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Cations (cat'-eye-ons) and You

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I believe that one of the most important things you can know if you are trying to be the best organic gardener, farmer or orchardist, is the principle that everything depends on the soil. Cultural practices are important, the quality of your seeds and stock, the availability of water and good weather are all critical, but knowing your soil and caring for it make all these other aspects of growing much easier. We have been hearing a lot lately about composting and compost tea as important elements in the care of soil and the microbial life in it. We know that harsh herbicides and pesticides and overtilling and compaction harm this soil life and consequently diminish the physical and chemical quality of the soil and its ability to make nutrients available to plants. But there is another important concept to be understood when talking about the availability of plant nutrients. That is the Cation Exchange Capacity or CEC.

You are probably familiar with CEC as a number that appears on your soil test, which refers to the capacity of soil to store nutrients. I have found that many growers are somewhat befuddled by the complexities of soil chemistry, but because it is so important in understanding the soil you're dealing with, as well as why it behaves the way it does, and because we are always trying to improve our soils rather than mining them, I think it is worth the effort to understand what the CEC is and what it tells you about your soil and its needs.

Mineral soils are characterized by their texture—sand, sandy loam, clay, etc.—based on the proportion of the particle sizes that make it up. Any soil that contains but one size particle will be poor soil. Sand is the largest of these and is ordinarily very resistant to weathering because it is made up of very insoluble materials like quartz and it does not contribute significantly to the nutrient supply of the soil. Silt is the particle size smaller than sand and yet larger than clay. Silt is ordinarily made up of minerals that are easily weathered and is the primary source of minerals used by plants as they dissolve in the soil water. Sand and silt are not able to absorb dissolved nutrients from the soil water and hold them against the pull of gravity. Clay is the smallest of soil particles. It is made up of relatively stable mineral crystals of silica, typically bound to aluminum. Clay particles are so small that their molecular structure results in a negative electrical charge existing permanently on the crystal surfaces. Finally, organic matter helps keep the soil loose and provides nutrients for the microbes and other soil life to break down into suitable forms for the plants to use. Both the clays and the organic matter in soils have a net negative charge. Thus, these negatively charged soil particles can attract positively charged nutrient particles in much the same manner as a magnet attracts metal. Conversely, they will repel negatively charged particles. Positively charged particles are called cations, negatively charged particles are called anions.

The most common soil nutrient cations are calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), ammonium (NH_4^{+}), hydrogen (H^{+}) and sodium (Na^{+}). (Note that some cations have more than one positive charge.) Less abundant but important cations include the trace elements: iron, zinc, manganese, copper, and boron and sulfur. Common soil anions include chlorine (Cl^{-}), nitrate ($N0_3^{-}$), sulfate ($S0_4^{=}$) and phosphate ($P0_4^{3-}$). Anions can have more than one negative charge and often are combinations of elements with oxygen, e.g. nitrates, sulfates, borate, etc. These anions will also be attracted to and attached to cations to form compounds like gypsum, Epsom salts, rock phosphate, etc., and they will be repelled by clay and organic matter.

The total number of cations a given soil can hold (its total negative charge) is the soil's *cation exchange capacity*. You can think of the soil then as a warehouse for keeping nutrients stored and available until the soil life and plants have need of them. The higher the CEC, the larger the warehouse. Light sandy soils may have a CEC of less than 5, for example, while loams may range from 10 to 25; silty clay loams up to 40 and organic soils 50-100. The higher the CEC , the more cations can be supplied: this is called the soil's buffer capacity.

Cations are classified as either acidic or basic. Common acidic cations are hydrogen and aluminum; common basic ones are calcium, magnesium, potassium and sodium. The proportion of acids and bases on the CEC is called the percent base saturation. So why do we care? Because this proportion determines the soil's pH. As calcium and magnesium ions decrease and hydrogen or aluminum ions increase the pH is lowered. Adding limestone replaces acidic cations with basic cations, thus increasing the base saturation and raising the pH. Soils that have a high CEC and high buffer capacity change pH much more slowly than low CEC soils, but if they do become acid and require liming, higher lime rates are needed to reach optimum pH. On low CEC soils, leaching is likely; thus fertilizing in the spring may result in better nutrient retention, while in higher CEC soils fall applications are practical.

The relative percentage of the various nutrients is also very important. For example, let's imagine a soil whose cation composition is

Calcium 70%
Magnesium 15%
Potassium 3-5%
Sodium 1%
Other 1% (zinc, manganese, iron, copper, boron)

Total 90-92% cations (l00%=pH7, a neutral soil)

which would leave 8-10% available for hydrogen attachment and we would have a slightly acid pH. The above proportions seem to be good for most plant development. pH is the measurement of hydrogen ion concentration in solution.

Since it is usually when trouble appears in our crops that we become especially concerned about our soil's properties, we watch for signs that are indicative of certain problems; for example apple bitter pit, blossom end rot in tomatoes, and squash which doesn't store well may all be caused by too low a percentage of calcium. All have to do with a breakdown in cell wall structure.

Here's a trick. If your soil pH were 9, would you ever add calcium to your soil? You actually might if, for example your percentage of calcium were less than 20% and your magnesium 55% ,potassium 15% and sodium +1-6%, a seriously unbalanced soil. By adding gypsum (calcium sulfate) and saturating the water with calcium, you would give the calcium a better chance of attaching in place of (exchanging) the magnesium, creating a better balance and bringing down the pH! For specific cases and cures, come to my talk at the Tilth Producers Conference this year.

In summary then, a soil's CEC is like a smaller or larger warehouse, depending on the amount of negative charge available for nutrients to attach to. A CEC of 12-15 should provide adequate nutrition for the annual needs of any crop, assuming that the nutrients are in adequate relationship to one another. If they are not, measures should be taken to correct this. If the warehouse is too small, (less that 10) then organic or slow release fertilizers need to be used. If less than 5-6, more frequent fertilization is critical as leaching and lack of 'magnets' will make nutrients available for only a short time. The regular addition of organic materials (compost, green manure, humic acid, etc.) will gradually increase the CEC over time.