Cation Exchange Capacity – Everything You Want to Know and Much More

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What is cation exchange capacity?

Cation exchange capacity, or CEC, refers to the quantity of negative charges in soil existing on the surfaces of clay and organic matter (see Figure 1). The negative charges attract positively charged ions, or cations, hence the name ‘cation exchange capacity’. Many essential plant nutrients exist in the soil as cations and are accumulated by the grass plant in this form. Examples are potassium (K^{+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), and ammonium (NH_4^{+}). Sodium (Na^{+}) which may cause severe problems in Coastal region soils irrigated with poor quality irrigation water also occurs as a cation. Hydrogen (H^{+}) and aluminum (Al^{+3}) are the other predominant cations occupying the CEC in soils. These ions are responsible for the detrimental effects on turfgrass health that occurs in acid soils. The superscript ($^{+}$) indicates how many positive charges the cation carries.

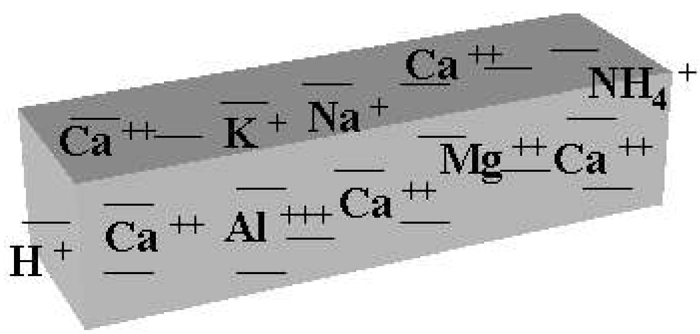

Figure 1. Schematic of a clay particle with negative charges on the surface attracting various cations.

Factors determining CEC

The primary factor determining CEC is the clay and organic matter content of the soil. Higher quantities of clay and organic matter beget higher CEC. Different types of clays have different CECs (discussed later).

Amounts of negative and positive charges are both expressed in milliequivalents. One milliequivalent of negative charge on a clay particle is neutralized by one milliequivalent of cation. A milliequivalent takes into account both the weight and the charge of the cation. To get an appreciation for this concept in practical terms consult Table 1 which lists the approximate amount of a cation in pounds per acre found in an acre of soil to a depth of 6 inches at 1 meq/100 g.

Table 1. Cation characteristics and amount of various cations in pounds per acre equal to 1 meq/100 g in one acre soil to a depth of 6 inches.

Cation	**Charge**	**Molecular Weight**	**Amount in 1 acre soil 6-inch deep at 1 meq cation/100g**
			pounds per acre
Aluminum	3^+	27	180
Calcium	2^+	40	400
Hydrogen	1^+	1	20
Magnesium	2^+	24	240
Potassium	1^+	39	780
Sodium	1^+	23	460

Organic matter has a CEC of about 150 milliequivalents per 100 grams (often abbreviated 150 meq/100 g). There are several types of clay minerals that occur in soils and their CECs differs. The predominant clay mineral in most Carolina soils is kaolinite which has a CEC of 5 meq/100 g. Other clay minerals, such as smectite and vermiculite, have in excess of 100 meq/100 g CEC, but only occur in limited amounts in some Carolina soils.

An average loamy sand soil in the Coastal Plain of the Carolinas will typically have a clay content of 10% and an organic matter content of 1%. The CEC will be expected to be about 2.0 meq/100 g soil; 1.5 meq/100 g from 1% of 150 meq/100 g for the organic matter and 0.5 meq/100 g from 10% of 5.0 meq/100 g for kaolinite clay.

What does CEC do for me?

Only a small percentage of the essential plant nutrient cations (K^+, Ca^{2+}, Mg^{2+}, and NH_4^+) will be 'loose' in the soil water and thus available for plant uptake. Thus the CEC is important because it provides a reservoir of nutrients to replenish those removed from the soil water by plant uptake. Similarly, cations in the soil water that are leached below the rootzone by excess rainfall or irrigation water are replaced by cations formerly bound to the CEC.

Not only does 'buffer capacity' exist for cation nutrients, but also for soil pH. The higher the CEC the more it takes to change soil pH. This principle applies to increasing pH with lime or high bicarbonate irrigation water as well as to decreasing pH with nitrogen fertilizers or elemental sulfur.

The CEC of a soil is a good indicator of the nutrient holding and buffer capacity of the soil, but in itself is not particularly useful for managing soil properties. However, the concept of base saturation, which is a function of CEC, can be used to manage soil properties and nutrient availability

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What is base saturation and what can I do with this information?

