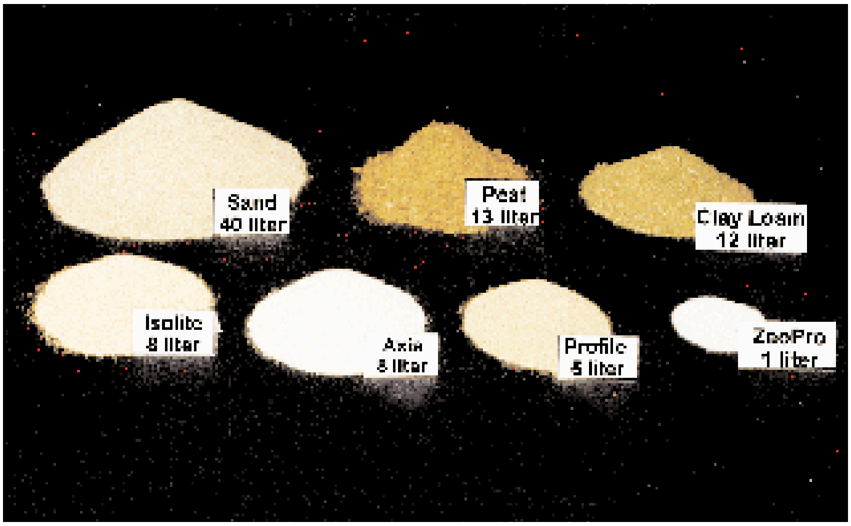
Cation exchange capacity affects greens’ turf growth

Sand holds nutrients poorly; properly tested amendments can help.

James W. Shaw and Richard D. Andrews

Cation exchange capacity (CEC) is one way to measure the capacity of a soil (or root zone) or soil amendment to hold key nutrients. Several important plant nutrients are present as positively charged ions in soil solution (including ammonium, potassium, calcium, magnesium and several trace elements), so a measurement of a root zone’s ability to exchange cations provides a reasonable understanding of the root zone’s ability to store these nutrients until taken up by plant roots.

More technically, the CEC is the number of moles of positive charges that can be exchanged onto negatively charged ion exchange sites in a unit mass or volume of soil under specified conditions. The unit of measure is expressed in milliequivalents per unit mass or unit volume. A milliequivalent (meq) is 1 milligram of hydrogen or the amount of any other ion that will combine with or displace it. Thus, a root-zone material with a CEC of 10 milliequivalents per 100 grams is capable



Adding cation exchange capacity is more effective with amendments that have higher CECs in smaller volumes. For example, 40 liters of sand has the same CEC (1,000 meq) as 13 liters of peat or 1 liter of ZeoPro.

Photo courtesy of Richard Andrews

Key points

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- Cation exchange capacity (CEC) is an important measure of the ability of soil and root-zone materials to hold certain nutrients.
- No standard methods have been adopted by soils labs to measure CEC.
- When judging materials of significantly different densities, compare the CEC of amendments and root zones on a per-volume basis, not on a mass basis.
- It is important to improve the CEC of sand root zones to provide more-uniform feeding of turf and prevent excessive loss of fertilizers to the environment.

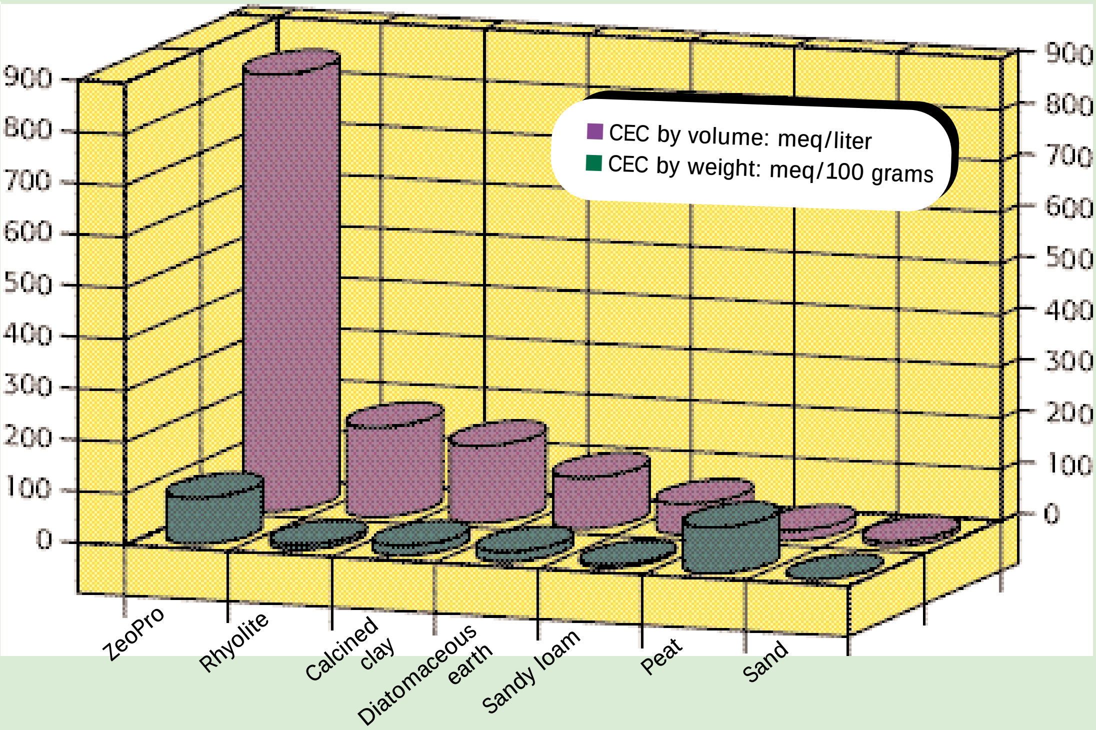
of adsorbing and holding:

