Understanding Cation Exchange Capacity and % Base Saturation

FACT SHEET

Plant nutrition and plant to soil interaction is a complex mechanism with a number of environmental and external conditions affecting the process. There are 16 elements involved in plant nutrition, three that are supplied naturally that we have little control over and 13 that are supplied by soil and or fertilizer application.

These elements are either negatively charged or positively charged and compete with each other for position on soil particles and uptake by plants. The positively charged ions are called Cations, Potassium K^+, Sodium Na^+, Ammonium NH_4^+, Hydrogen H^+, Calcium Ca^{++}, and Magnesium Mg^{++}. The negatively charged ions are called anions, Chloride Cl^-, Nitrate $N0_3^-$, Sulfate $S0_4^-$, Borate $B0_4^-$, and Phosphate $H_2P0_4^-$.

Since soil particles are negatively charged and like charges repel and unlike charges attract it is easy to see the antagonistic relationship that these elements may have or that some elements can enhance the utilization of others.

Therefore it is important when interpreting soil analysis and designing a fertility program to keep balanced nutrition and proper placement of these nutrients in mind.

There are two basic philosophies in soil test interpretation used today and both have merit and solid data to substantiate these philosophies.

The SLAN Concept "SUFFICIENCY LEVELS OF AVAILABLE NUTRIENTS" originated or resulted from research done by Bray et al in 1944-45. This research monitored crop response to the addition of an element until crop response was zero or negative with additional increments of an element. This concept does not attribute any affect of the level of availability of one element on another. It does however recognize that the addition of the most limiting element may enhance the efficiency of another element.

The "BASIC CATION SATURATION RATIO" Concept BCSR, originated from research on soils where the cation saturation was varied and the yields and quality of the crops recorded. This work done by Bear and co-workers in 1945 identified optimum saturation levels of the basic cations for an ideal soil at 65% saturation of Calcium, 10% saturation of magnesium and 5% saturation for Potassium. Other work suggests that 10% saturation of Mg may be marginal for Alfalfa. Later work done by Bear in 1948 compared ratios in plant tissue with ratios in soils to determine optimum levels.

Fisher in 1975 introduced another parameter to express the fertility index where by yield could

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be predicted from soil test values for P and K. He substituted an equation of optimum K based on C.E.C. that predicts a sufficient level of K in different soil types based on the C.E.C. This new philosophy integrates the SLAN approach with the BCSR concept. This is the trend used today by a number of soil laboratories and some researchers in plant nutrition and is the direction of future studies.

FISHERS FORMULA FOR PREDICTING OPTIMUM SOIL K LEVELS

110 + 2.5 X C.E.C. = Ksl ppm.

Cation Exchange Capacity is a chemical property of each and every soil. The bench top method in the Lab for determining C.E.C. involves extracting all the cations from an oven dried soil with 1 N NH_4Ac (ammonium Acetate). The ammonium acetate will replace all the cations on the exchange site. This soil containing the absorbed ammonium ions is extracted with 1.0 N KCl and filtered and the ammonium contained in that filtrate is measured to determine C.E.C. This method is very expensive to perform and would drive the cost of a soil test up too high for practical use. Therefore we use a calculated determination of C.E.C. based on an ammonium acetate extraction of the cations and a calculation to adjust for pH to give us a more practical approach to C.E.C. This calculated method for C.E.C. has been well correlated with the lab procedure.

Cation Exchange Capacity is no more than a measurement of the soils ability to hold and exchange cations. Different soil types have different optimum levels of nutrients and the C.E.C. helps us identify these different soil types so we can establish optimum levels.

Therefore Cation Exchange Capacity is the total number of exchangeable cations a soil can hold.

As soils weather and lose Al and Si it leaves the soil colloid with a negative charge. The kind of parent material and the degree of weathering determine the kinds of clays present in the soil and the amount of negative charge it will have.

The higher the clay contents in soils the greater the C.E.C. and the greater the negative charge on that colloid. The higher the clay content the greater is that soils ability to hold nutrients in a given soil depth, and the greater that soils buffering capacity. The lower the C.E.C. the lower the clay content. This soil cannot hold nutrients as readily and Nitrogen and Potassium are more easily leached. These soils contain a higher percentage of sand.

As a result for the most part C.E.C. is a good indication of the soils texture. Sand soils generally fall in the 0-5 C.E.C., Sandy loam, Loam’s and Silts 5-15 C.E.C. and Clay Loam’s and Clays 15+ C.E.C.

In order to understand C.E.C. you must understand that negative charge clay will attract a certain number of positive bonds. A clay always satisfies those bonds or holds on to 100% of the cations it attracts. The positive charged Ions are called cations, Potassium, Sodium, Ammonium, Hydrogen, Calcium, Magnesium.

The principle factor influencing the absorption affinity of cations is valence. The following are the ions in decreasing adsorption affinity.

$$\mathbf{Al^{3+} > Ca^{2+} = Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}}$$

As we apply Cations to the soil K, Ca, Mg, NH_4, the negative charged clay colloids adsorb these cations and for every cation that it adsorbs it releases one of the same into soil solution making it available for plant uptake. As the soil reaches equilibrium however the cations are held tighter to the clay colloid until another application of nutrients is made upsetting the equilibrium or until the soil reaches an optimum level of saturation. In order to make sure nutrients are available for plant utilization in soil solution we must make sure all the soil exchange sites are satisfied or that the cations are at optimum saturation.

This release of the cations from the soil colloid is cation exchange and is how the soil feeds the plant. As agronomists and crop production people we must understand that of the fertilizer we apply in a given year (except N), only 15 to 20% of that fertilizer is taken up by the plant the rest of the fertilizer is absorbed by the soil and those nutrients that are on the clay surface from the previous application feeds the plant the majority of the nutrients it requires. In a sense we are feeding the soil and the soil is feeding the plant. Therefore it is important that we build soils up and balance the nutrients in the soil so that the plant has a readily available supply during the growing season.

