2.4	8.2
49	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	2.2	8.3
50	Honeoye	Honeoye Fine-Loamy, Mixed, Active, Mesic Glossic Hapludalfs	1.9	8.4

RESULTS

- The CEC_{sum} estimates based on Mehlich 3 or Morgan greatly overestimated the ECEC for high pH soils (Figure 1).
- This results in less accurate predictions of K, Ca, and Mg saturation for high pH soils (Table 2).
- The single extraction with 0.01 *M* $SrCl_2$ correlated well with the compulsive exchange method across all soils (Figure 1).
- A double extraction with 0.01 *M* $SrCl_2$ did not add to the accuracy of the prediction (Figure 1).
- Summations of all cations did not improve ECEC predictions over the use of K, Ca, and Mg only.

Table 2. Linear regression equations of $SrCl_2$ determined K, Ca, and Mg saturation and saturation estimates derived from Morgan or Mehlich-3 soil test results.

Dependent parameter	r^2	RMSE	Intercept (a)			Slope		
			a	SE_a	Prob. a=0	b	SE_b	Prob. b=1.0
Morgan K saturation	0.95	0.458	0.257	0.085	0.004	0.757	0.025	<0.0001
Mehlich 3 K saturation	0.81	0.901	-0.060	0.218	0.009	1.016	0.071	<0.0001
Morgan Ca saturation	0.86	2.423	5.973	4.378	0.179	0.919	0.052	<0.0001
Mehlich 3 Ca saturation	0.72	3.473	14.652	6.088	0.020	0.841	0.075	<0.0001
Morgan Mg saturation	0.83	2.435	-0.310	1.064	0.772	1.115	0.072	<0.0001
Mehlich 3 Mg saturation	0.71	3.187	-0.093	1.473	0.950	1.012	0.092	<0.0001
Morgan K saturation								
Soil pH < 7.0	0.98	0.368	-0.105	0.122	0.399	0.784	0.024	<0.0001
Soil pH 7.0-7.5	0.92	0.392	0.198	0.140	0.176	0.881	0.063	<0.0001
Soil pH >7.5	0.75	0.463	0.487	0.177	0.019	0.695	0.115	<0.0001
Mehlich 3 K saturation								
Soil pH < 7.0	0.84	1.169	-1.408	0.509	0.014	1.269	0.134	<0.0001
Soil pH 7.0-7.5	0.87	0.500	-0.036	0.198	0.858	0.751	0.070	<0.0001
Soil pH >7.5	0.78	0.435	0.015	0.221	0.948	0.696	0.106	<0.0001
Morgan Ca saturation								
Soil pH < 7.0	0.89	2.332	-3.472	7.408	0.646	1.048	0.091	<0.0001
Soil pH 7.0-7.5	0.85	2.399	6.252	7.410	0.411	0.903	0.089	<0.0001
Soil pH >7.5	0.83	1.891	17.720	9.035	0.076	0.787	0.102	<0.0001
Mehlich 3 Ca aturation								
Soil pH < 7.0	0.68	3.890	1.773	13.094	0.894	0.996	0.164	<0.0001
Soil pH 7.0-7.5	0.73	3.241	22.829	8.399	0.015	0.731	0.105	<0.0001
Soil pH >7.5	0.65	2.699	32.210	11.360	0.016	0.651	0.134	<0.0005
Morgan Mg saturation								
Soil pH < 7.0	0.91	1.701	-3.960	1.569	0.023	1.280	0.097	<0.0001
Soil pH 7.0-7.5	0.79	2.811	-0.509	2.233	0.823	1.196	0.143	<0.0001
Soil pH >7.5	0.82	1.760	2.630	1.284	0.065	0.838	0.113	<0.0001
Mehlich 3 Mg saturation								
Soil pH < 7.0	0.80	2.536	-2.219	2.272	0.343	1.170	0.141	<0.0001
Soil pH 7.0-7.5	0.60	3.906	1.965	3.046	0.528	0.927	0.176	<0.0001
Soil pH >7.5	0.70	2.281	1.946	1.892	0.326	0.742	0.139	<0.0002

RESULTS

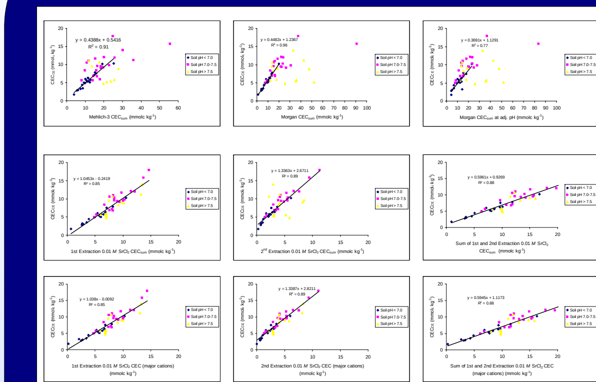

Figure 1. Regression of ECEC measured with the compulsive exchange method and ECEC estimated using Mehlich-3, Morgan or $SrCl_2$ extractable cations).

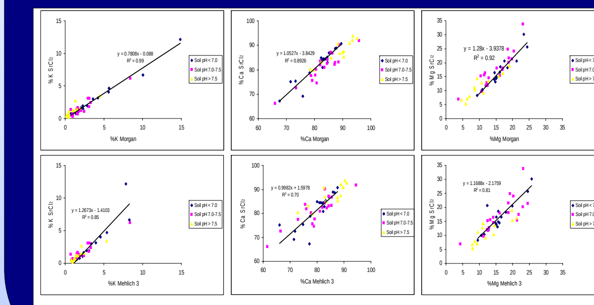

Figure 2. Regression of percentage base saturation determined with the 0.01 *M* $SrCl_2$ extraction method and summation methods based on Morgan and Mehlich-3 soil test data.

PRELIMINARY CONCLUSIONS

We conclude:

- Agronomic soil test data (Morgan or Mehlich-3) can be used to estimate ECEC when soil pH is less than 7 but conversion equations are needed to derive accurate predictions.
- A single 0.01 *M* $SrCl_2$ extraction is a simple and inexpensive method of estimating ECEC and nutrient saturation levels across all soil pH levels.
- Summation of 0.01 *M* $SrCl_2$ extractable Ca, Mg, and K is sufficient to derive accurate estimates of ECEC.

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