Cation Exchange Capacity (CEC)

Cations are positively charged ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), sodium (Na^{+}) hydrogen (H^{+}), aluminum (Al^{3+}), iron (Fe^{2+}), manganese (Mn^{2+}), zinc (Zn^{2+}) and copper (Cu^{2+}). The capacity of the soil to hold on to these cations called the cation exchange capacity (CEC). These cations are held by the negatively charged clay and organic matter particles in the soil through electrostatic forces (negative soil particles attract the positive cations). The cations on the CEC of the soil particles are easily exchangeable with other cations and as a result, they are plant available. Thus, the CEC of a soil represents the total amount of exchangeable cations that the soil can adsorb.

The cations used by plants in the largest amounts are calcium, magnesium, and potassium. In most soils within humid regions such as in New York, sodium is not present in sufficient quantities to occupy a significant amount of the CEC. However, in dry climates, sodium can occupy an important portion of the CEC. Other cations that can occupy cation exchange sites in New York soils are hydrogen, aluminum, iron and manganese. Cations such as zinc and copper are typically present in the soil in too low a concentration to occupy much of the CEC.

Why do soils have a CEC?

Soils have a CEC primarily because clay particles and organic matter in the soil tends to be negatively charged. New York soils have silicate clay minerals (clay minerals that contain silica). Each silicate clay particle is made up of individual layers or "sheets". If the mineral was pure silica and oxygen (silica-oxide more commonly referred to as quartz), the particle would not have any charge. However, clay minerals common in New York agricultural soils, contain aluminum as well as silica. They have a net negative charge because of the substitution of silica (Si^{4+}) by aluminum (Al^{3+}) in the mineral structure of the clay. This replacement of silica by aluminum in the clay mineral's structure is called isomorphous substitution, and the result is clays with negative surface charge.

Since the soil as a whole does not have electric charge, the negative charge of the clay particles is balanced by the positive charge of the cations in the soil. The negative charges associated with isomorphous substitution are considered permanent, that is, the charges do not change with pH changes.

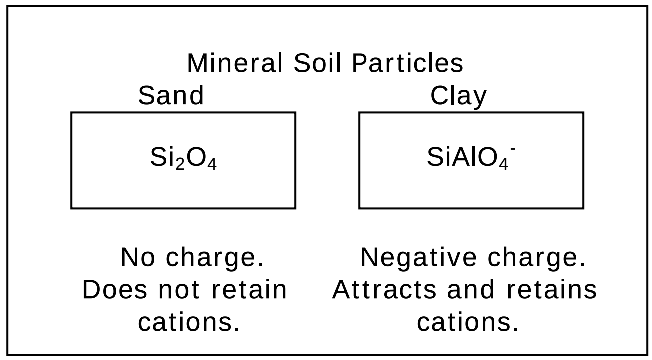

Figure 1: Substitution of silica by aluminum in soil clay particles causes clays to have a negative charge. Because of this negative charge, the soil can hold on to positively charged cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}).

Organic matter can have a 4 to 50 times higher CEC per given weight than clay. The source of negative charge in organic matter is different from that of clay minerals; the dissociation (separation into smaller units) of organic acids causes a net negative charge in soil organic matter, and again this negative charge is balanced by cations in the soil. Because organic acid dissociation depends on the soil pH, the CEC associated with soil organic matter is called pH-dependent CEC. This means that the actual CEC of the soil will depend on the pH of the soil. Given the same amount and type of organic matter, a neutral soil (pH ~7) will have a higher CEC than a soil with e.g. pH 5, or in other words, the CEC of a soil with pH-dependent charge will increase with an increase in pH.

Units

The CEC of a soil is expressed in $cmol_c/kg$ (centimol positive charge per kg of soil) or meq/100 g (milli-equivalents per 100 grams of soil). Both expressions are numerically identical (10 $cmol_c/kg$ = 10 meq/100 g).

Common CEC ranges in New York

Sandy soils low in organic matter have a very low CEC (less than 3 $cmol_c/kg$) while heavier clay soils or soils high in organic matter generally have a much higher CEC (greater than 20 $cmol_c/kg$). Table 1 gives an estimate of a typical CEC of soils of each of the five soil management groups in New York (see Agronomy Fact Sheet #19: Soil Management Groups, for more detailed descriptions of the five soil management groups).

Table 1: Estimated cation exchange capacity (CEC) of soils typical for New York State agricultural land (modified from: Cornell Field Crops and Soils Handbook, 1987).

SMG*	General Description	CEC ($cmol_c/kg$ soil)
1	Fine-textured soils developed from clayey lake sediments and medium- to fine-textured soils developed from lake sediments.	25
2	Medium- to fine-textured soils developed from calcareous glacial till, medium-textured to moderately fine-textured soils developed from slightly calcareous glacial till mixed with shale, and medium-textured soils developed in recent alluvium.	20
3	Moderately coarse textured soil developed from glacial outwash and recent alluvium and medium-textured acid soil developed on glacial till.	18
4	Coarse- to medium-textured soils formed from glacial till or glacial outwash.	16
5	Coarse- to very coarse-textured soils formed from gravelly or sandy glacial outwash or glacial lake beach ridges or deltas.	12

*SMG = soil management group.

For New York soils, it is better to *measure* the CEC rather than use the values reported in Table 1, as the CEC will change with soil pH (i.e. is pH dependent). Soil pH changes can be caused by natural processes, such as decomposition of organic matter and leaching of cations, but also by human actions such as application of acidifying nitrogen fertilizers and/or liming materials. Most laboratories approximate the CEC from regular soil test results. So, the CEC value listed on regular soil test report is the results of a *calculation*, not an actual measurement. See Agronomy Fact Sheet #23: Estimating CEC from Cornell Soil Test Data, for more details.

Implications

- The higher the CEC the more clay or organic matter present in the soil. This usually means that high CEC (clay) soils have a greater water holding capacity than low CEC (sandy) soils.
- Low CEC soils are more likely to develop potassium and magnesium (and other cation) deficiencies, while high CEC soils are less susceptible to leaching losses of these cations. So, for sandy soils, a large one-time addition of cations e.g. potassium can lead to large leaching losses (soil isn't able to hold on to the excess K). More frequent additions of smaller amounts are better.
- The lower the CEC, the faster the soil pH will decrease with time. So, sandy soils need to be limed more often than clay soils.
- The higher the CEC, the larger the quantity of lime that must be added to increase the soil pH; sandy soils need less lime than clay soils to increase the pH to desired levels.

Additional Resources

- Cornell University Agronomy Fact Sheet #5: Soil pH for Field Crops; #6: Lime Recommendations; and #19: Soil Management Groups; and #23: Estimating Cation Exchange Capacity from Cornell Soil Test Data: nmsp.css.cornell.edu/publications/factsheets.asp.
- Lime Guidelines for Field Crops in New York: nmsp.css.cornell.edu/publications/articles/extension/Limedoc2006.pdf.

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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