Base saturation refers to the fraction of the CEC that is occupied by the basic cations, K^+, Ca^{2+}, Mg^{2+}, and Na^+. Base saturation is used to manage soil Na^+ and can be utilized to determine soil Mg^{2+} availability. When Na^+ exceeds 15% of the CEC, water and air infiltration into the soil may be reduced and poor growing conditions may result. To overcome this problem Ca^{2+} is added to replace the Na^+ from the CEC. Sodium in the soil water is then be leached out of the rootzone by excess irrigation or rainfall. The amount of Ca^{2+} needed to replace the Na^+ is based on the amount of exchangeable Na^+ as well as Na^+ saturation.

Similarly, Mg^{2+} availability is based on both the total amount of Mg^{2+} and the Mg^{2+} saturation. As a general rule of thumb, Mg^{2+} saturation greater than 10% at soil Mg^{2+} between 60 and 120 pounds per acre is sufficient. If Mg^{2+} saturation is less than 10% Mg and soil Mg^{2+} is between 60 and 120 pounds per acre then additional Mg^{2+} is needed to provide sufficient Mg^{2+} availability. If soil Mg^{2+} is below 60 pounds per acre, additional Mg^{2+} is needed irrespective of Mg^{2+} saturation. No additional Mg^{2+} is needed if soil Mg^{2+} exceeds 120 pounds per acre.

How can CEC be modified?

In coarse native sands of the Sandhills, Coastal Plain, and Coastal regions, as well as sand-based golf greens and sports fields the CEC arises almost entirely from organic matter. To provide more nutrient holding capacity it is desirable to preserve and increase CEC when possible.

Reducing organic matter by core aerification and replacement with topdressing sand will obviously decrease CEC. Generally aerification decisions are based on reducing compaction and increasing water and air movement through the rootzone. Be aware that reducing organic matter in this way greatly decreases CEC, therefore, perform these operations only when needed.

Calcined clay, diatomaceous earth, and zeolite/clinoptilolite are sometimes added to sand-based fields to increase CEC. The CEC of these materials are variable but typical values are in the range of 25 meq/100 g for calcined clay, 50 meq/100g for diatomaceous earth, and 100 meq/100g for zeolite/clinoptilolite. Whether or not these amendments provide more advantages than peat or organic matter is still a question that needs to be answered.

Soil pH is a less obvious factor affecting CEC. Soils contain two sources of negative charge, permanent and variable. Permanent charge is located within the structure of the clay particles. Variable charge is located on the edges of clay and organic matter particles. A large proportion of the negative charge in Carolina soils is variable. The primary factor affecting the variable charge is pH. Increased pH increases CEC. Changing pH from 5.5 to 6.5 may double the CEC of a typical Carolina soil or sand-based field. A pH of 6.5 is the highest pH recommended for most grasses in most situations. Maintaining soil pH near this level provides near optimum CEC and phosphorus availability while providing acceptable conditions for micronutrient availability.

How is CEC measured and why is this important?

The direct measurement of CEC is costly. Therefore soil-testing laboratories estimate, rather than measure, CEC. Estimates are made by determining the extractable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) and estimating H^+ and Al^{+3} from soil and buffer pH measurements. Estimates will be erroneously high in two commonly occurring situations. Firstly, CEC will be overestimated if a soil is sampled shortly after a heavy fertilizer or gypsum application. This error arises because the cations that are in the soil solution are misrepresented as exchangeable. Secondly, extraction of high pH soils containing calcium carbonate (limestone) with an acid extracting agent, such as those commonly used in the Southeast, will also provide inflated CEC estimates. The acid extractant dissolves a portion of the limestone and considers the Ca^{2+} removed as exchangeable. Under these circumstances CEC estimates are inaccurate and best ignored.

Summary

Cation exchange capacity (CEC) is the amount of negative charge in soil that is available to bind positively charged ions (cations). Essential plant nutrients, K^+, Ca^{2+}, Mg^{2+}, and NH_4^+ and detrimental elements, Na^+, H^+, and Al^{+3} are cations. Cation exchange capacity buffers fluctuations in nutrient availability and soil pH. Clay and organic matter are the main sources of CEC. The CEC of most native soils in the Carolinas and sand-based sports fields is low because they are low in clay and organic matter. What little CEC exists in these soils is pH dependent, thus it is beneficial to maintain soil pH near 6.5 for optimum levels. Adding calcined clay, diatomaceous earth, or zeolite/clinoptilolite increases CEC, but the benefits of adding these materials in lieu of peat or organic matter maintenance are not well established. Cation exchange capacity is estimated and reported by most soil testing laboratories. Estimates are reasonably accurate unless the soil has been heavily fertilized or amended just prior to sampling or an acid extractant was used on a soil containing precipitated calcium carbonate. Base saturation, the quantity of CEC occupied by one or more of the basic cations, is useful for managing detrimental levels of soil Na^+ and Mg^{2+} availability.

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