Estimating CEC from Cornell Soil Test Data

The cation exchange capacity (CEC) of a soil represents the total amount of exchangeable cations that a soil can retain and make available for plant uptake. The basics of CEC are explained in Cornell Agronomy Fact Sheet #22: Cation Exchange Capacity. This fact sheet explains: (1) how to measure CEC; (2) how to estimate CEC from a Cornell Nutrient Analysis Laboratory soil test report; and (2) the limitations of CEC estimation methods.

Measuring CEC

Original CEC measurements were determined using chemical extractants buffered at neutral or basic pH. One such test uses ammonium acetate buffered at pH 7. Another test uses barium chloride-triethanolamine buffered at pH 8.2. Because these tests are buffered at a high pH, the actual CEC of acidic soils is overestimated. For determination of the actual CEC of a soil, the Soil Science Society of America recommends using the "barium chloride compulsive exchange method" developed by Gillman and Sumpter in 1986. This method is time-consuming (i.e. expensive) and generates a hazardous waste ($BaCl_2.2H_2O$). As a result, not many soil testing laboratories measure the CEC of standard soil samples but rather *estimate* the CEC from regular soil test results. In other words, the CEC reported on soil test reports is typically the result of a *calculation* and not an actual measurements

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Estimates of the soil's CEC can be derived by summing the cations extracted using regular soil tests (Ca^{2+}, Mg^{2+}, and K^{+}) and accounting for the soil's exchangeable acidity (sum of H^{+}, Al^{3+}, Mn^{2+}, and Fe^{2+}). Because a regular soil test might not extract all of the exchangeable cations from the soil, a measure of the extraction efficiency is needed to estimate CEC.

Research by Lathwell and Peech at Cornell University (back in 1965) showed that for 200 New York soils the Morgan's solution extraction used by the Cornell Nutrient Analysis Laboratory (CNAL) had an extraction efficiency of about 90%. Thus, the sum of extractable Ca, Mg and K reported on a CNAL report needs to be divided by 0.90 for CEC determination.

To compute the CEC from Ca, Mg, and K results listed on the soil test report, the data must be converted to meq/100 g or $cmol_c$/kg by dividing the results in lbs/acre by the equivalent weight (molecular weight/valence) of the cation, and multiplying by 20. This means the Ca soil test in lbs/acre needs to be divided by 400, Mg should be divided by 240, and K needs to be divided by 780.

The sum of the acidic cations H^{+} and Al^{3+} is measured as exchange acidity (EA) reported in meq/100 g soil. CNAL measures EA using the barium chloride-triethanolamine method which determines the total acidity present in the soil between its actual pH and a pH of 8. The EA measures 100 percent of the acidity and, therefore, the EA does not need to be converted for CEC determination.

For example, the estimated CEC at pH 8 of a soil with 2240 lbs/acre Ca, 230 lbs/acre of Mg, 165 lbs/acre of K, and 11 meq/100 g exchange acidity is:

Estimated CEC at pH 8 =
[(Ca/400+Mg/240+K/780)/0.90]+EA =
[(2240/400+230/240+165/780)/0.90]+11
= 18.5 $cmol_c$/kg

As mentioned earlier, there is a relationship between the quantity of basic cations, acidic cations, and soil pH. This relationship for 200 New York soils using in the study by Lathwell and Peech is shown in Figure 1.

This figure shows that as the percent base saturation increases, the soil pH increases. This general relationship occurs in most mineral soils with similar soil mineralogy and climate but as the relationship between base saturation and pH depends on soil characteristics, the relationship shown in Figure 1 *should not be applied to non-New York soils* without confirmation that this

equation is appropriate. The results of the 200 New York soils indicate that at about pH 8 the soil is 100% base saturated (100% of the soil is saturated with bases) and at pH 7 the soil is about 80% base saturated.