- 10 milligrams of hydrogen in every 100 grams
- 140 milligrams of ammonium-nitrogen (NH_4^+), which has an equivalent weight of 14 milligrams per milliequivalent
- 200 milligrams of calcium (Ca^{+2}), which has a double positive charge and thus an equivalent weight of 40 divided by 2, or 20 milligrams per milliequivalent (mole weight divided by charge)

Soils' ability to exchange ions has been known a very long time, most notably since the rise of soil science in the mid-19th century, when it was expressed as "base exchange." Measuring this soil property has been difficult to standardize because of the tremendous variation in the mineral character of different soils. Many different methods have evolved in labs and academic institutions to meet local needs. Even today, no standardized method has emerged to measure CEC in root zones.

This lack of a standard becomes troublesome as new materials are used to improve root zones. Although sand is the predominant root-zone material used in construction of golf greens (primarily to ensure drainage and playing surface uniformity), it has virtually zero CEC and therefore has little ability to hold nutrients. Many amendments promise to correct the problem. Increased CEC in sand-based root zones would improve nutrient use efficiency, reduce nutrient leaching and

CECs compared



When comparing CECs, it's important to consider the volume rather than the weight of the amendment.

CEC units conversion

Use this formula to convert CEC from mass units to volume units:

CEC (by weight) of sand = 2 milliequivalents per 100 grams

Bulk density of sand = 100 pounds per cubic foot
= 1.6 grams per milliliter

CEC (by volume):

2 milliequivalents/100 grams × 1.6 grams/milliliter
× 1,000 milliliter/liter = 32 milliequivalents per liter

make plant environmental systems more robust and better able to deal with stress.

CEC is usually reported in milliequivalents per unit of mass, frequently per 100 grams. But how much nutrient-holding capacity do you need per 100 grams or pounds of soil?

How much nutrient-holding capacity per 100 grams do you need for 1,000 cubic feet of actual root zone? That is the real question. Good-quality agricultural soils will have a CEC of 15-20 milliequivalents per 100 grams and a typical bulk density of 1.28 grams per milliliter (80 pounds per cubic foot), for a volumetric CEC of 192-256 milliequivalents per liter.

Compare this with a golf green built on a sand base that has a CEC of about 1-2 milliequivalents per 100 grams and density of 1.6 grams per milliliter (100 pounds per cubic foot), or 16-32 milliequivalents per liter, and you suddenly understand why greens must be so carefully and frequently fed with soluble fertilizers. Applied soluble nutrients, if not taken up by the turf immediately, simply stream through sand as leachate.

Even adding a significant amount of peat, say 10 percent by volume, will only raise the CEC by about 12 milliequivalents per liter. To reach a desirable level of CEC with peat alone would result in a green that is not firm, drains poorly and is easily damaged. Organic materials can help, but what is needed is a material with sand's drainage and porosity, plus a high volumetric CEC.

Differences between CEC on a weight basis vs. a volume basis can be significant for various root-zone materials because materials used in golf course root zones can have major differences in density. Sand has about 20 times the bulk density of a typical peat. Sand is about twice as dense as a zeoponic material, about three times the density of porous ceramics and four times denser than diatomaceous earth.

A typical peat with a CEC of 100-150 milliequivalents per 100 grams and a bulk density of 0.08 grams per milliliter (5 pounds per cubic foot) will have a CEC of only 80-120 milliequivalents per liter, whereas a zeoponic material with a CEC of 100-110 milliequivalents per 100 grams and a density of 0.80 grams per milliliter (50 pounds per cubic foot) will have a CEC of 800-880 milliequivalents per liter. In other words, it would take approximately eight to 10 times the volume of peat, about five times the volume of a calcined clay or about eight times the volume of a diatomaceous earth to provide the same improvement in CEC as a zeoponic soil amendment.

