

# Cation Exchange Capacity

Cation Exchange Capacity (CEC) can be defined as follows:

1. **Cation** – the positively charged elements in the soil that are electrically attracted to the negatively charged sites on soil colloids (clay & humus). Examples of cations are  $Al^{+++}$ ,  $Ca^{++}$ ,  $Mg^{++}$ ,  $K^+$ ,  $NH_4^+$ ,  $Na^+$  &  $H^+$ .
2. **Exchange** – cations are held on the surface of negatively charge clay particles in a form that they can be exchanged with other cations. For example, a plant can send out two acid cations ( $2 \times H^+$ ) in exchange for a  $Ca^{++}$ , which is taken up into the plant.
3. **Capacity** – is simply defined as the sum of the total cations that a particular soil is capable of absorbing. This is a way of measuring the “volume”.

The cation exchange capacity (CEC) of a soil represents the total amount of negative charges available to attract positively charged ions (cations) in solution (soluble). On most soil tests CEC is expressed as milliequivalents of negative charge per 100 grams of soil (meq/100 g). The milliequivalents per 100 grams also represent the total amount of charge of cations in the soil. Milliequivalents (meq) is used instead of mass (pounds, tons, etc) because CEC represents the total charge involved.

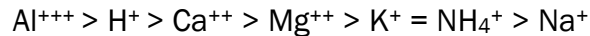
A good explanation of exactly how CEC is tested and calculated can be found in “*Soil Fertility & Fertilizers*” 5<sup>th</sup> edition, by Tisdale, Nelson, Beaton & Havlin, Macmillan Publishing Company, starting on page 80.

Acid Soils (pH <7.0)	Alkaline Soils (pH >7.0)
Mostly $Al^{+++}$ , $H^+$ , $Ca^{++}$ , $Mg^{++}$ & $K^+$	Mostly $Ca^{++}$ , $Mg^{++}$ , $K^+$ & $Na^+$
Small amounts of $Na^+$ & other bases	Small amounts of $Al^{+++}$ & other bases

The balance of cations commonly found on soil colloids is depends on the pH of the soil:

Cations are held to the colloid with different adsorption strengths; therefore, the ease with which cations can be replaced or exchanged with other cations varies. One way cations are “preferred” are by their respective charge (Al has 3 +’s, Ca has 2 +’s or K has 1 +), the higher the greater the strength of adsorption and the harder they are to “knock off”. Hydrogen is unique, it is so small but it carries a high charge for its “size”. Therefore, it ranks between  $Al^{+++}$  and  $Ca^{++}$  in adsorption strength. The adsorption strength for cations with similar charges (Ca & Mg) is determined by the size of the hydrated (attached water) cation. For example, calcium has 2 charges and a hydrated radius (size) of 0.96, whereas; magnesium also has 2 charges, but a hydrated radius of 1.08. Therefore, magnesium cannot get as “close” to the colloid because of the water present.

These two forces of strength of adsorption result in a “preference” of soil colloids for cations in the following order:



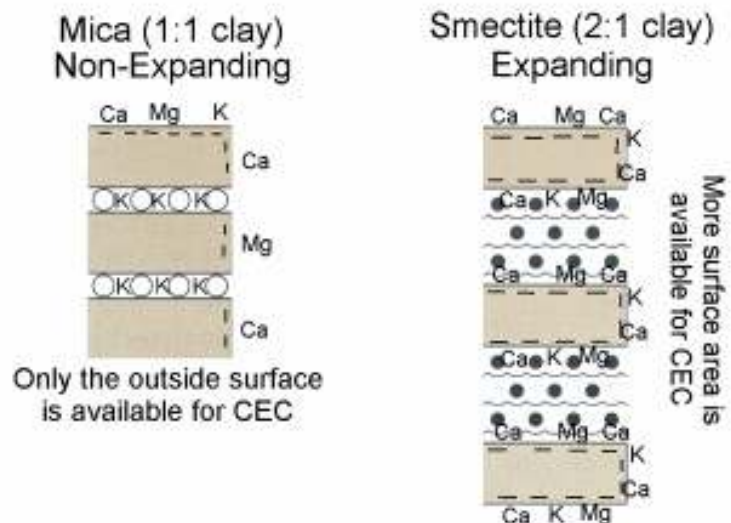
If you have been following this topic closely and work with soils in areas where there are large amounts of sodium (Na) in the water, or naturally present, you may ask why it is that the % of Na is so high. Good question.

The ratio of elements on the colloid is governed by several factors; however, the most important is the amount of free cations present. If there is a lot of calcium present, it will predominate the colloid over magnesium or potassium. However, in many agricultural areas there has been a constant supply of sodium added in the form of irrigation water, fertilizers, manure and accumulation of natural levels. On the other side of the equation, large amounts of calcium have been removed in crops and not replaced by soluble fertilizer sources, natural weathering or action of microbes. As calcium is removed and sodium accumulates, there is much more soluble sodium present (higher concentration) than calcium. Cation exchange capacity of soils is determined in the soil testing laboratory utilizing this same factor by adding ammonium ( $\text{NH}_4^+$ ) and then potassium ( $\text{K}^+$ ). The higher concentration replaces the others.

Soils vary in CEC, based on the amount and types of clay present. The following table shows the CEC of various soil types.

Sands (light colored)	3 – 5 meq/100 g
Sands (dark colored)	10 – 20 meq/100 g
Loam's	10 – 15 meq/100 g
Silt Loam's	15 – 25 meq/100 g
Clay & Clay Loam's	20 – 50 meq/100 g
Organic Soils (peat)	50 – 100 meq/100 g

Soil low in clay and humus has a low CEC, whereas soil high in clay and/or humus has a higher CEC. Soils that contain equal amounts of 1:1 clay in comparison to soils that contain 2:1 clay will be lower in CEC because 1:1 clay only holds cations on the outside of the clay particle. By this we can see the importance of clay type in determining CEC of soils.



## Base Saturation

The percentage of the total CEC of each mineral gives important information of the quality and productivity of soils. It is expressed by calculating the percentage of total CEC occupied by each cation. The following table illustrates an example:

PPM of Cations	Convert to meq/100 g by;	Divided into total CEC
100 ppm Ca	$(100 \times 2)/(40) = 5 \text{ meq/100 g}$	$5/15 \times 100 = 33.3\%$
30 ppm Mg	$(30 \times 2)/(24) = 2.5 \text{ meq/100 g}$	$2.5/15 \times 100 = 16.7\%$
78 ppm K	$(78 \times 2)/(78) = 2 \text{ meq/100 g}$	$2/15 \times 100 = 13.3\%$
23 ppm Na	$(23 \times 2)/(46) = 1 \text{ meq/100 g}$	$1/15 \times 100 = 6.7\%$

Total bases = 70% of total cation exchange capacity.

From the above example, one can determine that the soil is acidic because base exchange percentage is related to soil pH. Although this varies slightly with soil types, as a rule the above example would have a pH of approximately 6.2 – 6.4. Soils with a base saturation of over 90% usually mean that the pH is neutral or higher.

A spreadsheet is available that can calculate the cation exchange capacity, the base saturation and the % of other minerals (Zn, Fe, Mn, etc) on the colloid by knowing only the ppm of Ca, Mg, K, Na and pH.