pH	Base Saturation (fraction)
<4.5	0.00001
4.5	0.021
4.6	0.035
4.7	0.050
4.8	0.073
4.9	0.102
5.0	0.135
5.1	0.171
5.2	0.228
5.3	0.320
5.4	0.420
5.5	0.480
5.6	0.515
5.7	0.540
5.8	0.570
5.9	0.600
6.0	0.620
6.1	0.635
6.2	0.655
6.3	0.675
6.4	0.695
6.5	0.710
6.6	0.730
6.7	0.740
6.8	0.755
6.9	0.770
7.0	0.795
7.1	0.812
7.2	0.830
7.3	0.847
7.4	0.863
7.5	0.880
7.6	0.900
7.7	0.925
7.8	0.950
7.9	0.975
>7.9	1.000

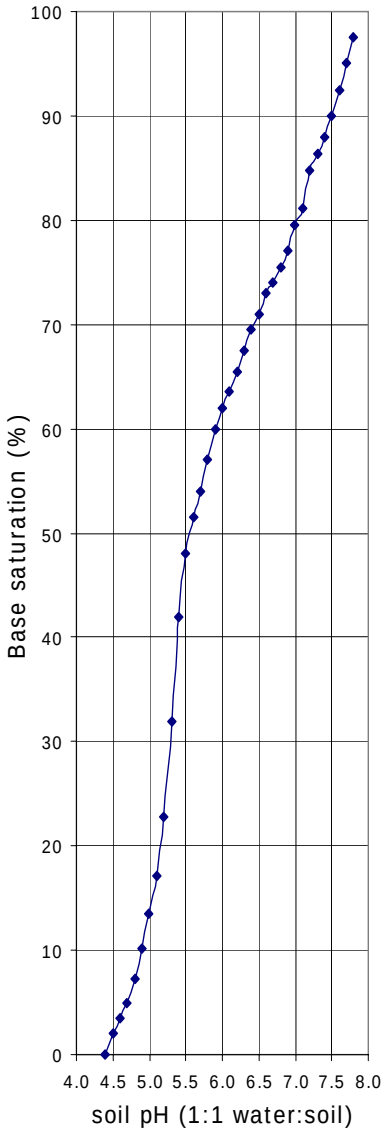

Figure 1: generalized relationship between the percent base saturation and soil pH (1:1) for 200 New York soils (Source: Lathwell and Peech, 1973).

The CEC is usually reported for a soil pH of 7.0. The above computation of the CEC was for pH 8.0 because the exchange acidity measurement was for 100 percent base saturation and pH 8.0. To estimate the CEC at pH 7 instead of pH 8, the base saturation of the soil (Figure 1) should be taken into account. Since the base saturation at pH 7 is 79.5%, the CEC at pH 7 is 79.5% of the CEC at pH 8.0. Thus, the estimated CEC at pH 7.0 for the soil in the example is:

Estimated CEC at pH 7.0 =
18.5 x 0.795 = 14.7 $cmol_c/kg$

If the soil pH is greater than pH 6.1, the exchange acidity is not determined by the Cornell Nutrient Analysis Laboratory but the CEC can still be estimated using the base saturation relationships in Figure 1. For example, a CNAL soil test reports 3880 lbs/acre of Ca, 110 lbs/acre of Mg and 135 lbs/acre of K and a soil pH of 6.5. The sum of the basic cations in cmol/kg (meq/100 g) is calculated first:

Sum of cations =
(3880/400+110/240+135/780)/0.90 =
11.5 $cmol_c/kg$

Figure 1 shows a base saturation of 71.0% at pH 6.5 so the estimated CEC at pH 7 is:

Estimated CEC at pH 7.0 =
11.5 x (0.795/0.710) = 12.9 $cmol_c/kg$

When Not to Trust Calculated CEC Values

- If the soil has residual carbonates (calcareous soils), the calculation will overestimate the CEC due to an overestimation of the amount of extractable Ca. If the soil pH is about 7.6 or above, residual carbonates are likely present and if lime has been recently applied, there may be some residual carbonates as well.

Additional Resources:

- Agronomy Fact Sheet #22: Cation Exchange Capacity: nmsp.css.cornell.edu/publications/factsheets.asp.

For more information

Cornell University Cooperative Extension

Nutrient Management Spear Program
http://nmsp.css.cornell.edu

Cornell Nutrient Analysis Laboratory
http://www.css.cornell.edu/soiltest

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