For a golf green, a good target CEC may be 80-160 milliequivalents per liter (or 5-10 milliequivalents per 100 grams). Simple calculations can determine the effect of adding various amendments to raise CEC.

Sample blend CEC calculation

This sample calculation illustrates the effect on cation exchange capacity from blending CEC-enhancing materials to a root zone.

Percent volume	CEC (meq/100 grams)	Density (grams/milliliter)
80 percent sand	2	1.6
10 percent peat	150	0.08
10 percent ZeoPro	100	0.80

CEC by volume total

0.80 × (2/100 × 1.6 × 1,000)
\+ 0.10 × (150/100 × 0.80 × 1,000)
\+ 0.10 × (100/100 × 0.80 × 1,000)

= 25.6 milliequivalents/liter for sand
\+ 12.0 milliequivalents/liter for peat
\+ 80 milliequivalents/liter for ZeoPro
= 118 milliequivalents/liter total CEC by volume

CEC by weight = 8.6 meq/100 grams

What are the benefits of CEC?

A higher CEC in the root zone will provide temporary storage of key nutrients until the plant needs them and retrieves them from the soil. The result will be more-even feeding of cation-form nutrients and less feast-or-famine stress on turf between fertilizations. Because feeding becomes more uniform and fewer nutrients are lost to leaching, fewer total nutrients are required. This is both an environmental and management benefit.

How is CEC measured?

CEC is measured many different ways with many different results, some totally inappropriate for materials used in golf greens. Conceptually, CEC is quite easy to measure. In a common method, the analyst extracts all cations from a known mass of material, analyzes for each extracted cation and sums the chemical equivalents of each extracted cation. A better method is to completely load a single cation onto all ion exchange sites and then extract it and measure the amount of the added cation. In practice, there are many variables that influence how cations exchange with different materials. These differences make finding one test that works in all cases difficult.

Various "index or substituting" cations are typically used. The index cation is loaded onto a sample of a known weight by exposing the sample to a high concentration of the cation. The sample is then rinsed (commonly with an alcohol) to get rid of any of the index cation not attached or exchanged onto the sample. Finally, a second index cation is then used to exchange off all of the first index cation. All of the first index cation loaded onto the sample is recovered and quantitatively measured. This can then provide the cation exchange capacity for the known mass of the sample. Many laboratories use ammonium ions for the first saturation and potassium for the second.

Variables such as pH, particle size, particle structure, temperature, pressure, type of material, time of contact and the number of successive extractions can all affect the CEC measurement.

For example, although both clays and zeolites are alumino-silicate materials, they are very dissimilar in structure. Many clays are phyllosilicates, which are layered molecular structures that can expand and contract between layers, allowing virtually all cations to exchange. Clays also easily break down into tiny particles or soil colloids. In contrast, zeolite and zeoponic materials have three-dimensional rigid crystalline structures that have much greater control over molecule movement. This means special care must be taken in testing to provide enough time for the ion exchange to occur.

Zeolites also have different cation selectivities. In other words, zeolites have greater or lesser affinities for different cations. That means that the cation loaded onto the zeolite and the cation that unloads the loaded zeolite will have different abilities to replace different cations. The internal pore sizes of certain zeolites can exclude certain cations from portions of the exchange sites as a result of ionic size constraints. For example, under normal soil temperatures, only a fraction of the exchange sites of clinoptilolite, a zeolite used in zeoponic greens amendment materials, can be occupied by calcium or magnesium. Saturating or extracting solutions with calcium or magnesium in CEC tests should not be used when zeolite is in the sample.

Some CEC tests use one ion replacement step instead of two. When the index cation ammonium is used to remove the existing cations, these removed cations are then analyzed directly, and the amount of removed cations are then summed. Some argue this so-called sum of cations method can give a proxy value for the CEC. However, when a zeoponic material such as ZeoPro is tested in this manner, the pre-exchanged ammonium ions on the zeoponic material will not be measured. The result is a very low and incorrect CEC value.

The bottom line in dealing with CEC results from labs is you must know what test was used and whether that test is appropriate for the material or materials tested. Many well-known soil labs do not run appropriate test procedures for measuring the CEC of zeolitic materials. As with tissue and general soil samples, you should never directly compare results from different labs. Labs using different procedures probably will not give comparable results. Within a given lab, results may be correct in a relative sense between materials, but at the same time they may be very wrong on an absolute scale. ■

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