An example of this is as follows. Assume we have in solution the same amount of both calcium and hydrogen ions competing for a place on the exchange complex. Plus an equal number on the clay surface.

As natural processes such as decomposition of organic matter, rain, weathering, etc. occurs, more hydrogen ions are made available to the soil. The force of their greater number lets some of them change places with calcium ions. This is **"cation exchange".**

Add calcium to the soil in the form of lime and now the calcium ions have the upper hand. Their greater numbers let them force their way to the clay mineral surface, forcing hydrogen ions off the clay colloid and CATION EXCHANGE has taken place again.

Since most of our nutrients are taken up by diffusion (the movement of nutrients and water to the root) as a root grows through a soil it depletes the reserves in that micropore space. The only way to ensure that it is replenished and that the soil colloid doesn't fix or hold these nutrients is to make sure that the percent available of that nutrient is sufficient. Therefore the heavier the soil or the greater the C.E.C. and clay content the greater the need for Potassium to make sure that it will be available to the plant.

Cation Exchange Capacity categorizes soil types so that we can establish optimum levels for certain nutrients. The higher the C.E.C. the higher the optimum level of nutrients, the more exchange sites that have to be satisfied. Sand soil with a C.E.C. of 5 will need Potassium in the 100-120 ppm level to be optimum this will give a percent saturation of 5-6 %K. With the few available exchange sites it is important to have between 4-6 percent saturation of K in these sand soils in order to have enough exchangeable K available for crop production. These soils also tend to be droughty which will also effect the availability of K. Magnesium needs to be at 100 ppm also which will give us 16% saturation of Mg. Calcium levels in this soil tend to be greater than 700 ppm to be higher than 65% saturation.

A loam soil with a C.E.C. of 12 would require 180 ppm of K to be in the optimum range. This only represents 3.8% saturation of K however with more exchange sites the efficiency of this soil is greater and we only need to maintain between 3-5 % saturation of K. Again we will require 150 ppm Mg to give greater than 10% saturation of Mg. According to Bear and co-workers this maybe almost critical as we want between 10-20% Mg in most soils. Calcium levels of this soil will need to be 1600 ppm or greater to be greater than 65% saturation.

A soil of 20 C.E.C. will need 250 ppm K, 240 ppm Mg and Ca greater that 2400-ppm to be in the optimum range. As C.E.C. increases so does the efficiency of the exchange sites and root interception. Therefore the optimum range in this soil although the nutrients are higher in ppm the % saturation of K needs to be between 2-5%, Mg 8-20%, and Ca 60-80%. In this case the percent K is 3.2%, Mg 8.3% and Calcium is 60%.

Increasing the ppm of one Cation through fertilization or liming practices without paying attention to the percent saturation of the others may induce deficiencies of these nutrients. Therefore when designing a fertilization program or adding lime to a soil or just working with placement and timing of nutrients care must be taken as to not upset the balance.

Too much of one of these cations in relation to another may create as many problems as not enough because of the competition for available exchange sites on the clay colloid.

OPTIMUM RANGE FOR PERCENT SATURATION OF CATIONS IN MOST SOILS.

CALCIUM	**60-80**
MAGNESIUM	**10-20**
POTASSIUM	**2-6**
HYDROGEN	**10-15**
OTHERS	**2-4**

Other cations that make up C.E.C. in small amounts are Fe, Mn, Cu, Zn, and Na.

In order to determine C.E.C. in a soil by calculation we use the following calculation.

$$\frac{ppmK}{390} + \frac{ppmMg}{120} + \frac{ppmCa}{200} + \text{pH factor}$$

The following is the Millequivelent weight of K, Mg, and Ca in 2,000,000 pounds of soil. These values are required in calculating C.E.C.

780 lbs. of K per acre = 1 meq of K
400 lbs. of Ca per acre = 1 meq of Ca
240 lbs. of Mg per acre = 1 meq of Mg
* Per 100 grams of soil.

We can use all but the adjustment for pH to determine the Base Saturation of the Cations. Base Saturation for soils to be productive must be greater than 80%. A soil that has a Base Saturation of less than 40% will develop problems and it will be difficult for this field to produce a crop. This is a measurement of a soils energy level. In most cases when the base saturation is less than 80% a field is usually lacking Calcium. The addition of Calcium or liming will increase the Base saturation and hence improve the energy level in a soil. Therefore the Base Saturation is very much pH and calcium dependent.

An example of determining C.E.C.
Soil Values

K = 111ppm   pH = 5.7
Mg = 50 ppm   BpH = 6.5
Ca = 590 ppm

Therefore to determine C.E.C.

$$\frac{111}{390} + \frac{50}{120} + \frac{590}{200} + 12(7 - 6.5) = .2846 + .4166 + 2.95 + 6$$

C.E.C. = 3.651 + 6 = 9.651

Percent Base Saturation = 3.651/9.651 x 100 = 37.8%

This soil will require an application of lime to increase the base saturation of Ca before it will be a productive soil.

TO CALCULATE THE PERCENT SATURATION OF THE CATIONS.

Percent Saturation of K:

$\frac{\text{lbs. K}}{780}$ **/ C.E.C. x 100 = %K**

$\frac{111}{390}$ **/9.7 x 100 = 2.9%**

Percent Saturation of Mg

$\frac{50}{120}$ **/9.7 x 100 = 4.3%**

Percent Saturation Ca

$\frac{590}{200}$ **/9.7 x 100 = 30.6%**

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